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THE COPPER DEPOSITS OF RAY AND MIAMI, ARIZONA

BY

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OUTLINE OF THE REPORT.

The Ray and Miami districts lie about 18 miles apart in central Arizona, in the belt of mountain ranges that borders the Arizona Plateau along its southwestern edge. The presence of copper in both districts has been known since about 1880, but it was not until 1907 that the low-grade disseminated copper ores began to be successfully exploited on a large scale. Up to the end of 1918 these ores have yielded 1,098,409,607 pounds of copper, and the three principal mining companies have declared dividends amounting to $67,592,552, of which $8,548,050 was paid by the Inspiration Consolidated Copper Co. as a result of its first full year's operations, in 1916, with copper averaging a little over 25 cents a pound.

The region is generally mountainous and arid, with scanty vegetation, save on the relatively high Pinal Range, where pines, oaks, and other trees requiring a moderate supply of moisture flourish.

The oldest rocks in the region are the Pinal schist, which consists mainly of metamorphosed siliceous sediments, and various granitic intrusive rocks. All these rocks are of pre-Cambrian age. Resting on the eroded surface of the old crystalline rocks are beds aggregating from 1,200 to 1,300 feet in thickness, apparently in conformable sequence and, although containing no fossils, supposed to be Cambrian. More than two-thirds of this thickness is represented by two quartzite formations; the remaining beds include shale, dolomitic limestone, and conglomerate. Above the Cambrian, without any recognizable unconformity to explain the apparent absence of the Ordovician and Silurian, is 325 feet of limestone, supposed to be Devonian, although the fossils upon which this age determination rests all come from the upper part of the formation. Conformably above the Devonian limestone is the light-gray Carboniferous limestone, at least 1,000 feet thick.

After the deposition of the Carboniferous limestone the region was uplifted and eroded. At about the same time molten diabase was injected in great volume into fissures in the older rocks, particularly the Cambrian and pre-Cambrian, and from these fissures the hot liquid magma was forced as thick sheets or sills between the beds themselves, so that great masses of strata were driven apart and in places were completely enveloped in the igneous rock.

The intrusion of the diabase was probably followed by erosion and possibly by the deposition of Cretaceous sediments, although no remnant of these is present in the region here particularly described. Their nearest known representatives are in the Deer Creek coal field, south of Gila River. The deposition of the supposedly Cretaceous beds was succeeded by andesitic eruptions, of which some of the products remain in the southern part of the Ray quadrangle.

The andesitic eruptions were followed by the successive intrusion of (1) quartz diorite, in small irregular masses and a few fairly large dikes; (2) granite, quartz monzonite porphyry, and granodiorite in masses, some of which, as the Schultze granite, are several miles in diameter; and (3) quartz diorite porphyry, in dikes, sills, and small rotund bodies. The intrusion of the rocks of the second group was the cause of the original or hypogene metallization that, followed some time later by downward or supergene enrichment, gave rise to the disseminated copper ores of Ray and Miami. The time of the intrusion of the rocks in these three groups is not known but is thought to have been early or middle Tertiary.

A period of active erosion, during which the coarse clastic material of the Whitetail conglomerate was washed by streams into local basins, followed the granitic intrusions, and this formation in turn was buried under a flow of dacite, probably in late Tertiary time. After this outburst the region was much faulted, vigorous erosion set in, and the generally coarse fluviatile deposit known as the Gila conglomerate was deposited, probably in early

Quaternary time. This deposit has since been deformed by faulting and has been much dissected by the intermittent streams of the present drainage system.

The main mountain ranges and valleys of the Ray-Miami region are believed to have been determined by faulting of the Great Basin range type, although the details of the mountain topography were fashioned by erosion. The rocks of these ranges are cut by innumerable faults running in all directions. There is scarcely any flexing or folding of the beds. The structure is characterized by the dominance of deformation by faulting, mostly of the normal type.

The principal copper deposits at Ray and Miami are of the enriched disseminated type, and their most valuable constituent is chalcocite. Estimates based on drilling and mining give the ore originally present in the Miami district as 145,000,000 tons and in the Ray district as 115,000,000 tons, a total for the two districts of 260,000,000 tons. The tenor in copper ranges from about 1.5 to 6 per cent, and the average of the ore mined lies between 1.5 and 2 per cent.

The ore, with the exception of one comparatively rich body in which square sets are used, is mined by caving systems of stoping. It is concentrated by flotation and by flowing water, and the concentrates are smelted locally at Miami and Hayden.

The ore bodies are undulating, flat-lying masses of irregular and more or less indefinite horizontal outline and of varying thickness. The shape and size of each body depend largely upon the lower limit set for the percentage of copper in material classifiable as ore. Generally, the ore is overlain by leached, nearly barren rock known as capping, although in places the overburden contains considerable chrysocolla and malachite. The capping ranges from 40 to 1,000 feet in thickness. The average thickness at Ray, on the ground of the Ray Consolidated Copper Co., is between 200 and 250 feet. The ore grades downward into pyritic material that generally contains too little copper to be workable under present conditions and in this report is designated protore. The ore varies greatly in thickness from place to place. The maximum is about 500 feet, but the average thickness of the Ray Consolidated Copper Co.'s ore body is 120 feet.

The ore bodies in a very general way have a marginal position with reference to intrusive masses of granite, granite porphyry, and quartz monzonite porphyry, but the ore occurs both in the schist and in the intrusive granitic or monzonitic porphyry. By far the greater part of the ore is metallized Pinal schist.

The ore bodies are the result of the operation of two general processes—upward or hypogene metallization as a consequence of the intrusion of granitic or monzonitic porphyries and downward or supergene enrichment by percolating atmospheric water. The hypogene solutions are believed to have been of moderate chemical activity and must have carried copper and sulphur, with probably molybdenum and silicon. Metallization apparently involved no addition of iron to the rocks, the pyrite having been formed by the attack of the sulphur-bearing solutions on the iron already present in the schist and porphyry as oxides and silicates. Permeability of the rocks, permitting the ore-depositing solutions to penetrate them readily, was brought about by fissuring—very largely by a multitude of very small irregular fissures. This fissuring was doubtless a consequence of the intrusion and solidification of the granite porphyry and quartz monzonite porphyry.

From the relation of the ore bodies to the present surface, and from other considerations, it is concluded that the greater part of the enrichment was effected before the development of the present topography and probably before the eruption of the dacite.

Supergene enrichment has generally been treated as a continuously progressive process. There is considerable probability, however, that it is essentially cyclic, although the cyclic character may not be patent in all deposits. A full development of the cycle can take place only under a certain equilibrium of a number of factors, including climate, erosion, topography, and character of rock. The essential fact appears to be that as enrichment progresses and chalcocite increases the process of enrichment becomes slower in action, and erosion may, in some circumstances, overtake it. With the removal of some of the protecting zone of chalcocite the protore is again exposed to oxidation and a second cycle of enrichment begins.

Although much of the enriched ore is now below ground-water level, it probably was once above that level, and enrichment is believed to have taken place mainly in the zone of rock above any general water table. If it is true that the enrichment was mostly earlier than the eruption of the dacite, it must, of course, have preceded also the laying down of the Gila conglomerate. This conclusion admits the possibility of the discovery of ore underneath certain areas of the conglomerate, particularly between Miami and Globe.

THE COPPER DEPOSITS OF RAY AND MIAMI, ARIZONA.

By Frederick Leslie Ransome.

Chapter I.—Introduction.

SITUATION AND ROUTES OF ACCESS.

The Ray and Miami districts,[1] as may be seen from the accompanying general map of Arizona (Pl. I), lie some 70 miles southeast of the center of Arizona, in the prevailingly mountainous belt that separates the Plateau province on the northeast from a region to the southwest whose chief topographic characteristic is the predominance of broad and comparatively low desert plains. Ray, the more southerly of the two districts, is in Pinal County and lies for the most part in the northwest corner of the area designated by the United States Geological Survey the Ray quadrangle (mapped on the 1:62,500 scale), although a part of the district extends to the west into the Florence quadrangle (1:125,000 scale). The Miami district, about 18 miles north-northeast of Ray, in Gila County, is in the central part of the Globe quadrangle (1: 62,500 scale). Miami, its principal settlement, is 4 miles west of Globe, which is a town of about 7,000 people and is the seat of Gila County.

Ray is served by the Hayden division of the Arizona Eastern Railroad, which leaves the main Maricopa-Phoenix line at Tempe, 8 miles east of Phoenix. From Tempe to Ray Junction, where Mineral Creek flows into the Gila, the distance is 73 miles. Here connection for the town of Ray is made with the Ray & Gila Valley Railroad, about 7 miles in length, owned by the Ray Consolidated Copper Co.

Miami is reached by the Globe division of the Arizona Eastern Railroad, which runs from Bowie, on the main line of the Southern Pacific. The distance from Bowie to Miami by rail is 134 miles.

Although Ray and Miami are only 18 miles apart, a railway journey from one town to the other necessitates a detour of about 442 miles. The railway route, however, will be greatly shortened when the Hayden division is extended, as is proposed, up the Gila to San Carlos, a station on the Globe division. The stage road from Ray to Miami is over 50 miles in length and has steep grades, and the only routes between the two places that are fairly direct are those afforded by the rough trails across the north ends of the Dripping Spring and Pinal ranges. Among the ways of reaching Miami should be mentioned also the excellent road from Phoenix and Mesa by way of Roosevelt. By automobile the run from Phoenix to Miami or Globe requires about 7 hours, whereas the journey by rail consumes nearly 24 hours.

FIELD WORK AND ACKNOWLEDGMENTS.

The first detailed geologic work in the Ray-Miami region was the mapping and study of the Globe quadrangle by F. L. Ransome, assisted by J. D. Irving, in 1901 and 1902. The results of this work were published in 1903[2] and 1904.[3] Although it was evident during the geologic investigation that copper is widely dispersed through the schists north of what is now the town of Miami, little attention at that time had been paid by mining men in this country to disseminated copper deposits so low in grade, and neither the extent nor the future importance of those near Miami was then suspected. Consequently the early field work in the Globe

[1] In this report the expressions "Ray district" and "Miami district" will be used as convenient names for areas that correspond approximately to those covered by the map of Ray and vicinity (Pl. XLV) and the map of the Miami copper belt (Pl. XL). Such usage is not intended to imply exact coincidence in boundaries between the tracts so designated and the corresponding maps and is independent of those frequently indefinite areal units established by local regulations and known technically as mining districts. What is here called the Ray district, for example, happens to be a part of the Mineral Creek mining district.

[2] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, 1903.

[3] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Globe folio (No. 111), 1904.

quadrangle was contributory to the present report only in so far as it was the initial attack on the geologic problems of the region.

Field work was begun on the geology of the Ray quadrangle in October, 1910, and with the capable assistance of J. B. Umpleby was finished in January of the following year. This area proved to be stratigraphically much more illuminating than the Globe quadrangle, and it was soon apparent that some earlier interpretations, based on the incomplete geologic sections exposed in the Globe area, needed correction.[1]

While geologic work in the Ray quadrangle was in progress an accurate topographic map of Ray and vicinity on the scale of 1:12,000, covering 186 square miles, was made by W. M. Beaman, topographer, and a similar map of the Miami copper belt on the same scale, covering 273 square miles, was made by Albert Pike and R. W. Berry, topographers. The geology of these areas was mapped by Messrs. Ransome and Umpleby in January and February, 1911. The copper deposits themselves were studied at Ray and Miami by F. L. Ransome in March and April, 1912, with supplementary visits in 1914 and 1916.

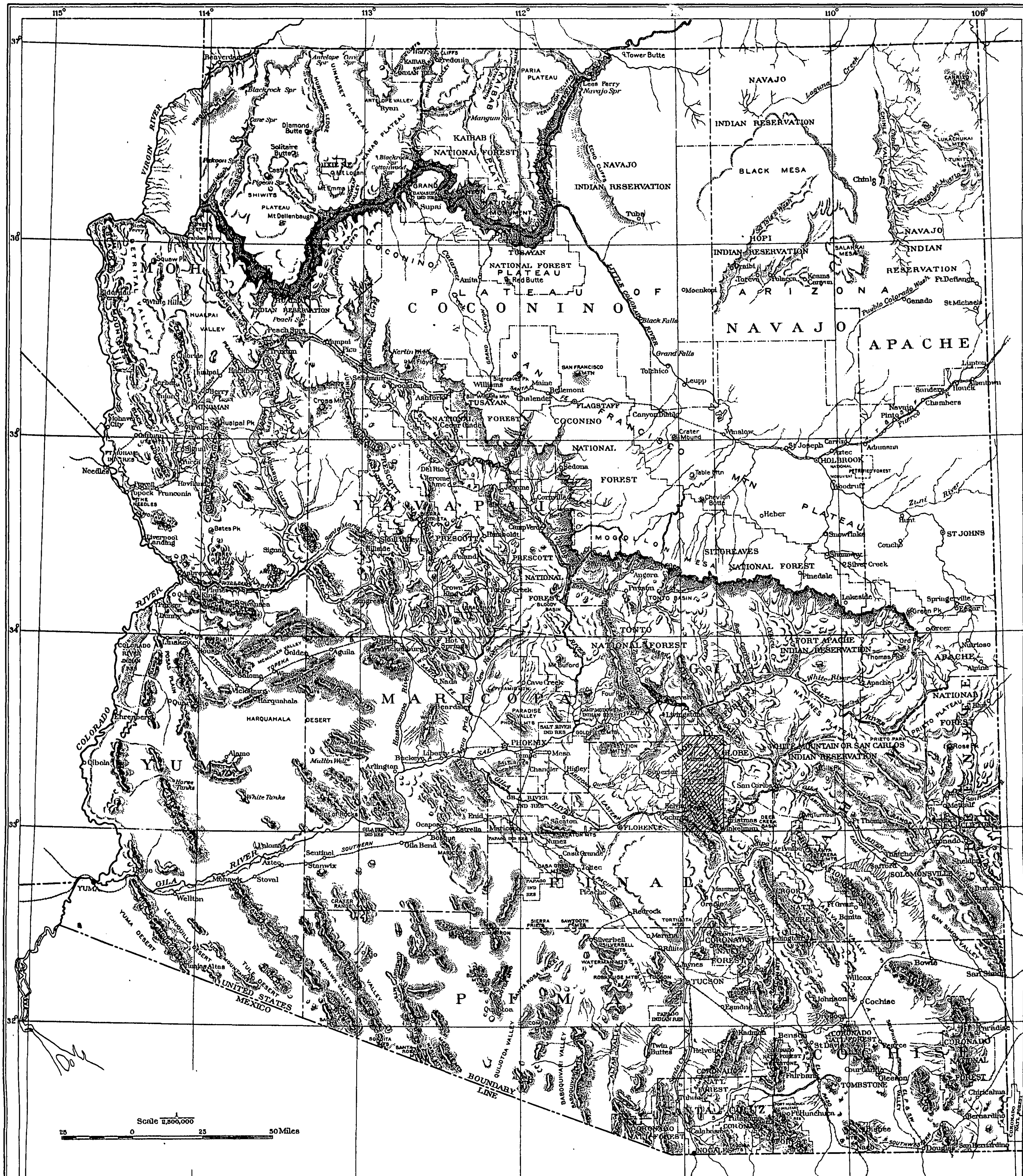
Where so many persons as at Ray and Miami have cheerfully and courteously contributed time and information to the visiting geologists, the selection of a few for individual mention is difficult. Appreciative acknowledgment is made to the Ray Consolidated Copper Co. and the Arizona Hercules Copper Co., at Ray, and to the Miami Copper Co., the Inspiration Copper Co., the Live Oak Development Co. (the latter two now united as the Inspiration Consolidated Copper Co.), and the New Keystone Copper Co. (whose property has been purchased by the Inspiration Co.), at Miami, for special courtesies extended personally through Mr. David Cole, then manager, and Mr. L. S. Cates, formerly superintendent of mines but now general manager of the Ray Consolidated Copper Co.; Mr. W. S. Boyd, superintendent of the Ray Consolidated mines; Mr. W. P. Dunham, president, and Mr. Frank H. Probert, at one time consulting geologist, of the Arizona Hercules Copper Co.; Mr. B. Britton Gottsberger, general manager, and Mr. O. N. Lawton, formerly superintendent, of the Miami Copper Co.; Mr. F. W. Maclennan, assistant manager in charge of mining, of the Miami Copper Co.; Mr. T. R. Drummond, formerly manager of the Inspiration Copper Co.; the late Mr. H. McCarthy, former manager of the Live Oak Development Co.; and Mr. E. B. Tinker, formerly superintendent for the New Keystone Copper Co.

To the engineering staffs of the mines I am particularly indebted for much information and many courtesies, notably to Mr. Ralph C. Nowland, at that time chief engineer of the Ray Consolidated mines; Mr. R. B. Earling, in charge of the Ray Central mine at the time of visit; Mr. H. P. Bowen, chief engineer of the Miami mine; Mr. W. C. Browning, formerly chief engineer of the Inspiration mine; and Mr. George R. Lehman, in 1912 chief engineer of the Live Oak mine and now chief engineer for all the Inspiration Co.'s mines. To mention by name the many others who cooperated to a lesser extent but with equal heartiness in the work upon which this report is based would unduly extend a list already long. They may be sure that their help was of service and is remembered with appreciation.

That the present report makes its appearance far too long after the completion of the main field work is regretfully admitted. The delay is due, it is hoped, less to lack of industry than to certain official duties that for five years prevented consecutive application to this particular piece of work. The information given herein has been brought up to August, 1917, and statistical tables, where practicable, have been extended in proof to the end of 1918.

Geologists of the United States Geological Survey are so accustomed to the expert services of the editorial and illustrations staffs of the organization that they are perhaps inclined to accept these services with as little comment as is accorded to the familiar comforts and conveniences of modern civilization. There are obvious objections to the expression of this universal obligation in every publication issued, but I desire in at least one official report to record my own appreciation of the great advantage enjoyed by an author whose manuscript undergoes such careful scrutiny and whose rough illustrative material receives such skillful preparation.

[1] Ransome, F. L., Geology of the Globe district, Ariz.: Min. and Sci. Press, vol. 22, pp. 747-748, 1911.



Drawn from General Land Office and U. S. Post Office maps
National forests from latest proclamations (January, 1919)

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

GENERAL MAP OF ARIZONA
SHOWING THE POSITION OF THE GLOBE AND RAY QUADRANGLES

PLAN OF GEOLOGIC DESCRIPTION.

As the geology of the Globe quadrangle has already been mapped and described in detail and that of the Ray quadrangle will receive equally full discussion in a forthcoming folio, it will be unnecessary in the present report to do more than describe briefly the rocky materials involved in the structure of the region and to trace rapidly the steps by which their present position and relations to one another have been brought about. Descriptions of fact and the discussions based upon them will have as their main object the presentation and interpretation of the geologic circumstances, broadly viewed, under which the disseminated copper ores, the particular subject of this report, were deposited.

The fact that this report will be read, at least in part, by those who are not geologists has been kept constantly in mind, and an effort has been made to present the subject matter in clear and, so far as practicable, untechnical language. It is not possible, however, to make all portions equally intelligible or interesting to all readers, and certain sections, such as those on the petrography of the igneous rocks, may be skipped without serious consequences by anyone who finds them less readable than other parts of the volume.

For the benefit of the nongeologic reader a glossary of some of the more technical terms used is appended to the report.

HISTORY OF MINING.

RAY.

Mining in the Mineral Creek or Ray district appears to have begun about 1880, when the Mineral Creek Mining Co. built a 5-stamp mill and did some work, presumably on the Mineral Creek claim, north of Copper Gulch. Probably about this time the Ray and many other claims in the district were located and prospected. In 1883 the Ray Copper Co. was organized in New York with a capital of $5,000,000, in shares of $10 each, par value. The company owned 17 claims and had a 30-ton copper furnace. The ore of the Ray group of claims was described as principally native copper. Little was accomplished by this company during the next 15 years, and it was not until 1898 that a few news items in the mining press indicated that the Ray mine, after a long period of idleness, was again in operation; but the work was evidently on a very small scale. In October, 1898, an option on the Ray, Taylor, and Innes groups of claims was obtained by Mr. Alexander Hill for the Globe Mines Exploration Co. (Ltd.), of London, and in June of the following year the ground was acquired for £210,000 by the Ray Copper Mines (Ltd.), an English corporation capitalized at £260,000. At the time of purchase the Ray mine was supposed to have in sight 190,000 tons of ore containing from 4 to 5 per cent of copper. A concentrating mill having a daily capacity of 75 tons was situated near the mine, on Mineral Creek.

During the first year of its existence the new company expended £117,465 in equipment and development. It founded the town of Kelvin, erected there a 250-ton mill, shops, office, and substantial staff buildings, and connected the mine and mill by a narrow-gage railway 7 miles in length. At the Ray mine a shaft was sunk to a depth of 344 feet, and the ore was blocked out on three levels by a rectangular grid of drifts and crosscuts, with the idea of mining ultimately by a caving system. The company also sank the Sharkey, Humboldt, and Tribunal shafts on what seemed the more promising portions of its large territory. It established connection by wagon road with the nearest rail shipping point, Redrock, 43 miles to the south, on the Southern Pacific, whence supplies were hauled to Kelvin by traction engines. Early in 1900 the company's capital was increased by £200,000, and a smelter was built at Kelvin. This was never used and in March, 1906, was destroyed by fire.

The ore was crushed at the mine and hauled to Kelvin in trainloads of about 65 tons each, or about one-thirtieth of the quantity now loaded on each train of the standard-gage line.

By December, 1900, the Ray Copper Mines (Ltd.) had treated about 16,000 tons of material which, instead of averaging between 4 and 5 per cent, as was expected, actually contained less than 2 per cent of copper. These results were of course disappointing, and the mill, moreover, proved to be defective in plan and equipment. Although the annual report for the year ending June 30, 1900, contained the hopeful statement that 1,032,595 tons of ore averaging 4.5 per cent of copper was in sight, the financial difficulties of the company soon became obvious, and in 1901 its property was mortgaged to the Trustees, Executors & Securities Insurance Co. of London for £13,565, payable on June 30, 1902.

It appears to have been while this transaction was pending that Mr. James D. Hague was called upon to examine the property. In his report [1] Mr. Hague, on the basis of careful sampling by Mr. Ellsworth Daggett, calls attention to the very important fact that whereas the average tenor of the ore had been supposed to be between 4 and 5 per cent of copper, it really lies between 2 and 3 per cent. He went on to state that "under present conditions a 4 per cent assay is very near and possibly below the limit of pay ore; and an ore assaying 3 per cent can hardly be touched without loss." Mr. Hague advised suspension of operations but remarked with prophetic insight: "I am far from the opinion that the property is without some considerable value. The mine contains a very large body of low-grade ore, too poor to pay under existing conditions, but with possibilities of large value, sooner or later, by improvement in methods of treatment, which may make a 2 per cent ore profitable." This prediction, made in 1901, has been amply fulfilled.

It has sometimes been alleged that the English company was unsuccessful because its managers failed to realize that the ore deposit is of the disseminated type and that they were endeavoring to find lode deposits, like those hitherto worked in the surrounding region. This assertion, however, is unfair and incorrect. In certain respects the company was in advance of its time, and many of the circumstances that later paved the way for success lay hidden in the future. The plans made for handling the ore were in many ways similar to those which have since been adopted on a much larger scale, and the equipment, instead of being extravagant, as many thought when it was installed, was naturally enough inadequate, for few in 1900 could foresee what recent years have brought to pass in copper mining, and it is doubtful whether it would then have been possible to procure sufficient capital to equip the mine for operation on the scale now recognized as essential in the exploitation of low-grade disseminated deposits. The company's technical staff, in short, appear to have recognized very clearly the geologic character of the deposit and to have laid their plans with boldness and skill. The fundamental cause of failure was too great reliance upon certain sampling which is now known to have been improperly done. Success was simply impossible under the circumstances.

For a few years the property appears to have lain idle, but in 1905 railway connection was established between Kelvin and Phoenix, and in 1906 there was some activity in the district, mainly by the Calumet Copper Co., which was shipping about 40 tons of high-grade ore a day from its mine east of Mineral Creek. The Ray mine was under lease to the Kelvin Reduction Co., which had an experimental leaching plant in operation.

In the following year the attention of Mr. D. C. Jackling and of others who had been prominently connected with the development of the Utah Copper Co. was attracted to Ray, and on May 11, 1907, the Ray Consolidated Copper Co. was organized under the laws of Maine to acquire and work the ground formerly held by the Ray Copper Mines (Ltd.). Capitalized originally at $6,000,000, the Ray Consolidated Copper Co. increased its capital to $8,000,000 in 1908, to $10,000,000 in 1909, to $12,000,000 in 1910, and to $14,000,000 in 1911. A $3,000,000 issue of convertible 6 per cent bonds, authorized in 1907, was retired by conversion into stock.

Underground exploration and churn drilling were started in the summer of 1907 under the immediate direction of Mr. Seeley W. Mudd as consulting engineer, and about the same time the Arizona Hercules Copper Mining Co., organized September 15, 1906, with an authorized capital of $10,000,000, and the Kelvin-Calumet Mining Co. also began operations in the Ray district. The Kelvin-Calumet Mining Co. was succeeded early in 1909 by the Ray Central Copper Mining Co., capitalized at $6,000,000.

On June 1, 1908, Mr. Mudd submitted a report to the Ray Consolidated Copper Co., in which he stated that the existence of about 3,000,000 tons of ore was reasonably assured.

[1] For permission to inspect this report I am indebted to Mr. Sherwood Aldrich, president of the Ray Consolidated Copper Co.—F. L. R.

In November of that year Mr. Henry Krumb was engaged to take charge of the sampling, measurement, and valuation of the ore bodies, and churn drilling was vigorously prosecuted. By the end of 1909 the company had expended $300,000 in prospecting alone and had ascertained the existence of about 50,000,000 tons of ore.

The Gila Copper Co. was organized February 25, 1907, to buy a number of claims which the English owners had declined to sell to the Ray Consolidated Copper Co. until certain stipulations should have been carried out. In 1910 over 97 per cent of the outstanding stock of the Gila Copper Co. was exchanged for stock of the Ray Consolidated Copper Co. at the rate of three shares of Gila for one of Ray.

In December, 1911, the Ray Consolidated Copper Co. entered into negotiations with the Ray Central Copper Mining Co., whose property had previously been held under option by the General Development Co. but had been relinquished in October, 1910. By April, 1912, the Ray Consolidated Copper Co. had acquired over 97 per cent of the stock of the Ray Central Co., and shortly afterward it took complete possession of the property and began to develop the ground in conformity with its own extensive plan.

Actual production from the Ray Consolidated Copper Co.'s mines began late in March, 1911. Up to that time the company had spent approximately $10,000,000 in land, preparatory work, and equipment. This work included the drilling of over 350 churn-drill holes of an average depth of 418 feet, the sinking and equipping of two main shafts, the driving of about 30 miles of drifts and crosscuts, the installation of adequate waterworks at Ray and Hayden, the construction of a standard-gage railway between Kelvin and Ray, the completion of three 1,000-ton units of an 8,000-ton concentrating mill at Hayden, the construction of a power plant capable of generating 10,000 kilowatts, also at Hayden, the building of a transmission line between this plant and the mines, and the erection of numerous buildings for various purposes. The company's activity has brought into existence, near the concentrating mill, the considerable town of Hayden, and near Ray, which itself has grown rapidly, there has sprung up on ground owned by the company the Mexican settlement of Sonora, with a population estimated at more than 4,000.

The Ray Consolidated Copper Co. at first planned to do its own smelting at Hayden and began the necessary construction, but subsequently arrangements were made with the American Smelting & Refining Co. to complete the smelter at Hayden on ground leased from the Ray Co. and to purchase the concentrates. This smelter was put into operation early in 1912.

MIAMI.

The earlier history of mining in the Globe region has already been summarized.[1]

In 1901, when the first geologic work was done by this Survey in the Globe district, the only important mining then in progress within the area now known to be underlain by disseminated chalcocite ore was at the Keystone mine, which at that time had yielded about $25,000 from chrysocolla ore and which continued to be productive for some years thereafter. The ore in this mine occupied a fissure in porphyry and was followed down to the underlying Pinal schist, where it ended at the contact. In the same year a little work was in progress at the Live Oak mine, and subsequently a vein of chrysocolla was stoped on this ground also. The Live Oak vein, like the Keystone, was in porphyry and did not extend into the schist. It was worked up to about 1907, at first by the Live Oak Copper Mining & Smelting Co., to which it is reported to have yielded more than $600,000, and afterward by lessees.

In 1901 much less was known about disseminated copper ore than at present, and even if the existence in the Miami district of large quantities of material containing from 2 to 3 per cent of copper had been widely published it is doubtful whether that information would have aroused much interest among mining men, when, as has been seen, so competent an engineer as Mr. Hague regarded 4 per cent ore as the lowest grade that could be profitably worked.

A few years later the Inspiration Mining Co. began work on the north side of Inspiration Ridge, in the ravine that opens into Webster Gulch a little over a quarter of a mile southeast of Willow Spring Gulch. This company drove

[1] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, pp. 114-118, 1903.

the Woodson tunnel. Disseminated chalcocite was found here in 1904 at a depth of 130 feet, and some crude ore, chiefly chalcocite, was mined from a zone of stringers in the schist and shipped to the smelters. In 1906 the company was shipping about 50 tons a day of this ore. In that year it was estimated that there was at least 5,000,000 tons of low-grade disseminated ore available, and a 50-ton mill was built, about a quarter of a mile from the tunnel, to concentrate this material. The attempt was not successful, but enough had been done to attract the attention of Mr. J. Parke Channing and his associates to the actual presence of disseminated chalcocite in the schist and to give a clue to what might be expected elsewhere under the leached and weathered schist of Inspiration Ridge.

During 1905 and 1906 Mr. F. C. Alsdorf procured options on most of the claims now included in the Miami group, and in December, 1906, these options were transferred to the General Development Co. and work was begun on the Captain shaft, at a point where the surface rocks were brilliantly stained by salts of copper. No ore was found, and a second shaft, known as the Redrock or No. 2 shaft, was sunk farther east. This went into ore about April 13, 1907, at a depth of 220 feet, and on November 30 the Miami Copper Co. was organized. From that time on development went actively forward. In October, 1909, the railway extension from Globe to the new town of Miami was finished, and in March, 1911, after completing its carefully planned and substantially constructed mill, power plant, and other units of its general equipment, the company began to produce concentrates. On April 17, 1913, a section of the overburden about 300 feet northwest of the No. 2 shaft suddenly collapsed, crushing everything together down to the 370-foot level. No fatalities resulted from the falling rock itself, but five men were killed and others injured by the explosion-like blast of air sent through the drifts by the descending mass.[1] Recurrence of such an accident is not likely, now that the capping or overburden has all settled down to the broken ore.

The stimulus of the Miami Copper Co.'s operations was quickly felt throughout the Miami district. Some companies confined their activity mainly to the stock market, but others began vigorous exploration. Among the latter the Inspiration Copper Co. and the Live Oak Development Co. deserve special mention.

The Inspiration Copper Co. was organized in December, 1908, and acquired the property of the Inspiration Mining Co., which had previously been under option to the General Development Co. Active prospecting by shafts, tunnels, and churn drilling was begun in January, 1909. In February of the same year the company acquired the Taylor group of claims, and in July it closed an option on the Black Copper group, formerly owned by the Arizona Banner Copper Co. The Joe Bush, Scorpion, Colorado, and Bulldog shafts were sunk by the new company, and many tunnels begun by its predecessors were driven farther into the ridge. By the beginning of 1911 the Inspiration Copper Co. had driven about 27,000 feet of drifts and crosscuts, had put down over 80 drill holes, and had developed over 21,000,000 tons of ore.

The Live Oak Development Co. was organized on January 21, 1909, and secured under bond and lease the property of the Live Oak Copper Mining & Smelting Co. for $438,600, of which the final payment of $337,000 was due in December, 1912. As much of the ore-bearing schist on the Live Oak ground is covered by porphyry or Gila conglomerate, and as the ore lies deep, the Live Oak Development Co. is entitled to much credit for the results which it achieved. By the end of 1911 it had, by drilling and by ordinary underground exploration, developed about 15,000,000 tons of ore.

In January, 1912, a consolidation was effected between the Live Oak and Inspiration companies. The new company, known as the Inspiration Consolidated Copper Co., was capitalized at $30,000,000 in 1,500,000 shares of $20 par value. At the time of consolidation the engineers employed by the two companies reported the Inspiration ore reserves to be 30,300,000 tons, assaying 1.95 per cent of copper and the Live Oak reserves to be 15,000,000 tons assaying 2.11 per cent of copper, or a total of 45,300,000 tons of approximately 2 per cent ore. This appears to have been a moderate estimate.

In the summer of 1912 active work was begun on an extensive plan of development and equipment. Two main hoisting shafts were sunk in Webster Gulch to a depth of 585 feet.

[1] Min. and Sci. Press, vol. 106, p. 629, 1913.

Additional land was acquired 1½ miles northeast of the shaft, and construction was begun on a 7,500-ton mill, the capacity of which was afterward increased to about 15,000 tons. A standard-gage railway was built from the mine to the mill and from the mill to a connection with the Arizona Eastern Railroad below Miami, a total distance of 4½ miles. The Arizona Eastern also built an extension from Miami to the Inspiration adit in Liveoak Gulch, on the south side of Inspiration Ridge. Extensive underground work was done in preparation for mining through the new main shafts. Construction was begun on a dam and pumping plant at Wheatfields, on Pinal Creek, to supply water for milling.

Early in 1915 negotiations for the sale of the property of the New Keystone Co. to the Inspiration Consolidated Copper Co. were successfully completed and the transfer was made, thus giving opportunity for direct underground connection between the Inspiration and Live Oak divisions of the consolidated property.

In May of this same year the smeltery of the International Smelting & Refining Co., begun in 1914 and situated a short distance southeast of the Inspiration concentrating mill, was completed and put into operation. The plant has a capacity of 250 tons of copper a day.

The production of copper from the mine on a large scale began in June, 1915.

PRODUCTION.

Both at Ray and Miami small quantities of copper ores were produced intermittently over a period of many years prior to the modern development of the low-grade disseminated ores. It is doubtful, however, whether it would be possible to ascertain even approximately the quantity of copper yielded by the two districts during this period, and it is certain that the results would not justify the attempt. The modern production at the date of writing (July, 1917) has been practically all made by the Miami, Inspiration, and Ray companies, and as these companies publish accurate figures in their annual reports the output for the two districts is easily ascertained.

The production of the Miami mine is shown in the accompanying table.

Production of the Miami mine, 1911–1918.

Year.	Ore milled.	Concentrates produced.	Copper in concentrates.	Net production of refined copper.	Dividends paid.
	Tons.	*Tons.*	*Pounds.*	*Pounds.*	
1911	445, 036	20, 065	16, 195, 561	15, 385, 783	....
1912	1, 040, 744	46, 683	34, 560, 665	32, 832, 609	$1, 105, 572. 50
1913	1, 058, 784	45, 410	34, 597, 568	32, 867, 666	1, 492, 838. 50
1914	1, 096, 633	44, 579	35, 048, 445	33, 296, 010	1, 120, 463. 00
1915	1, 348, 122	52, 539	44, 033, 761	41, 832, 059	1, 681, 004. 25
1916	1, 842, 017	66, 289	56, 335, 103	53, 518, 331	4, 295, 905. 50
1917	1, 640, 206	53, 639	46, 172, 322	43, 863, 699	6, 537, 247. 50
1918	2, 132, 941	76, 750	61, 481, 662	58, 407, 563	3, 362, 013. 00
	10, 604, 483	405, 954	328, 425, 087	312, 003, 720	19, 595, 043, 75

The refining of the copper yields a little gold and some silver. The quantity of these metals produced annually is not stated in the company's reports, but it appears that in 1915 the silver proceeds were a little over $30,000, corresponding to approximately 15,000 ounces.

The Inspiration Consolidated Copper Co. has produced as follows:

Production of the Inspiration mine, 1915–1918.

Year.	Ore concentrated.	Copper produced.	Dividends paid.
	Tons.	*Pounds.*	
1915 [a]	778, 851	[b] 20, 067, 310	....
1916	5, 316, 350	[c] 120, 772, 637	$8, 548, 050. 75
1917	3, 891, 075	[d] 80, 566, 982	9, 751, 227. 75
1918	5, 110, 101	[e] 98, 540, 041	9, 655, 736. 00
	15, 096, 377	319, 946, 970	27, 955, 014. 50

[a] Some earlier production from the test mills, but the amount is not stated in the annual reports.
[b] 378,360 pounds of this was from oxidized ore sent directly to the smelter.
[c] 1,341,248 pounds of this was from oxidized ore sent directly to the smelter.
[d] 1,220,949 pounds of copper was from oxidized ore sent directly to the smelter.
[e] 1,063,464 pounds of copper was from oxidized ore sent directly to the smelter.

The production of the Ray Copper Co. has been as follows:

Production of the Ray mine, 1911–1918.

Year.	Ore treated.	Copper in concentrates.	Refined copper produced.	Silver produced.	Gold produced.	Dividends paid.
	Pounds.	*Pounds.*	*Pounds.*	*Fine ounces.*	*Fine ounces.*	
1911	681, 519	15, 721, 520	14, 935, 047	1, 733. 53		
1912	1, 565, 875	35, 861, 496	34, 674, 275	13, 439. 54		
1913	2, 365, 296	53, 745, 937	52, 341, 029	70, 841. 96	467. 49	$1, 631, 504. 35
1914	2, 427, 700	58, 020, 955	57, 004, 281	51, 608. 04	306. 53	1, 089, 321. 95
1915	2, 848, 969	61, 114, 514	60, 338, 936	45, 083. 55	319. 81	1, 872, 319. 07
1916	3, 332, 340	75, 182, 915	74, 983, 540	8, 125. 98	828. 00	4, 337, 954. 75
1917	3, 560, 900	86, 797, 586	[a] 88, 582, 649	8, 020. 00	1, 227. 00	5, 835, 562. 30
1918	3, 411, 000	82, 445, 710	[b] 83, 599, 160	8, 395. 00	1, 144. 81	5, 275, 831. 75
	20, 193, 599	468, 890, 633	466, 458, 917	207, 247. 60	4, 293. 64	20, 042, 494. 17

[a] Includes refined equivalent of 5,409,770 pounds gross from ore sent directly to smelter.
[b] Includes refined equivalent of 4,473,560 pounds gross from ore sent directly to smelter.

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CLASSIFICATION.

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Chapter II.—Physical Geography of the Ray-Miami Region.

BROAD TOPOGRAPHIC FEATURES.

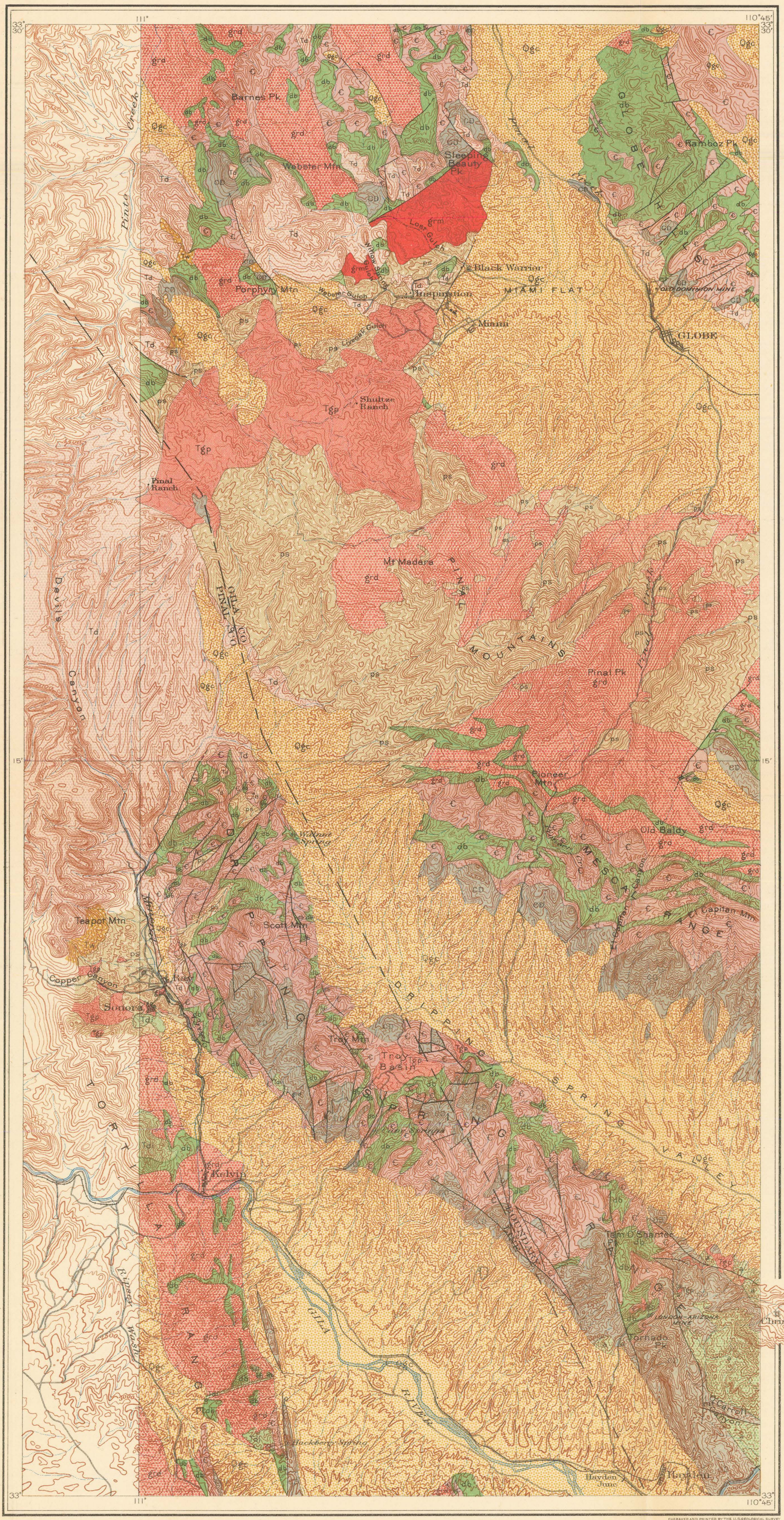
The mountains and valleys that diversify a landscape are an immediately visible result of geologic processes which have been active for untold ages and which are still effecting changes before our eyes. In a consistently historical treatment, therefore, description and discussion of the surface configuration of the region should come last, both as a fit conclusion to the geologic story and as an introduction to geography, which deals with existing conditions on the earth's surface. It is probable, however, that to most readers accounts of rocks and geologic structure will be the clearer and more interesting the more vivid their mental picture of the region in its outward aspect. The broader features of relief and drainage, with some of the relations of these features to geologic structure, will accordingly be briefly presented in advance of the chapters devoted to geology proper.

As already intimated, the copper deposits of Ray and Miami are within what has been termed the mountain region of Arizona, as distinguished from the Plateau of Arizona to the northeast and the desert region to the southwest. The general boundary between the plateau and the mountain region, as may be recognized from Plate I, although irregularly dentate, is on the whole fairly definite and has been generalized in figure 1. That between the mountain region and the desert region, however, is much more obscure, although a line drawn from Nogales, on the Mexican border, through Tucson, Florence, Phoenix, Wickenburg, and Needles would, in a general way, separate these two provinces.

The mountain region is characterized by numerous short ranges, as a rule nearly parallel with each other and with the curved edge of the plateau. Few of these ranges exceed 50 miles in length or attain altitudes greater than 8,000 feet. They are separated by valleys which are narrow as compared with their lengths or with the wide undrained plains or bolsons to the southwest. Some of these valleys, such as that of San Pedro River in southern Arizona, are very much longer than any one of the individual ranges by which they are laterally confined.

Although it can not be safely said that these ranges generally exemplify the simple Great Basin range type of uptilted blocks, it is certain that faulting has been far more important than folding in the development of their structure, and it is highly probable that the greater faults have determined the trend of the ranges and of the longitudinal valleys. The ranges and larger valleys probably owe their relative difference in relief primarily to faulting, although the valleys have since been partly filled with the Gila conglomerate and other fluviatile and lacustral deposits of Quaternary or late Tertiary age. In other words the long valleys are structural troughs and have not, like the Appalachian valleys, been excavated by erosion.

The Ray-Miami region (Pl. II) lies for the most part between Gila River and its principal tributary, Salt River, streams which head under the edge of the plateau and flow westward across the mountain belt, escaping from one longitudinal valley to another by deep gorges through the mountains. The area represented in Plate II illustrates well the general topographic features of the mountain region. Three of the typical ranges traverse it obliquely from southeast to northwest. On the north, mainly in the Globe quadrangle, is the Pinal Range, which attains an elevation of 7,850 feet. Although sawmills have thinned the pine groves that gave the range its name, young trees are fast growing on these mountains, which in their wooded aspect contrast strongly with their near neighbors. The Pinal Range is composed of pre-Cambrian crystalline rocks with some younger granitic intrusives. Its topography has the bold irregularity characteristic of a comparatively early stage in the erosion of an uplifted mass of heterogeneous and unsystematically arranged materials.



EXPLANATION

QUATERNARY
- Qgc — Gila conglomerate

LATE TERTIARY (?)
- Td — Dacite
- Tw — Whitetail conglomerate

EARLY TERTIARY (?)
- Tgp — Granite and granite porphyry, etc.
- Tdi — Quartz diorite

CRETACEOUS (?)
- a — Andesite tuff and breccia

MESOZOIC (?)
- db — Diabase
- grm — Granite and quartz monzonite

CARBONIFEROUS AND DEVONIAN
- CD — Tornado and Martin limestones

CAMBRIAN, POSSIBLY ALSO ORDOVICIAN AND SILURIAN
- € — Troy quartzite, Mescal limestone, Dripping Spring quartzite, Barnes conglomerate, Pioneer shale, Scanlan conglomerate

PRE-CAMBRIAN
- grd — Granite and quartz diorite
- ps — Pinal schist

For descriptive details see Plates XXXIX and XLV

Fault

Base from Globe, Ray, and Florence topographic maps.

GEOLOGIC MAP OF THE GLOBE-RAY REGION, ARIZONA

Field work by F. L. Ransome, assisted by J. D. Irving and J. B. Umpleby. Compiled from larger-scale maps and simplified by F. L. Ransome.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

1919

Southeast of the Pinal Range, and topographically more or less a continuation of it, is the Mescal Range, composed of Paleozoic and perhaps older sediments cut by great irregular sills of diabase. The general homoclinal structure, with dip of about 22° SW., is conspicuously displayed in the topography (Pl. III), and the beds at one time evidently lapped up over the southwest slope of the Pinal Range, culminating probably in a lofty scarp overlooking the lower country along Pinal Creek near Globe. Inasmuch as these same sedimentary rocks also form the low hills northeast of Globe it is fairly certain that the Pinal and Mescal ranges constitute in the main a great fault block, upheaved relatively to the country northeast of Globe and tilted about 20° SW. The fault plane or zone is probably covered by the Gila conglomerate, which fills the valley of Pinal Creek.

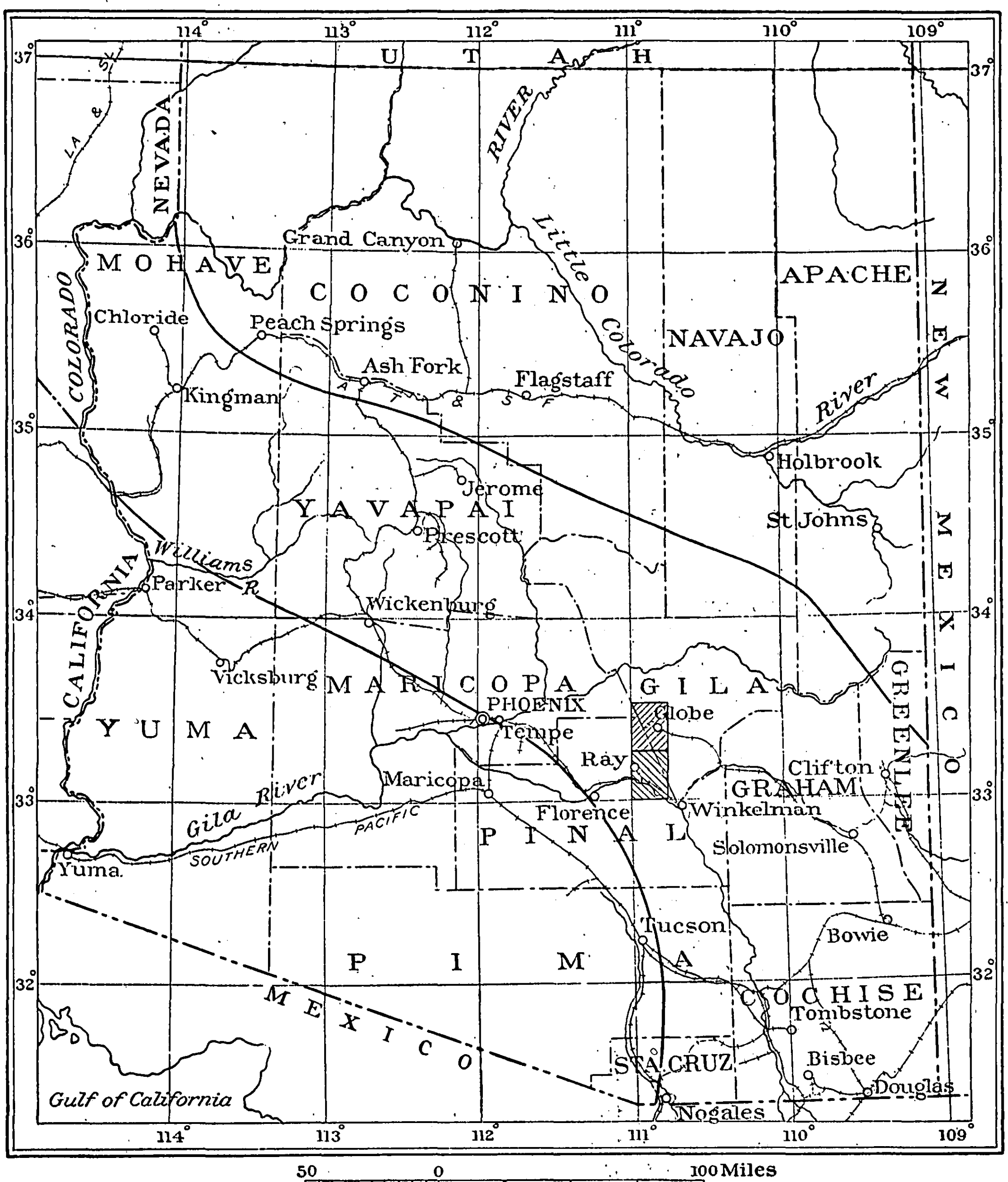


FIGURE 1.—Index map showing position of the Globe and Ray quadrangles and the approximate outlines of the three principal topographic regions of Arizona. The plateau region is on the northeast, the desert region is on the southwest, and the mountain region lies between them.

Southwest of the Mescal Range is Dripping Spring or Disappointment Valley, which drains southeastward into the Gila. With its thick filling of Gila conglomerate elaborately sculptured by erosion and scored by steep-walled, branching arroyos, which open into broader sandy "washes" (see Pl. IV, *A*), this is a typical though small intermontane valley of the mountain region.

The Dripping Spring Range, which forms the southwest wall of the valley, is a minor but distinctly linear range which reaches an altitude of 5,115 feet in Scott Mountain, northeast of Ray. Seen from a distance (Pl. IV, *B*) these mountains show none of that topographic regularity which gives so obvious a clue to the structure of the Mescal Range but present an appearance which to the experienced eye indicates that their form is due to the action of erosion on an uplifted mass of small fault blocks that are without systematic arrangement. These blocks are so small and so numerous that it is impossible to show them adequately on a map of the scale of Plate II.

Southwest of the Dripping Spring Range is the valley locally occupied by the Gila, which, after traversing that range through the gorge of which a small part lies in the southeast corner of the area mapped on Plate II, flows northwestward for about 9 miles in a lowland that is structurally a part of the long depression followed by San Pedro River from the Mexican border to its junction with the Gila at Winkelman, just south of the area mapped on Plate II. This valley is filled to a great and unknown depth with the Gila conglomerate and perhaps older deposits, intrenched within which is the present flood plain of the river, having a maximum width of about 1 mile. At Kelvin the river turns westward and escapes through another gorge in the Tortilla Range to the broad plains around Florence and Phoenix.

The Tortilla Range marks locally the southwest edge of the mountain region. This range is rather narrow and almost buried by the Gila conglomerate a few miles south of the area here described, but to the north of the Gila it becomes wider and less definite, and certain bold units of this confused mass of hills, such as the Superstition Mountains, have received separate names. The higher portions of that part of the range included within the area represented by Plate II consist mainly of pre-Cambrian granite with younger intrusives. South of the Gila this granitic axis is flanked on the east by sharp, narrow ridges composed of the same sedimentary formations that occur in the Dripping Spring and Mescal ranges, but these formations are here steeply upturned. Northwest of Ray, as far as the south end of the Mazatzal Range, great flows of dacite partly cover the older rocks, and from this lava have been carved many of the most conspicuous topographic features in that part of the field.

STREAMS AND SPRINGS.

The only large perennial streams in the region are Gila River and Pinal and Mineral creeks, although little runnels of pure water may generally be found throughout the year in some of the shady ravines of the Pinal Range. Small springs of potable water are distributed rather evenly over the mountainous portions of the area, there being probably between 40 and 50 perennial springs in the Globe and Ray quadrangles combined.

The discharge of the Gila has been measured at San Carlos, 25 miles above the point where it enters the Ray quadrangle, and also at a locality known as "the Buttes," about 12 miles west of Ray Junction. The results are shown in the following table:[1]

Estimated annual discharge, in acre-feet, of Gila River at the Buttes and San Carlos, Ariz.

	The Buttes.	San Carlos.[a]
Seasonal year 1889–90, Sept. 1 to Aug. 31	366, 561	329, 905
Fractional year 1895, Aug. 1 to Dec. 31	354, 429	318, 986
Year 1896	616, 206	554, 585
Fractional year 1897, Jan. 1 to Oct. 3	503, 585	453, 227
Year 1898, approximate	363, 902	327, 512
Fractional year 1899, Jan. 1 to Sept. 30	203, 910	187, 519

[a] Discharge at San Carlos estimated as 90 per cent of volume at the Buttes.

Lippincott[2] has concluded that the mean annual discharge at San Carlos is 422,184 acre-feet and at the Buttes 469,093 acre-feet, the difference being due chiefly to the contribution of the San Pedro near Winkelman, just south of the Ray quadrangle, although Mineral Creek at certain seasons is also a considerable affluent. An annual discharge of 469,093 acre-feet is

[1] Lippincott, J. B., Storage of water in Gila River: U. S. Geol. Survey Water-Supply Paper 33, p. 29, 1900.

[2] Idem, p. 30.

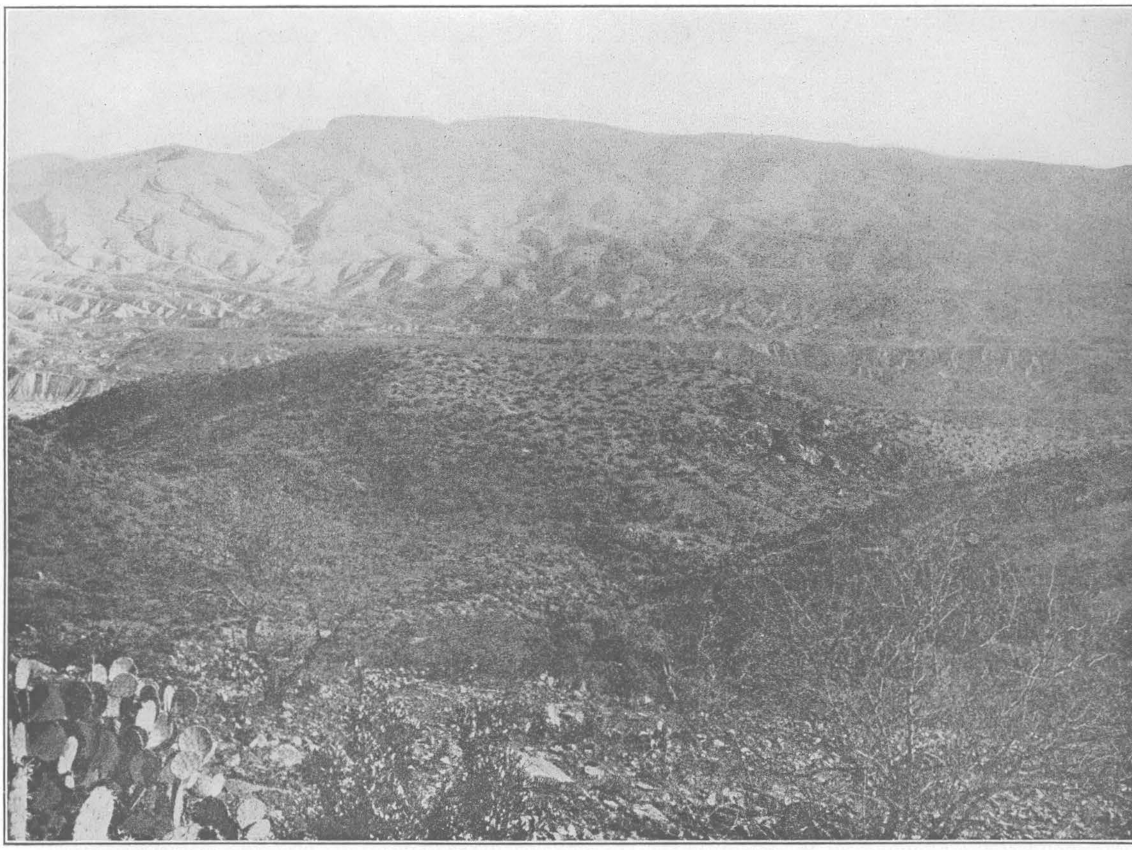
A. EL CAPITAN, THE CULMINATING PEAK OF THE MESCAL RANGE, SEEN FROM THE NORTHWEST.

The peak is Troy quartzite with Devonian and Carboniferous limestones lapping part way up its gentle back slope (see *B*, below). Hills in the middle of the view are capped with masses of Dripping Spring quartzite resting on and surrounded by diabase but retaining the general homoclinal attitude.

B. SOUTHWEST SLOPE OF THE MESCAL RANGE FROM POINT 2 MILES EAST-SOUTHEAST OF DRIPPING SPRING RANCH.

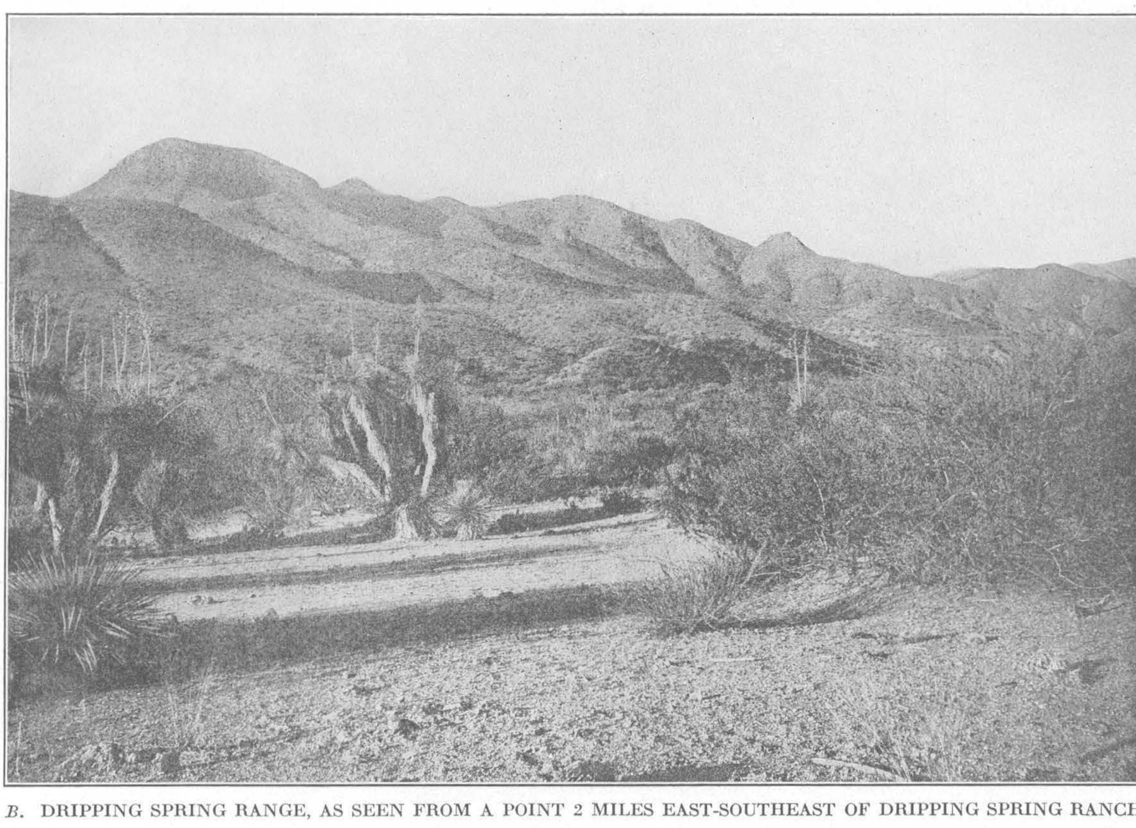
Direction of view is east-northeast. The gentle back slope, almost a dip slope, is cut by deep canyons and is overlapped by the spurs of Gila conglomerate seen in the middle of the view. A large boulder weathered from the Gila conglomerate lies in the foreground.

MONOCLINAL STRUCTURE OF THE MESCAL RANGE.



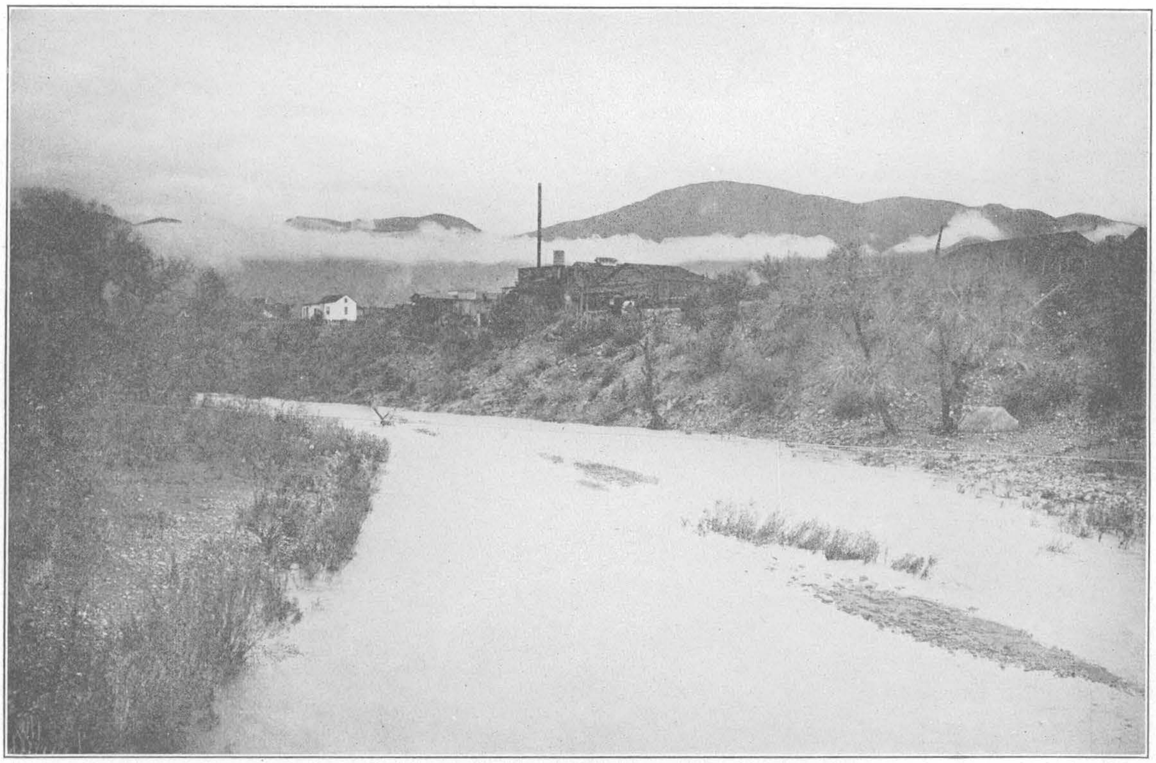
A. DRIPPING SPRING VALLEY FROM THE SOUTHWEST, LOOKING ACROSS TO THE MESCAL RANGE.

Shows intricately dissected filling of Gila conglomerate.



B. DRIPPING SPRING RANGE, AS SEEN FROM A POINT 2 MILES EAST-SOUTHEAST OF DRIPPING SPRING RANCH.

View is nearly west. Note absence of regular forms and compare with Plate III, *A*.



A. MINERAL CREEK AS VIEWED UPSTREAM NEAR KELVIN.

This portion of the stream bed, usually dry, is here shown carrying abundant water during a rainstorm. Photograph by J. B. Umpleby.

B. VIEW DOWN GILA RIVER FROM THE MOUTH OF MINERAL CREEK.

The river, slightly swollen by recent rains when the photograph was taken, is here cutting through the pre-Cambrian granite of the Tortilla Range. Photograph by J. B. Umpleby.

equivalent to an average flow of 25,900 miner's inches, or approximately 4,850 gallons a second.

The river where it crosses obliquely the valley between the Dripping Spring and Tortilla ranges is bordered by an irregular flood plain that has a maximum width of 1¼ miles. Some of this land is under cultivation, but the river, which in midsummer is a shallow, easily fordable stream, is subject to violent floods, especially in January and February, which render more or less precarious the tenure of the cultivators. Even at low water the Gila carries much fine silt, and of course at times of flood it is much more heavily laden. The San Pedro in the dry season carries little visible water, and the bed of Mineral Creek near its mouth is normally dry. The appearance of Mineral Creek immediately after a rain is shown in Plate V, *A*, and a view of the Gila as it enters the gorge west of Ray Junction appears in Plate V, *B*. At the time this view was taken the river was slightly swollen by local rains.

Abundant water is obtainable by pumping from wells of moderate depth sunk in the alluvial plain of the Gila, and it is from this source that the large supply is obtained for the concentrating mill and smelter at Hayden. Similarly, the underground flow of Pinal Creek supplies the town of Globe, and water for the mills of the Miami district is obtained partly from the same flow, partly from a storage dam across Pinal Creek, and partly from the lower levels of the Old Dominion mine, which pumps (1915) from 7,500,000 to 8,000,000 gallons a day and drains a large area of the Gila conglomerate adjacent to the town of Globe. The Miami Copper Co. in 1915 purchased 730,000,000 gallons.

The water used at Ray is derived partly from springs and partly from the upper portion of Mineral Creek.

CLIMATE AND VEGETATION.

The ore bodies described in this volume owe their importance to enrichment effected through the agency of downward-moving atmospheric water, and it is therefore clear that precipitation, as determining the quantity of water available for erosion and enrichment, and vegetation, as influencing the character of erosion and the quantity of water absorbed by the ground, are factors to be considered in the discussion of the ores, even though it should be shown that the main enrichment took place before the present climatic conditions were established.

In consequence of its considerable differences in altitude, the region enjoys corresponding diversity of climate and flora, the conditions ranging from those exemplified by the comparatively well-watered and pine-clad crest of the Pinal Range to the dry, gravelly ridges of the larger valleys, with their scanty growth of typical desert plants. At Globe, where the elevation is 3,500 feet, no complete records of precipitation have been kept, but figures reported to the Weather Bureau for the years 1894, 1908, and 1909 give a mean annual rainfall of about 15.5 inches. At the Pinal ranch, 12½ miles southeast of Globe and 1,000 feet higher, the mean annual precipitation is 23.5 inches; at San Carlos, on the Gila, a few miles east of the region mapped on Plate II and 1,000 feet lower than Globe, it is 13 inches; and at Dudleyville, on the Gila just south of the area represented by Plate II and 2,360 feet above the sea, it is 14 inches. The heaviest precipitation is along the crest of the Pinal Range, where considerable snow falls during a normal winter.

The upper parts of these mountains are still well wooded, in spite of the ravages made by sawmills and woodcutters before the establishment of the Crook National Forest. Elsewhere in the region, except here and there in partly shaded ravines and northern slopes, the vegetation is too sparse to have much influence in the retention of the surface water or in the protection of soil. Cactuses of wide diversity in form and flower, from the giant saguaro to small creeping or sessile species, yuccas and agaves of various kinds, and thorny shrubs such as the cat's-claw, mesquite, and paloverde are the plants that give character to the landscape and at times of bloom adorn it with distinctive beauty.

CHAPTER III.—GEOLOGY OF THE RAY-MIAMI REGION.

INTRODUCTORY OUTLINE.

The sequence and thickness of the geologic formations in the Ray-Miami region are shown in figure 2. The column, however, does not represent the full history of deposition in this region. Between certain divisions are unconformities showing that at times the accumulation of sediments on a sea bottom or near sea level was interrupted by uplift and erosion. In addition to the four unconformities plainly recognizable there are possibly others in the rocks below the Devonian, although all the beds provisionally included in the Cambrian appear to have been laid down without any break in sequence.

The fundamental rocks of the region are those designated the Pinal schist, commonly a thinly laminated sericitic variety, and certain granitic rocks that have been intruded into the schist. The Pinal schist consists in the main of metamorphosed sedimentary rocks. Both the schist and the granite are pre-Cambrian and were subjected to long erosion before the deposition of the succeeding formations.

Resting as a rule directly on the worn surface of the pre-Cambrian crystalline rocks is the Scanlan conglomerate. This formation varies in character and thickness from place to place. Generally in the Ray quadrangle it is about 15 feet thick and contains abundant well-rounded pebbles, some of which are quartzite. In some places weathered, disintegrated, and recemented granitic detritus, or arkose, lies between the conglomerate and the pre-Cambrian granite.

The Scanlan conglomerate is overlain conformably by the Pioneer shale. As a rule this formation consists of dark reddish-brown more or less arenaceous shale composed largely of fine granitic detritus with little or no calcareous material. At many places the shale grades downward into arkosic sandstone. Abundant round or elliptical spots of light-buff or greenish color are highly characteristic of the shale.

Next above in the stratigraphic series is the Barnes conglomerate, which in its typical development consists of smooth pebbles of white quartz and of hard vitreous quartzite in an arkosic matrix. The pebbles are generally less than 6 inches in diameter. Small fragments or pebbles of bright-red jasper, although nowhere abundant, are a very characteristic and constant feature of this conglomerate, which in the Ray-Miami region is from 10 to 40 feet thick.

Conformably overlying the Barnes conglomerate is a formation of quartzite and quartzitic sandstone from 400 to 500 feet thick, the Dripping Spring quartzite. In most localities in the Globe, Ray, Florence, and Roosevelt quadrangles this formation is closely associated with thick intrusive masses of diabase, chiefly in the form of sheets following the bedding planes but also as crosscutting bodies connected with the sheets.

The Mescal limestone conformably overlies the Dripping Spring quartzite. It is composed of thin beds that have a varied range of color but are persistently cherty. The siliceous segregations as a rule form irregular layers parallel with the bedding planes, and on weathered surfaces these layers stand out in relief and give the limestone the rough, gnarled banding that is its most characteristic feature. The average thickness of the Mescal limestone in the Ray-Miami region is about 225 feet. At the time of the diabase intrusions the Mescal offered less resistance to the advance of the magma than the other formations, and it has been much broken and displaced by the force of the igneous invasion. In places it is represented only by fragments included in the diabase. Between the limestone and the overlying formation is a layer of decomposed vesicular basalt whose maximum observed thickness is from 75 to 100 feet. Although the basalt in places is much thinner than this, the flow was apparently coextensive with the Mescal limestone throughout the Ray and Globe quadrangles and has been recognized as far north as Roosevelt. This basalt, owing to its small thickness, has been mapped with the

Mescal limestone in the Ray quadrangle, although it is not included in the definition of that formation.

The succeeding formation is the Troy quartzite, about 400 feet thick, in the Ray-Miami region. Everywhere in this region it is separated from the Mescal limestone by the basalt flow, and this may possibly indicate some unconformity. No evidence of erosion, however, has been detected either below or above the basalt, which may have flowed over the sea bottom.

All the beds thus far described as above the great unconformity at the base of the Scanlan conglomerate constitute the Apache group and, although no fossils have been found in them, are believed, for reasons presented on pages 49 and 50, to be of Cambrian age. It is possible that some of the beds near the top of the group may represent Ordovician and Silurian time, but there is no fossil evidence for this. Nor has any unconformity been detected to account for the apparent lack of representation of these two great periods.

Conformably above the Troy quartzite is the Martin limestone, which is about 325 feet thick in the Ray-Miami region. This formation is divisible into upper and lower portions of nearly equal thickness. The upper portion carries characteristic Devonian fossils, but no identifiable fossils have been found in the lower portion, which consequently can not be regarded as unequivocally Devonian.

The Martin limestone is conformably overlain by a thick-bedded light-gray limestone that is nearly everywhere a prominent cliff maker. This is the Tornado limestone. As exposed in the Ray quadrangle it has a maximum thickness of at least 1,000 feet. As its upper limit is a surface of erosion dating in part from early Mesozoic time, the limestone was probably once much thicker. It is of Carboniferous age.

After the deposition of the Tornado limestone the region was uplifted above sea level and underwent erosion, probably until Cretaceous sedimentation began. The diabase is thought to have been intruded when this uplift occurred, in late Paleozoic or early Mesozoic time. Intrusive relations show very clearly that the diabase is younger than the Troy quartzite. The Martin and Tornado limestones have been cut only here and there

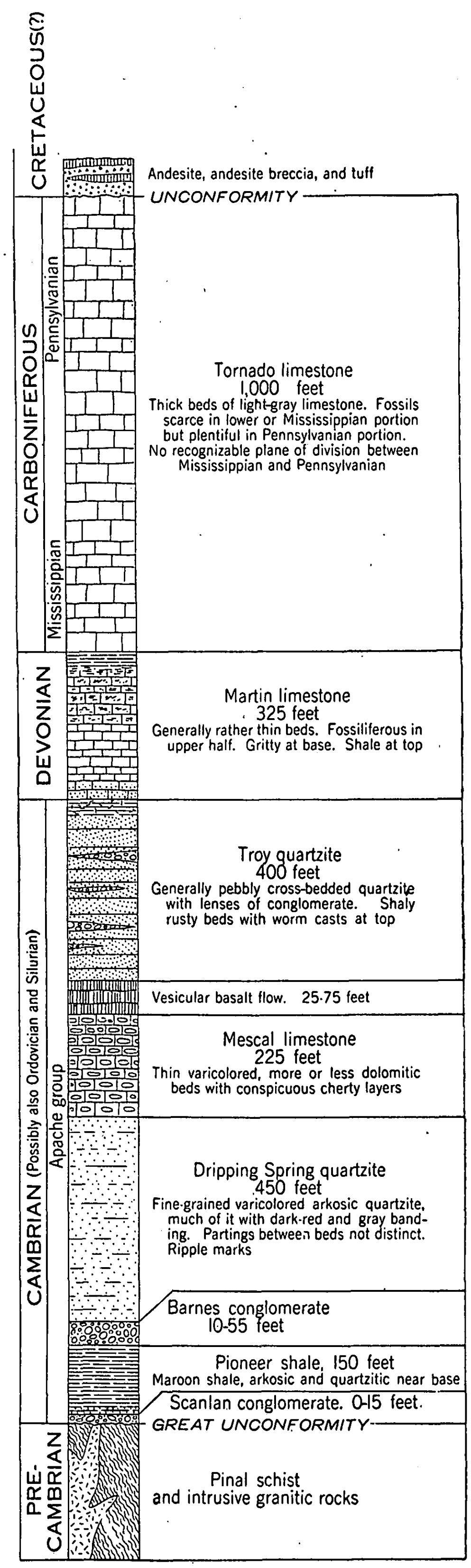


FIGURE 2.—Generalized columnar section of the rocks of the Globe-Ray region.

by small bodies of diabase that are supposed to represent parts of the same magma that solidified in larger masses at lower stratigraphic horizons.

In the southern part of the Ray quadrangle and stretching southward across the Gila is a broad belt of andesitic tuff and breccia associated with some andesitic lava flows and cut by many porphyry dikes of andesitic to dioritic or monzonitic character. In places the andesite is separated from the eroded surface of the underlying Tornado limestone by a few feet of angular cherty detritus, clay, or fine, soft tuff. Along the Gila, however, and according to Campbell [1] south of that stream a coarse conglomerate lies at the base of the volcanic series. Walcott[2] and Campbell both refer to the andesite as overlying Cretaceous sediments and connected with them by the intercalation of sedimentary layers containing a little coal. Presumably, therefore, the andesite, like the coal, is Cretaceous.

The eruption of the andesitic rocks was followed by the intrusion, in the general order enumerated, of (1) quartz diorite, in small irregular masses and a few dikes of considerable size; (2) granite, quartz monzonite porphyry, and granodiorite, in masses, some of which, as the Schultze granite, are several miles in diameter; and (3) quartz diorite porphyry, in dikes, sills, and small rotund masses. The rocks of the second group are closely related to the copper deposits. The time of intrusion of all the rocks mentioned is not definitely known. They are provisionally considered early or middle Tertiary.

The intrusion of these rocks was followed by a period of erosion during which was deposited in parts of the region the Whitetail formation, of very irregular thickness, consisting chiefly of coarse angular or only slightly waterworn land detritus.

The next rock in order of time is dacite, which was poured out as a thick lava flow, or possibly as a series of flows. Although the continuity of this lava cover has been much broken by faulting and erosion the dacite still occupies a large portion of the area. The former maximum thickness is unknown, but existing remnants show that it must have exceeded 1,000 feet. The age of the dacite is not closely determinable, but the lava is supposed to have been erupted in the later half of Tertiary time.

The outpouring of the dacite was followed by extensive faulting and vigorous erosion. During the erosion period, probably in early Quaternary time, the Gila formation accumulated in the valleys. This is a fluvio-lacustrine deposit ranging from very roughly bedded coarse angular detritus near the mountains to well-bedded silts and gypsum layers in the middle of the broader valleys. The Gila formation has been deformed by faulting and in general has been deeply cut by erosion.

PRE-CAMBRIAN ROCKS.

PINAL SCHIST.

OCCURRENCE AND DISTRIBUTION.

The oldest formation in the Ray-Miami region is the Pinal schist,[3] of pre-Cambrian and possibly of Archean age. With various granitoid intrusives it constitutes a basal complex upon which the Paleozoic sediments were laid down, and is particularly important as being the general country rock of the disseminated copper deposits.

The most extensive body of schist visible in the region (see Pl. II) is that of the Pinal Range, exposed over an area about 16 miles long from southeast to northwest and about 12 miles in greatest width. This mass, however, is not all schist; it contains much irregularly intruded pre-Cambrian quartz diorite (Madera diorite) and granite, with a considerable body of a much younger intrusive rock, the Schultze granite. The Miami copper deposits occur in the northeast corner of this schist area, in association with the Schultze granite.

Faulting, followed by denudation, has led to the exposure of many small areas of Pinal schist at the northwest end of the Dripping Spring Range and in the valley of Mineral Creek near Ray. Evidently the schist is the prevalent fundamental rock of this part of the region, and deeper erosion would reveal its direct connection with the mass exposed in the

[1] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 247, 1904.

[2] Walcott, C. D., Description of the Deer Creek coal field: 48th Cong., 2d sess., S. Ex. Doc. 20, Appendix I, pp. 5-7, 1885.

[3] Named and defined in U. S. Geol. Survey Prof. Paper 12, p. 23, 1903.

Pinal Range. The principal area of schist near Ray lies for the most part on the west side of Mineral Creek and contains the valuable disseminated copper ores of the Ray district.

LITHOLOGIC CHARACTER.

Like most crystalline metamorphic formations, the Pinal schist is not uniform in appearance. The divergencies from what may be considered the typical schist are mainly of two kinds—those due to differences in the original materials from which the schists were formed and those dependent upon local variations in the intensity of the metamorphism. As examples of the first kind may be mentioned certain subordinate bands of amphibolite schist in the Globe quadrangle and some irregular bands of an unusual variety southwest of Ray, described on page 34. The second kind of variation is illustrated by the increase of the crystallinity of the schists and the development of additional minerals in them near the contact with intrusive masses, such as the pre-Cambrian quartz-mica diorite (Madera diorite) of the Pinal Range or the quartz monzonite porphyry of Granite Mountain, southwest of Ray (Pl. VI). On the whole, within the Globe-Ray region variations dependent upon degree of metamorphism are more conspicuous than those dependent upon differences in composition.

In general the Pinal schist is light gray to blue-gray, with a more or less satiny luster on cleavage surfaces. In texture the varieties range from very fine grained slaty sericitic schist to imperfectly cleavable, coarsely crystalline quartz-muscovite schist carrying locally andalusite or sillimanite. The coarsely crystalline varieties occur chiefly in the Globe quadrangle, in the vicinity of the Madera diorite in the Pinal Mountains, and grade into the less metamorphosed kinds that make up the bulk of the formation and are characteristic of most of the exposures in the Ray quadrangle. Associated with the lustrous silvery sericitic schists, particularly in the Globe quadrangle, are a few layers of green amphibolitic schist.

In the areas of schist exposed from the town of Ray northeastward to the south border of the Globe quadrangle the prevalent variety is an aphanitic fissile blue-gray rock that disintegrates readily so that slopes on the schist present a characteristic glistening blue surface distinguishable at a distance from the detritus into which other formations break down by weathering. Small, ill-defined dark spots, due to the local segregation of some of the deeper-colored constituents especially biotite or chlorite, are common in certain bands, and some rather conspicuously spotted schist occurs in the contact zone of the granite porphyry on Granite Mountain, near Ray.

Microscopic sections show that the principal constituent minerals of the typical fine-grained fissile schist are quartz and sericite. The quartz occurs in part as grains of irregular outline as much as 0.5 millimeter in diameter in a finely granular groundmass of quartz and sericite with many dustlike particles of magnetite. Small, short prisms of tourmaline are fairly abundant, and minute rounded crystals of zircon are sparsely disseminated through the rock. The fissility of the schist is determined by the general parallel arrangement of the sericite flakes and a tendency of this mineral to form thin layers separated by correspondingly thin layers of quartz granules.

A specimen collected 2 miles northeast of Pinal Peak, a few hundred feet from the Madera diorite, may be taken as typical of the coarser mica schist. This is a silvery-gray rock of imperfect cleavage and on surfaces of fresh fracture flashes with irregular plates of white mica, generally about half a centimeter across. Under the microscope the principal constituents are seen to be quartz and muscovite in very irregularly bounded crystal grains. The muscovite occurs both in comparatively large plates, many of which inclose grains of quartz, and as the small-leaved variety known as sericite. The subordinate minerals are magnetite, plagioclase, fibrolite, rutile (?), and chlorite. Similar varieties of the schist near the quartz diorite contain abundant andalusite.

Chemical analyses of samples of the Pinal schist are given on page 35, where are discussed the origin and metamorphism of the formation.

In connection with the general account of the Pinal schist, the exceptional variety already referred to as occurring west of Ray deserves brief description. As shown on the geologic map of the Ray district (Pl. XLV) the exposures of this schist form a complex east-west band that conforms with the general strike of the normal schist on the north slope of Granite Mountain, just south of the principal area of cupric metallization.

On surfaces transverse to the planes of schistosity this schist shows conspicuous lenticular eyes of quartz, the largest a centimeter in length, around which the finer material of the schist curves in flowing lines of foliation. (See Pl. VII.) Associated with the quartz in some facies are much more compressed lenses or films of dark material that appear to be chiefly aggregates of minute biotite or chlorite scales. These rocks are as a rule of dull gray color, are not conspicuously micaceous, and consequently do not have the luster or sparkle of the ordinary schist.

Under the microscope (Pl. VII, *B*) some of the quartz eyes, although cracked, deformed, and even granulated, show the embayed outlines characteristic of quartz phenocrysts in siliceous porphyries. Associated with these are crystals of feldspar, in part orthoclase and in part sodic plagioclase. The feldspar, which presumably at one time possessed automorphic outlines, is now separated from the groundmass of the rock by indistinct ragged lines, as seen in thin sections, suggestive of some recrystallization of the feldspar material. The crystals, moreover, contain abundant minute inclusions of sericite and biotite which have developed within them in the course of the metamorphism of the rock to a schist, and some aggregates of sericite probably represent completely altered feldspars. Most thin sections show also a few small phenocrysts of magnetite, which, like the quartz, have been fractured and deformed.

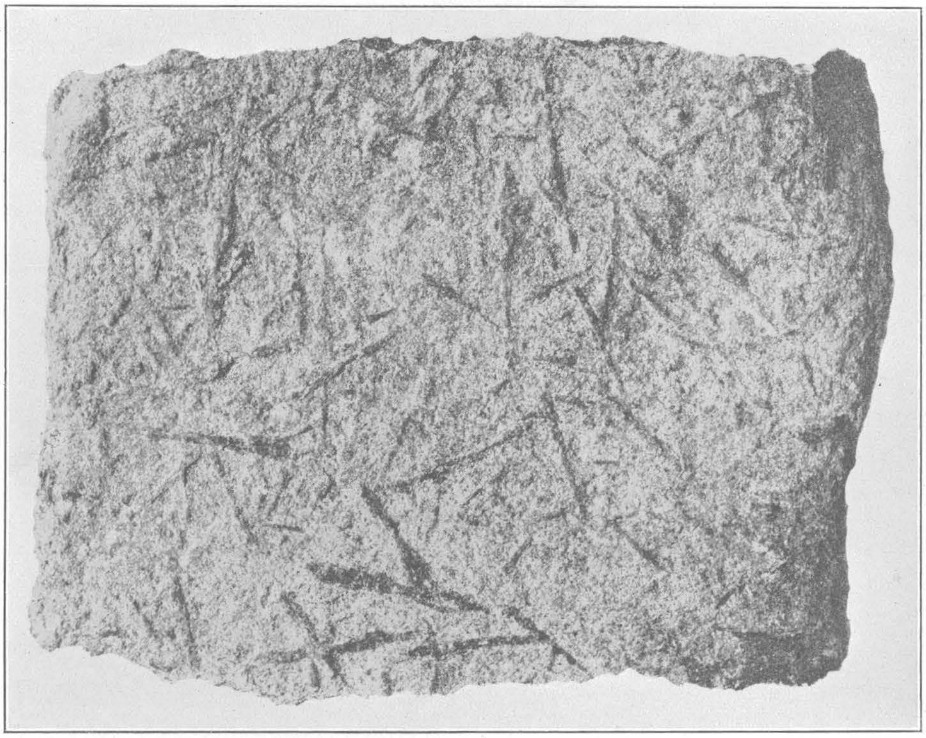
The groundmass of this variety of the schist is a fine-textured aggregate of quartz, sericite, biotite, and magnetite. These minerals are not evenly distributed but are segregated into curved irregular layers so that, when seen in thin sections transverse to the foliation, the rock suggests flow structure as well as schistosity.

It is highly probable, as will presently be shown, that this exceptional facies of the Pinal schist was originally a glassy rhyolitic lava with eutaxitic flow banding and that schistosity was subsequently developed in general parallelism with this earlier structure, just as it has followed, in the main, the planes of bending in the sediments, from which the prevalent sericitic schist was developed, although there are doubtless many places where the older and younger structures diverge. Field relations indicate that the igneous material was once a fairly regular layer in those sediments and not an irregular intrusion. The present intricacy of plan is probably the result of folding and close compression. A chemical analysis of this facies is given on page 36.

Associated with the metallized schist in the Ray district are bodies of dark, generally soft and decomposed schist that was evidently at one time an igneous rock, probably a diabase. These masses are not large and as a rule are not ore bearing, but they are so related to the ore bodies as to deserve careful study. They can be discussed in connection with the detailed account of the Ray ore deposits (see p. 125) more appropriately than in a general section on the Pinal schist.

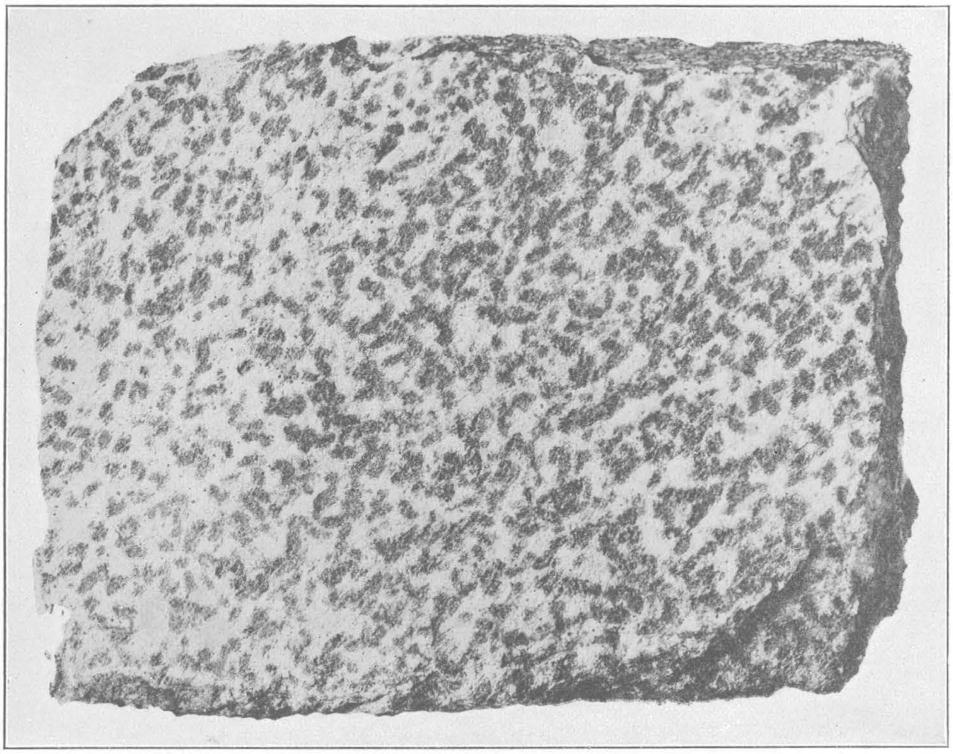
STRUCTURAL FEATURES.

As might be expected in rocks so old and so intricately intruded by batholithic granitic masses during more than one geologic period, the Pinal schist shows variations in the strike and dip of its planes of schistosity, and locally these planes are intensely crumpled and contorted. The disturbance is probably least in the broad belt on the lower southwest slope of the Pinal Range. In this area regularly laminated sericite schists, containing some layers in which the original character of quartzose grits is distinctly recognizable, predominate, but toward the Madera diorite they change to more coarsely crystalline muscovite schists. The prevailing strike of the schistose cleavage in this and in other schist areas of considerable extent is northeast. The dip ranges from 45° to vertical and is generally to the northeast. As a rule the schistosity is roughly parallel with whatever larger banding due to differences in the composition of the schists may be discernible. This fact is accepted as an indication that the schistosity is approximately parallel with the original bedding of the rocks. It is noteworthy that the



A. PHOTOGRAPH OF HAND SPECIMEN FROM NORTH SLOPE OF GRANITE MOUNTAIN. ACTUAL SIZE.

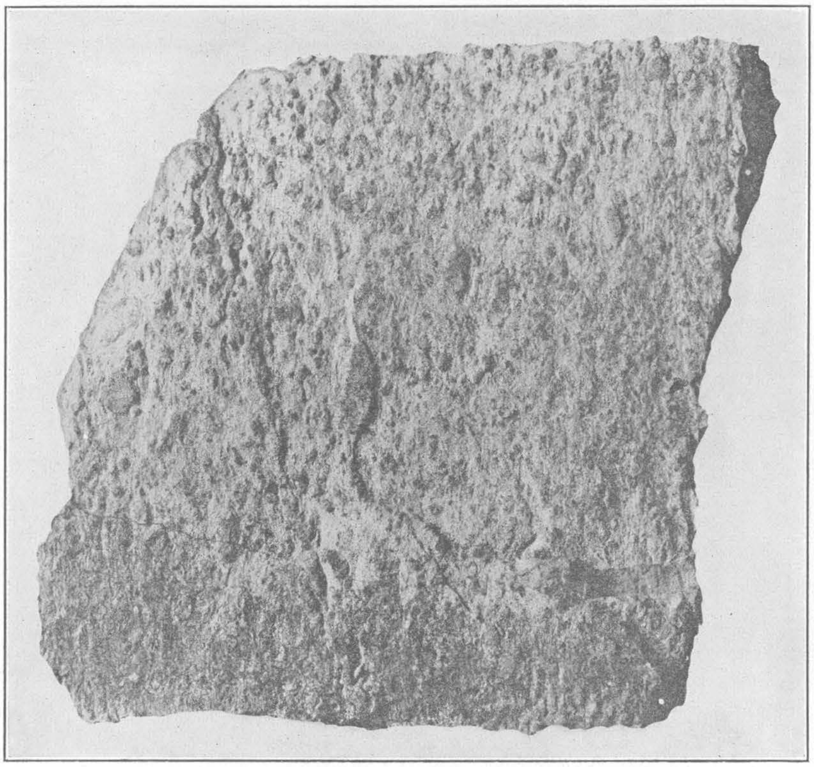
A quartz-sericite schist containing some chlorite apparently pseudomorphous after biotite. The conspicuous but ill-defined crystals, appearing dark in the illustration but really bluish gray, are andalusite.



B. PHOTOGRAPH OF HAND SPECIMEN OF ANOTHER VARIETY FROM THE SAME LOCALITY. ACTUAL SIZE.

In this conspicuously speckled schist the spots are aggregates of chlorite, probably pseudomorphous after biotite, in a matrix of sericite and quartz.

EXCEPTIONAL VARIETIES OF PINAL SCHIST, SHOWING RESULT OF LOCAL CONTACT METAMORPHISM IMPOSED ON REGIONAL METAMORPHISM.



A. PHOTOGRAPH OF HAND SPECIMEN FROM NORTH SLOPE OF GRANITE MOUNTAIN, RAY DISTRICT. ACTUAL SIZE.

Probably an altered rhyolite. Note eyes of quartz standing in relief on weathered surface.

B. PHOTOMICROGRAPH OF THIN SECTION.

Nicols crossed. Enlarged 9 diameters.

AN EXCEPTIONAL VARIETY OF THE PINAL SCHIST.

general strike of the schistose cleavage is not parallel with the present mountain ranges of the region but in the largest area of exposure runs nearly at right angles to them.

Excessively crumpled laminae are characteristic of the schist in the vicinity of Miami and on Pinto Creek, near the mouth of Cottonwood Creek. This intense local deformation, while probably favorable for ore deposition, other things being equal, was apparently neither a necessary factor in metallization nor an invariable accompaniment of that process.

ORIGIN AND METAMORPHISM.

The foregoing description has given anticipatory suggestions of the conclusion that the Pinal schist is, in the main, a series of metamorphosed sediments. The evidence in support of this view, part of which was adduced in 1904,[1] may now be examined a little more closely.

In general the mineral composition of the prevalent kinds of schist, their regular banding where not locally disturbed, and the finely fissile character of most of the rock are indicative of sedimentary origin. That at least a part of the formation was originally sedimentary is clearly proved by the presence near Mineral Creek, at the western base of the Pinal Range, of some layers in which small quartz pebbles are still recognizable. Moreover, in the vicinity of Ray and west of that town, a considerable part of the schist is a gray, fine granular, moderately fissile rock presenting the unmistakable aspect of a squeezed and metamorphosed sandstone, accompanied by still finer grained varieties that were evidently at one time shale. In some places the original bedding is plainly apparent. Thin sections of this variety, seen under the microscope, show rotund but irregular grains of quartz 5 millimeters in maximum diameter in a groundmass consisting chiefly of quartz and sericite. The large quartz grains show the effects of granulation with more or less recrystallization under pressure.

Additional evidence from the chemical side may be drawn from the data presented in the following table:

[1] U. S. Geol. Survey Prof. Paper 12, p. 27, 1903.

Chemical composition of Pinal schist and sedimentary rocks.

	1	2	3	4	5
SiO_2	61.62	65.58	66.84	60.15	60.49
TiO_2	.56	.83	.67	.76	.73
Al_2O_3	19.98	16.47	17.46	16.45	17.56
Fe_2O_3	3.46	4.19	4.88	4.04	2.74
FeO	2.57	2.25	.74	2.90	4.61
MnO		.06	.02	Trace.	
CaO	.62	1.29	.37	1.41	1.26
SrO				None.	
BaO				.04	
MgO	1.24	1.29	1.14	2.32	2.51
K_2O	5.35	4.58	4.65	3.60	3.31
Na_2O	1.78	1.42	.53	1.01	1.32
Li_2O	Trace.			Trace.	
H_2O at 110° C	.21	.22	.17	.89	.31
H_2O above 110° C	2.23	2.27	2.61	3.82	3.61
P_2O_5		.06	.03	.15	
CO_2				1.46	1.11
SO_3				.58	
Carbon (organic)				.88	
	99.62	100.51	100.11	100.46	99.56

1. Pinal schist (Ry 348). Ravine half a mile southwest of Vitoria, close to contact with granite porphyry mass of Granite Mountain, Ray district. R. C. Wells, analyst.
2. Pinal schist (Ry 332). South slope of Red Hills, Ray district. George Steiger, analyst.
3. Pinal schist (M 3). Dump of prospecting shaft 1,500 feet west of the office of the Warrior mine, on north side of Webster Gulch, Miami district. George Steiger, analyst.
4. Composite analysis of 51 Paleozoic shales. H. N. Stokes, analyst. U. S. Geol. Survey Bull. 419, p. 10, 1910.
5. Average of 79 slates and phyllites, mostly roofing slates, compiled by E. S. Bastin. (Chemical composition as a criterion in identifying metamorphosed sediments: Jour. Geology, vol. 17, p. 456, 1909.)

The variety of Pinal schist represented by analysis 1 is a fresh bright-gray sparkling rock which, owing to its proximity to the granite porphyry, is a little more conspicuously crystalline than most facies of the schist, and contains andalusite but probably has not undergone much change in composition.

The microscope shows that the constituent crystal grains are mostly less than 0.6 millimeter in diameter, although groups of the very irregular grains of andalusite have a common optical orientation over larger areas of the thin section, and this mineral exhibits a tendency toward poikilitic development. In the order of apparent volumetric abundance the component minerals are quartz, sericite, biotite, andalusite, magnetite, chlorite, and zircon. The chlorite is probably secondary after biotite.

The schist from the Red Hills, represented by analysis 2, is a fine-grained gray slaty rock, unaffected by contact metamorphism and not highly crystalline. It is obscurely banded, layers of slaty material alternating with layers of slightly coarser texture in which are granules of quartz visible to the naked eye. The microscope shows that the rock was probably once a fine impure sandstone or graywacke and that the clastic quartz grains have survived the recrystallization of the matrix as quartz, sericite, biotite, and magnetite. This rock is fairly typical of the schist in the northern part of the Ray district.

The rock from Webster Gulch (analysis 3) contrasts strongly with the Red Hills rock in general appearance, though the two are rather surprisingly similar in chemical composition. It is highly crystalline, and the abundance of sericite gives an unusually bright silvery luster to the rough, knotty masses into which the rock cleaves in consequence of its contorted lamination. The sample is thoroughly typical of the unmetallized schist of Webster Gulch and the northern part of the Inspiration mine.

With respect to fairly high silica, to an excess of over 10 per cent of alumina above the quantity required to combine with the K_2O, Mg_2O, and CaO molecules in a 1:1 ratio, to a preponderance of magnesia over lime, and to a like preponderance of potash over soda, the analyses of the Pinal schist satisfy the chemical criteria for sedimentary origin as summarized by Bastin.[1] The close resemblance of the composition of the schist to those of shales and slates is evident from the composite analysis and the average of analyses given in columns 4 and 5 of the table on page 35. On the whole, the schist analyses exhibit even more decidedly than those with which they are compared the chemical features characteristic as a rule of shaly sediments in comparison with igneous rocks.

The progressive steps whereby the pre-Cambrian sediments and small associated bodies of igneous material were transformed to schists are not easily retraceable, nor are the causes of the metamorphism entirely clear. The effects of the intrusion of the pre-Cambrian quartz diorite and granite of the Pinal Range are so pronounced near the contacts and decrease so gradually outward as to give considerable force to the suggestion that the first crystalline metamorphism dates from these intrusions. The Pinal schist at Clifton and Bisbee is accompanied by pre-Cambrian granitic intrusives, as are also the probably equivalent Yavapai schist of the Bradshaw Mountains and the schist of the Grand Canyon. Without further discussion of the question here, expression may be given to the opinion that the general metamorphism of the Pinal and equivalent schists in Arizona was probably connected directly with the extensive batholithic invasions of granitoid rocks in pre-Cambrian time. The fact that the Madera diorite and other pre-Cambrian intrusive masses are themselves in places more or less gneissoid shows that metamorphism continued after solidification of their now visible parts. Moreover, the intrusion of the Schultze granite and of the granite porphyries near Ray locally intensified the metamorphism of the Pinal schist. This may be well seen on Granite Mountain, southwest of Ray, where the schist near the granite porphyry is generally more coarsely crystalline than elsewhere and in places carries poikilitic crystals of andalusite. Other varieties are conspicuously spotted by the segregation of chlorite. Other varieties are conspicuously spotted by the segregation of chlorite or mica about numerous centers of crystallization. (See Pl. VI.)

The exceptional schist described on pages 33–34 as occurring west of Ray is different in composition from the normal Pinal schist, as appears below:

Chemical analysis of rhyolite schist three-fourths of a mile north of summit of Granite Mountain, Ray district.

[George Steiger, analyst.]

SiO_2	72.87
TiO_2	.66
Al_2O_3	12.89
Fe_2O_3	2.40
FeO	1.76
CaO	1.90
MgO	.82
Na_2O	3.01
K_2O	3.03
H_2O below 110°	.26
H_2O above 110°	.64
P_2O_5	.13
MnO	.07
	100.44

[1] Bastin, E. S., op. cit., p. 472.

In terms of the norm system of classification of igneous rocks the norm represented by the foregoing analysis is as follows:

Salic:	
Quartz	38.76
Orthoclase	17.79
Albite	25.15
Anorthite	9.45
Corundum	1.22
	92.37
Femic:	
Hypersthene	2.00
Ilmenite	1.22
Magnetite	3.48
	6.70

This corresponds to the subrang tehamose in that system, a subdivision that includes rocks commonly classified as granites and rhyolites. This variety of schist is therefore a metamorphosed rhyolite or quartz latite and was probably poured out as a small volcanic flow during the deposition of the ancient sediments that now form the Pinal schist.

Although andalusite appears to be confined to the immediate vicinity of the intrusive rocks, there is in general no definite recognizable distinction between the metamorphism effected at different periods or between the local contact modifications and the more general metamorphism.

GRANITIC INTRUSIVE ROCKS.

PRINCIPAL VARIETIES AND THEIR DISTRIBUTION.

On the accompanying general geologic map (Pl. II) all the pre-Cambrian granitic rocks are shown as a cartographic unit. In the Globe folio, however, six distinct intrusives were mapped, of which one, the Schultze granite, is now believed to be post-Cambrian and two others, the Willow Spring granite and the Lost Gulch monzonite, are possibly also post-Cambrian. Another, the Solitude granite, is exposed only over a small area about 5 miles southwest of Globe and need not be further considered here. This leaves for the pre-Cambrian granitoid rocks of the region two widespread and important types—quartz-mica diorite (Madera diorite) and biotite granite (including the Ruin granite of the Globe folio). The quartz-mica diorite is most abundant in the Pinal Range, where it is intricately intruded into the Pinal schist. The biotite granite is exposed as the basal rock in the much-faulted northwest corner of the Globe quadrangle and is the principal rock of the Tortilla Range from the vicinity of Ray southward past Kelvin and beyond the southern and western limits of the area here described.

QUARTZ-MICA DIORITE (MADERA DIORITE).

The name Madera diorite, from Mount Madera, in the Pinal Range, was first applied in the Globe report,[1] in which the diorite was described as generally a gray rock of granite texture and habit, consisting essentially of plagioclase feldspar (chiefly andesine) with quartz and black mica (biotite). Orthoclase and microcline occur in some varieties that approach granodiorite in composition; in others the occurrence of hornblende indicates gradation toward tonalite. A tendency toward gneissic foliation was noted in some localities.

The rock is not altogether uniform in texture or composition, and it is probable that were the surface scoured clean by glaciation, detailed work would afford data for the discrimination of two or more varieties. But disintegration, in part as a result of pre-Cambrian weathering, is deep and general, so that it is impracticable to treat the rock mass other than as a unit.

In the Globe report the facies exposed along the stage road northeast of Pioneer Mountain was described as being rather coarser than the typical Madera diorite and as consisting of plagioclase (Ab_1An_1), quartz, biotite, microcline, and a little muscovite, with accessory titanite, apatite, magnetite, and zircon. Biotite is so abundant as to give the rock as a whole a rather dark-gray color as compared with ordinary granite, and there is a suggestion of gneissic foliation in the arrangement of the minerals. The specimen appears to be fairly representative of the Madera diorite east of Pioneer Mountain, along the northern edge of the Ray quadrangle. A chemical analysis of this rock, taken from the Globe report, is given below, together with an analysis of what was regarded as the more nearly typical variety in the Globe quadrangle.

[1] U. S. Geol. Survey Prof. Paper 12, p. 58, 1903.

Chemical analyses of quartz-mica diorite from the Globe quadrangle.

[W. F. Hillebrand, analyst.]

	1	2
SiO_2	58.74	61.99
Al_2O_3	16.02	15.81
Fe_2O_3	4.16	3.28
FeO	3.50	2.69
MgO	2.18	2.24
CaO	5.12	4.62
Na_2O	3.26	2.73
K_2O	2.39	2.51
H_2O below 110° C	.83	.91
H_2O above 110° C	1.60	1.99
TiO_2	1.29	.94
ZrO_2	.05	.03
CO_2	None.	None.
P_2O_5	.56	.11
Cl	Undet.	Undet.
F	Undet.	Undet.
S	[a] .06	Trace.
Cr_2O_3	....	Trace.
NiO	Trace.	Undet.
MnO	.22	Trace.
BaO	.10	.06
SrO	Trace.	Undet.
Li_2O	Trace.	Undet.
FeS_2	.11	....
	100.13	99.91

[a] Calculated as FeS_2.

1. Globe-Kelvin stage road, 2 miles south of Pinal Peak or 1½ miles east-northeast of Pioneer Mountain.
2. West slope of Pinal Range, 2 miles southwest of Mount Madera.

In the norm system of classification the rock from the Globe-Kelvin stage road (No. 1) is tonalose.

At no place southeast of the stage road has any marked change been detected in the general character of the prevailing rock, yet examination of successive exposures in that direction shows a notable increase in pink potassium feldspar in the form of phenocrysts. A specimen collected a mile northeast of Old Baldy is a slightly foliated porphyritic gneiss containing anhedral phenocrysts of potassium feldspar 4 centimeters or less in length in a groundmass closely similar to the general mass of the rock represented by analysis 1, above. The feldspar phenocrysts as seen in thin section show in part the optical character of orthoclase and in part that of microcline, there being in this rock no sharp distinction possible between the two forms. The characteristic microcline twinning is as a rule not conspicuously developed, and, as is well known to petrographers, orthoclase may be regarded as microcline in which the twinning lamellae are submicroscopic.

The relative abundance of phenocrysts and groundmass varies from place to place, and where the porphyritic crystals are numerous the composition of the mass as a whole must be considerably different from that given in column 1 of the table on this page. Such facies should probably be classed as granodiorite or quartz monzonite. In the absence of abundant fresh material, however, it did not appear that decision on the exact place in classification of these variable porphyritic varieties was of such moment as to warrant chemical analysis.

GRANITE (BIOTITE GRANITE).

In all ordinary exposures the granite is weathered and in various stages of disintegration so that collection of fresh material is rarely possible. This is especially true in the vicinity of the lower Paleozoic sediments, where the granite is generally reddened by pre-Cambrian oxidation.

It consists as a rule of large, shapeless phenocrysts of flesh-colored potassium feldspar from 2 to 5 centimeters in length in a groundmass of coarsely crystalline anhedral plagioclase and quartz with a moderate proportion of biotite. (See Pl. XV, *A*, p. 55.)

The microscope shows that the phenocrysts are, in the main, slightly microperthitic orthoclase, although in parts of each crystal there are obscure suggestions of microcline twinning. These crystals are traversed by microscopic quartz-filled cracks, and the rock as a whole shows evidence of deformation in the zone of fracture. The plagioclase is a sodic variety, probably oligoclase, but is too decomposed for satisfactory identification. Much of the biotite is altered to chlorite.

Owing to its prevalent decomposition no detailed petrographic or chemical study has been made of this rock, which, although it is accompanied by some finer-grained facies, is fairly representative of the coarse, more or less reddish porphyritic granites that are characteristic of the pre-Cambrian generally in Arizona. Its relations to the Madera diorite are not discoverable in this region.

The Ruin granite of the northern part of the Globe quadrangle, including the mass of Porphyry Mountain, which in the Globe report was erroneously classed with the Schultze granite, is virtually identical with the granite of the Tortilla Mountains.

PALEOZOIC ROCKS.

STRATIGRAPHIC DIVISIONS AND SEQUENCE.

The names, thicknesses, and succession of the Paleozoic rocks that in the Globe-Ray region rest with conspicuous unconformity upon the pre-Cambrian crystalline complex are graphically summarized in the accompanying columnar section (fig. 2, p. 31).

Although in this region the stratified rocks have been elaborately faulted, the fault pattern being on an extraordinarily minute scale, and have been extensively invaded by diabase, excellent sections, of the kind illustrated in Plate VIII, *A*, may be studied in the Mescal Range and in many of the larger fault blocks of the Dripping Spring Range. The total thickness of the beds below the base of the Carboniferous limestone and above the pre-Cambrian crystalline rocks is about 1,600 feet. The Carboniferous limestone is at least 1,000 feet thick and is limited above by a Mesozoic erosion surface. No evidence of angular unconformity has been detected within the pre-Mesozoic sedimentary series, although the exposures are so good that any appreciable angular discordance could scarcely escape recognition.

In the report on the Globe quadrangle and in the Globe folio the name "Apache group" was applied to the beds supposed to lie between the base of the Devonian limestone and the ancient erosion surface on the Pinal schist. The Apache group, although mapped as a unit, was described in 1903 as being locally divisible into four formations, which, from the base up, were the Scanlan conglomerate, the Pioneer shale, the Barnes conglomerate, and the Dripping Spring quartzite. In the minutely faulted rocks of the Globe quadrangle no complete section of the group could be found, and the supposed constitution of the whole was arrived at by piecing together fragmentary data from different fault blocks under the assumption that there was in the region but one limestone formation (the Devonian and Carboniferous "Globe limestone") and but one quartzite formation (the Dripping Spring quartzite).

When, however, detailed work in the Ray quadrangle was begun in 1910 and better natural sections were studied, it soon appeared that below the Devonian, as shown in figure 2, there are two thick formations of quartzite separated by about 250 feet of dolomitic limestone. The initial assumption made in attempting to construct the Globe stratigraphic column was therefore incorrect. The Dripping Spring quartzite as mapped in the Globe report and folio included some of what is now named the Troy quartzite, and the "Globe limestone" of the same publications included not only the Carboniferous and Devonian limestones, to which the name was intended to apply, but also some fragmentary masses, many of them inclusions in diabase, of what is now named the Mescal limestone.

In the present report the name "Globe limestone" is abandoned, as it is now possible to map separately the Devonian and Carboniferous limestones; but Dripping Spring quartzite is retained, with redefinition, as the designation of the lower of the two quartzite formations.

SCANLAN CONGLOMERATE.

The Scanlan conglomerate was first described in the Globe report,[1] where it was said to be from 1 to 6 feet thick and to be composed of imperfectly rounded pebbles of vein quartz with scattered flakes of schist held in a pink arkosic matrix. The name was derived from Scanlan Pass, in the northwestern part of the Globe quadrangle. The conglomerate is extremely variable both in constitution and in thickness. It is interpreted as having been formed, with little transportation, from the materials that the waves of an advancing sea found lying on a well-worn ancient surface of low relief. On that surface areas of schist were littered with fragments of white vein quartz, and the upper parts of granitic masses were deeply disintegrated. Consequently the basal conglomerate where it rests on the Pinal schist is composed chiefly of imperfectly rounded pebbles of quartz in a matrix of small particles of schist, grains of quartz, and flakes of mica; where it rests on granite or quartz-mica diorite the pebbles are likewise mostly quartz, but the matrix is arkosic and the layers of pebbles may be associated with beds of arkose that in many places merge imperceptibly with the underlying massive rock or grade upward into the Pioneer shale. These two varieties of the conglomerate, however, are connected by transition facies.

In some localities the base of the Pioneer shale may be marked only by a few sparsely distributed pebbles or the Scanlan conglomer-

[1] U. S. Geol. Survey Prof. Paper 12, pp. 30-31, 1903.

ate may not be recognizable at all. In other places, as between Pioneer Mountain and Old Baldy in the Mescal Range, the conglomerate attains a thickness of fully 15 feet and carries abundant well-rounded pebbles, including a few of quartzite derived from some ancient formation not now exposed in this region. In the vicinity of Roosevelt, 35 miles northwest of Ray, the conglomerate rests on granite, is 30 feet thick, and contains well-rounded pebbles as much as 9 inches in diameter. The same conglomerate has been recognized in the Santa Catalina Range, about 45 miles south-southeast of Ray, where its thickness at one locality was estimated at about 12 feet. The original distribution of this basal conglomerate over an area at least 85 miles from northwest to southeast and at least 40 miles wide is well established. In some places weathered, disintegrated, and recemented granitic detritus, or arkose, lies between the conglomerate and the pre-Cambrian granite.

PIONEER SHALE.

As a rule the Pioneer shale,[1] named from the now abandoned mining settlement of Pioneer, in the northern part of the Ray quadrangle, consists of dark reddish-brown, more or less arenaceous shales composed largely of fine arkosic detritus with little or no calcareous material. In some beds fragments of pink feldspar are easily recognizable with the unaided eye, and as a rule the shales toward their base grade into arkosic grits. These arkosic basal beds are well developed in the Apache Mountains, just northeast of the Globe quadrangle, where they attain a thickness of approximately 175 feet. For 75 feet above the granite these beds are thick, but higher up in the formation thinner beds appear and these grade upward into the shale.

Abundant round or elliptical spots of light-buff or greenish color, caused by local reduction and removal of the ferruginous pigment, are highly characteristic of the formation and serve in the absence of clear structural relations to distinguish the Pioneer shale from certain similar beds in the stratigraphically higher Dripping Spring quartzite. Surfaces of fresh fracture generally sparkle with minute flakes of white mica.

[1] U. S. Geol. Survey Prof. Paper 12, p. 31, 1903.

Although the Pioneer shale is a soft formation in comparison with the conglomerates and quartzites and weathers into smooth slopes it is nevertheless a well-indurated, firm, and in places not very fissile rock. The general color of the formation as seen on the hill slopes is dark red, maroon, chocolate-brown, or dull purplish gray.

In the Globe report the average thickness of the Pioneer shale was given as 200 feet, which is about the thickness in the typical section at Pioneer, in the northeastern part of the Ray quadrangle. In the ravine west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the shale is 100 feet thick. In the canyon of Salt River, below the Roosevelt Dam, the formation, which here in its lower part consists of alternating beds of sandstone and shale, has an estimated thickness of 250 feet. The average thickness for the region is estimated to be about 150 feet.

The Pioneer shale so far as known is not fossiliferous and presents no characteristics that mark it indubitably as marine or fluviatile in origin. It is believed to be marine and to have been deposited in shallow water. No mud cracks have been observed in it.

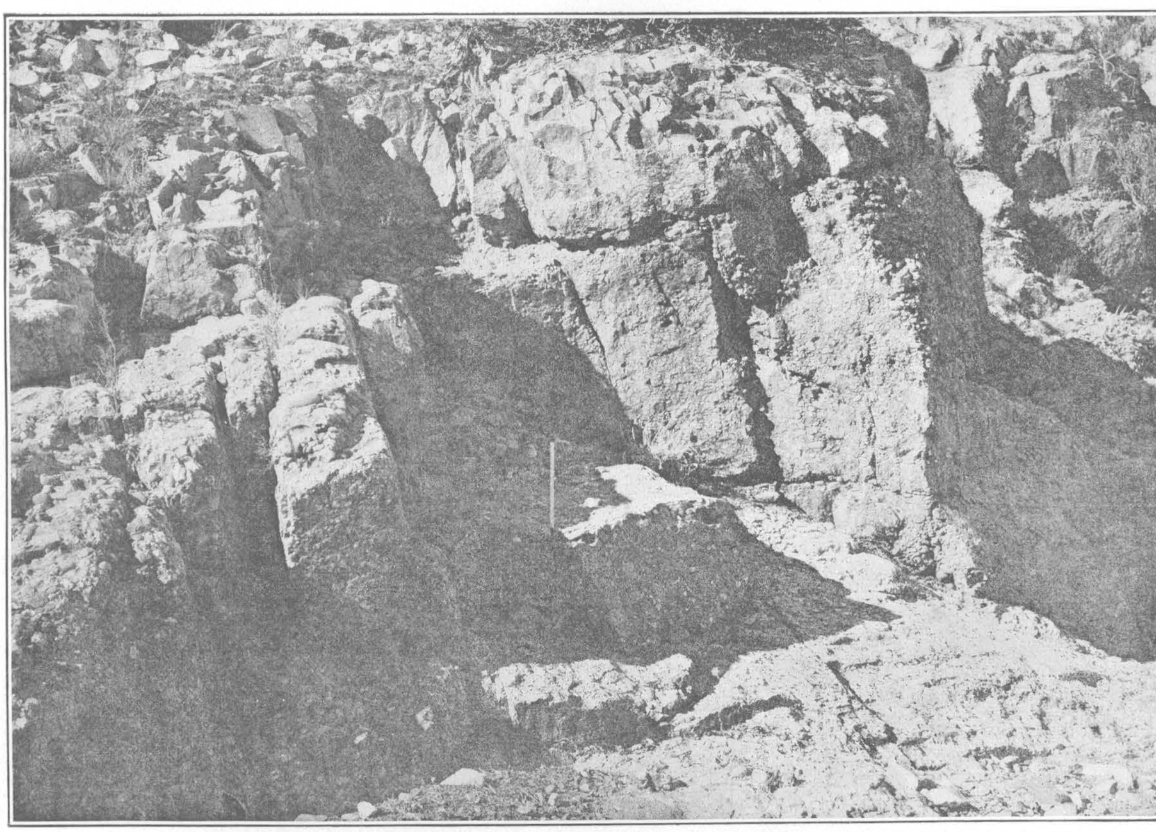
BARNES CONGLOMERATE.

The Barnes conglomerate, a characteristic, persistent, and readily recognized formation, lies stratigraphically above the Pioneer shale and below the Dripping Spring quartzite. The formation was first described in the Globe report [1] and took its name from Barnes Peak, in the northwestern part of the Globe quadrangle, where it ranges from 10 to 15 feet in thickness.

There is no apparent unconformity either above or below the conglomerate, although the abrupt change from a fine shale to a deposit of coarse pebbles is indicative of such extensive modification of the conditions of erosion and sedimentation under which the shales accumulated as would seem to demand notable contemporaneous unconformity somewhere within the region of deposition. The surface of contact between the shale and the conglomerate is wavy and irregular, but the adjacent shale layers conform to the unevenness of the contact, as if they had settled under load.

A. A TYPICAL HILLSIDE SECTION IN THE MESCAL RANGE.

Looking west near the junction of Pioneer and Silver creeks. The smooth lower slope, beyond the maguey or "mescal" plant in the foreground, is diabase and in the actual landscape is dark olive-green. The bluff just above the thick diabase sill is the upper part of the Troy quartzite. The slope above it, with thin outcropping beds, is on the Martin (Devonian) limestone, and the crest and back slope are Tornado (Carboniferous) limestone. In the distance, across the Dripping Spring Valley, is the Dripping Spring Range.



B. BARNES CONGLOMERATE ON EL CAPITAN CREEK, MESCAL RANGE.

CAMBRIAN BEDS.

In its typical development, as near Pioneer Mountain or on Silver and El Capitan creeks, in the Ray quadrangle, the Barnes conglomerate consists of smooth pebbles of white quartz and of hard vitreous quartzite in an arkosic matrix. The pebbles are generally not over 6 inches in diameter, but in a few places there are some that reach 8 inches. Although well rounded, the pebbles are not rotund but are flattened ellipsoids or round-edged disks. They are composed only of the most durable materials, and doubtless passed through long and varied processes of attrition before they came to rest in the Barnes conglomerate.

In some localities the pebbles, which generally lie with their flat sides roughly parallel with the bedding planes, are in contact and the proportion of arkosic matrix is correspondingly small; in other places the matrix predominates. As a rule in the Ray quadrangle the pebbles are seen to become larger and more abundant as the conglomerate is followed southward, although the gradation is probably not wholly regular. Thus at Barnes Peak the average diameter of the pebbles is 3 or 4 inches [1] and the thickness of the formation 10 to 15 feet. In the vicinity of El Capitan Mountain pebbles 6 inches in diameter are abundant; the average size is probably a little larger than at Barnes Peak, and the thickness of the formation is from 15 to 20 feet, but no rocks capable of supplying the pebbles are known in that direction, although of course exposures of pre-Cambrian quartzitic rocks may have existed in Cambrian time south of the Ray area.

At the north end of the Dripping Spring Range the conglomerate is rather variable. A small exposure about 1½ miles north of Walnut Spring shows thin bands of pebbles associated with pinkish arkose and gray shale. The pebbles, which are chiefly white quartz and not very well rounded, rarely exceed 2 inches in diameter and none were seen over 3 inches. About 2 miles northwest of Walnut Spring the whole formation is from 10 to 12 feet thick, but the arkosic matrix is much more abundant than the pebbles, which although not uniformly distributed are as a rule most numerous near the base. The lower part of the bed thus presents in some places the aspect of the typical Barnes conglomerate, whereas the upper part is distinguishable from the overlying quartzite only by containing few small and scattered pebbles.

[1] U. S. Geol. Survey Prof. Paper 12, p. 31, 1903.

Northeast of Tam o' Shanter Peak, on the other hand, the conglomerate is about 40 feet thick and consists chiefly of very smooth rounded pebbles which are generally in contact with one another, there being just enough matrix to fill the interstices. Some pebbles are as much as 10 inches in diameter, but most are under 6 inches. In the Tortilla Range, south of Kelvin, the conglomerate is about 55 feet thick and carries abundant characteristic pebbles as much as 8 inches in diameter.

The arkosic matrix of the conglomerate is generally similar to the material of the overlying Dripping Spring quartzite, although perhaps a little coarser. It varies in hardness, but as a rule all constituents of the conglomerate are cemented by silica into a hard and durable rock in which fractures traverse pebbles and matrix alike. A very characteristic feature of the Barnes conglomerate throughout the region described is the presence in the matrix of small fragments of vermilion-red chert or jasper an inch or so in maximum diameter. The only rocks known that might have furnished these red fragments are certain hematitic jaspers associated with schist in the northern part of the Mazatzal Range, about 70 miles north-northwest of Ray.

A view of the upper part of the Barnes conglomerate as exposed on El Capitan Creek, in the northeastern part of the Ray quadrangle, is shown in Plate VIII, *B*.

This conglomerate is very constant in character and has a wide distribution. It has been identified in the Sierra Ancha, to the north, and in the Santa Catalina Range, to the south, two localities about 80 miles apart.

DRIPPING SPRING QUARTZITE.

The Dripping Spring quartzite lies conformably above the Barnes conglomerate and under the Mescal limestone.[2] Approximately the lower third of the formation consists of hard fine-grained arkosic quartzites which, as seen in natural sections, show no very definite division into distinct beds but exhibit a pronounced striping, due to the alternation of

[2] This, as explained on page 39, is a redefinition of Dripping Spring quartzite as the name was originally used in the Globe quadrangle.

dull-red and dark-gray or nearly black bands parallel with the planes of stratification. These bands as a rule are less than 1 foot wide and give a generally thin-bedded aspect to this portion of the formation, as may be seen from Plate IX, *A*, although the illustration fails to show the contrasting tints of the bands. About midway between the top and bottom of the formation the striped beds are succeeded by fairly massive beds, as much as 6 feet thick, of even-grained buff or pinkish quartzite associated with flaggy variegated red, brown, and gray beds and with some layers of gray and reddish shales suggestive of the Pioneer shale. In the upper part of the formation the beds become thin, flaggy, and rusty and show a tendency to grade into the Mescal limestone.

The Dripping Spring quartzite was deposited in shallow water, and the sand was at times exposed to the air, as may be seen from the ripple marks, sun cracks, and fossil worm casts visible on the surface of the beds. It is, however, composed throughout of fine material and contains no pebbles so far as known. This feature and the banding of its lower beds serve to distinguish this quartzite from the pebbly cross-bedded Troy quartzite, described on pages 44–45.

Where almost vertically upturned in the Tortilla Range the Dripping Spring quartzite is apparently about 500 feet thick, but the presence of intrusive diabase detracts a little from the reliability of this measurement, as movements during the intrusion may have increased the apparent thickness. Southwest of Pioneer Mountain, where apparently the whole of the quartzite is exposed without noticeable faulting, the thickness, obtained by calculation from the width of the outcrop as mapped, the average dip of the beds, and the general angle of topographic slope, is between 450 and 500 feet. At Barnes Peak, in the Globe quadrangle, the thickness was estimated at 400 feet.[1] The average thickness for the Ray quadrangle is taken at 450 feet, which is probably under rather than above the truth. The formation in most localities in the Ray-Miami region is closely associated with intrusive masses of diabase, usually in the form of sheets. Some of the characteristics of the quartzite are probably due to the effect of the diabase intrusions.

[1] U. S. Geol. Survey Prof. Paper 12, p. 31, 1903.

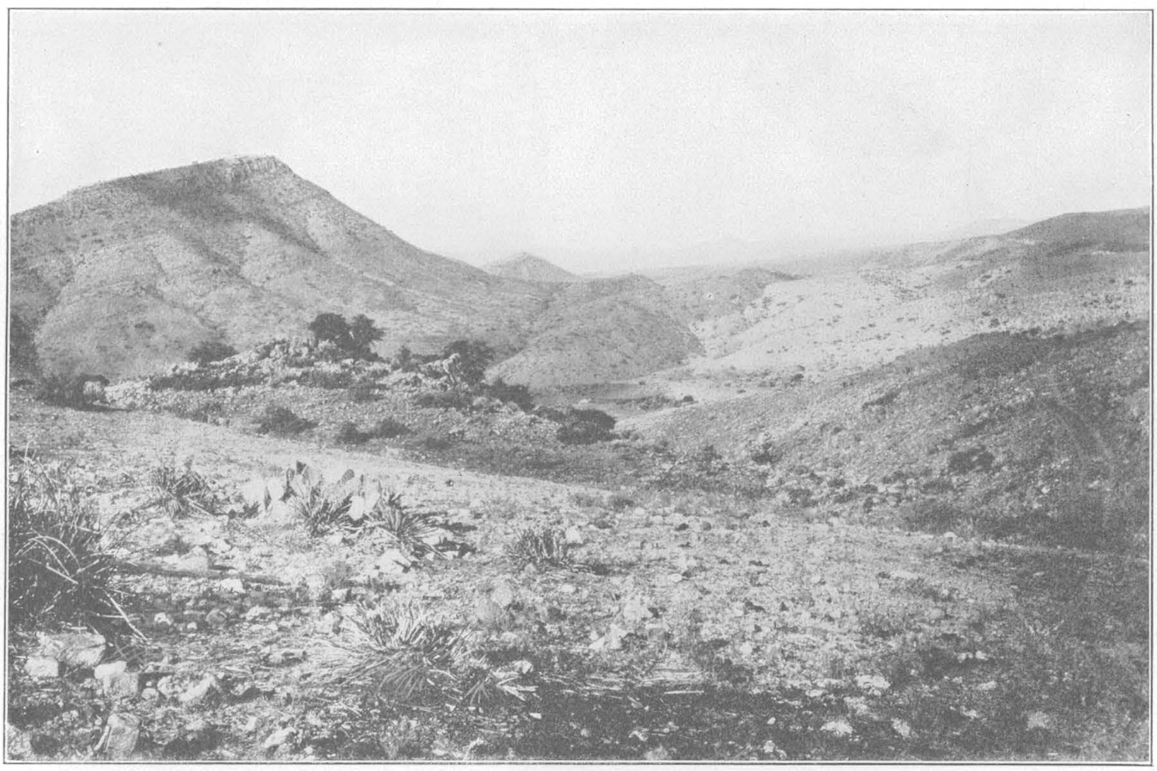
MESCAL LIMESTONE.

The Mescal limestone was first recognized as a distinct formation in the course of mapping the Ray quadrangle. It is named from the Mescal Mountains, where it is well exposed. Stratigraphically it is limited below by the Dripping Spring quartzite and above by the Troy quartzite. Some fragments of this formation, most of them intimately associated with intrusive diabase, occur in the Globe quadrangle, but when the report on that area was prepared these masses of strata were supposed to be somewhat metamorphosed portions of the thin Devonian beds in the lower part of the "Globe limestone."

In the Ray quadrangle also the Mescal limestone and the diabase are closely associated. Lying between the two heavy quartzitic formations, the thin-bedded dolomitic limestone proved an easy path for the invading diabase magma and retains little of its former continuity. In the development of the topography the diabase tends to wear down into swales and hollows, and an extended view over one of these depressions shows the generally olive-tinted surface characteristic of diabase areas varied by blotches of white. (See Pl. IX, *B*.) These light patches represent included blocks of the Mescal limestone, some of which are nearly a quarter of a square mile in area. Other portions of the formation rest in their original position on the Dripping Spring quartzite, with the diabase in igneous contact above them. Still others crop out along the bases of cliffs formed by the Troy quartzite and have the intruded diabase below them. Rarely the limestone lies unbroken between the two quartzites.

The Mescal limestone is composed of thin beds that have a varied range of color but are persistently cherty. The siliceous segregations as a rule form irregular layers parallel with the bedding planes, and on weathered surfaces these layers stand out in relief and give to the limestone the rough, gnarled banding that is its most characteristic feature. The usual appearance of the Mescal on outcropping edges is shown in Plate X, *A*. The general hue of the formation is gray or white, but some beds are yellow, buff, brown, or rusty. In some localities the rough, gnarled strata are accompanied by others in which are thin, regular buff and gray layers whose differ-

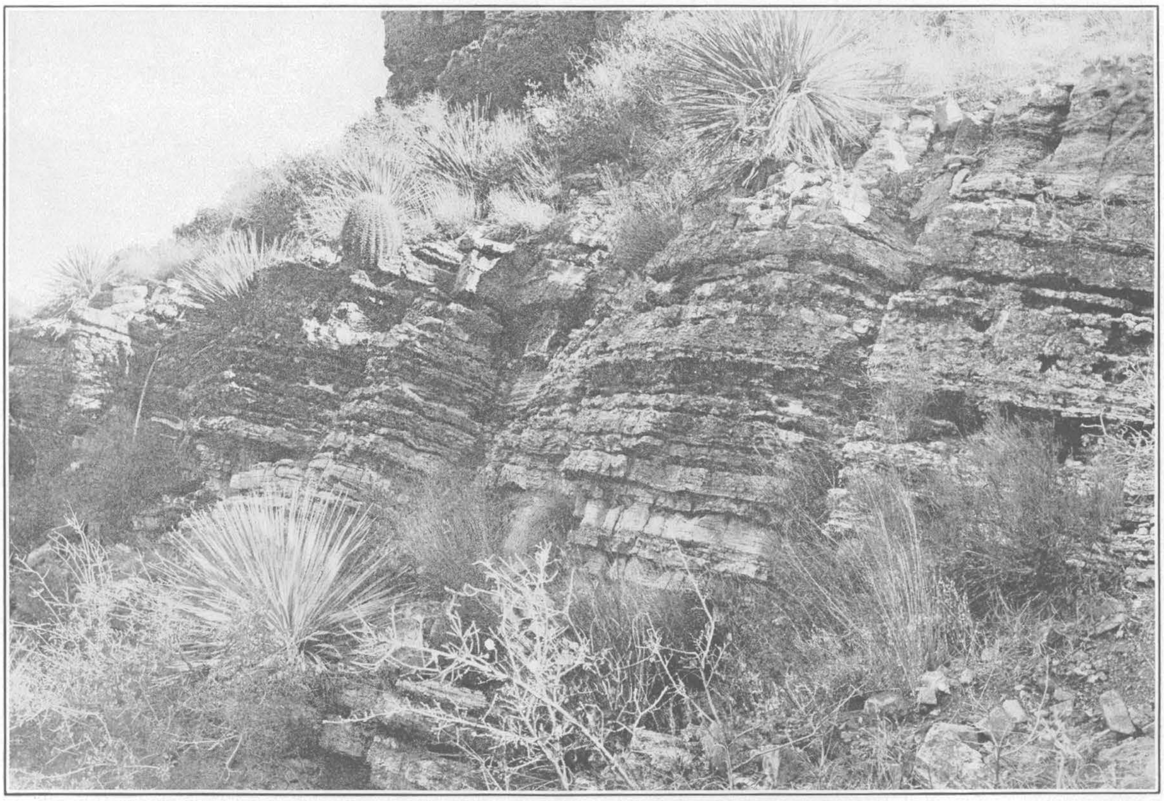
A. BANDED DRIPPING SPRING QUARTZITE, 1 MILE SOUTH OF PIONEER, IN THE MESCAL RANGE.



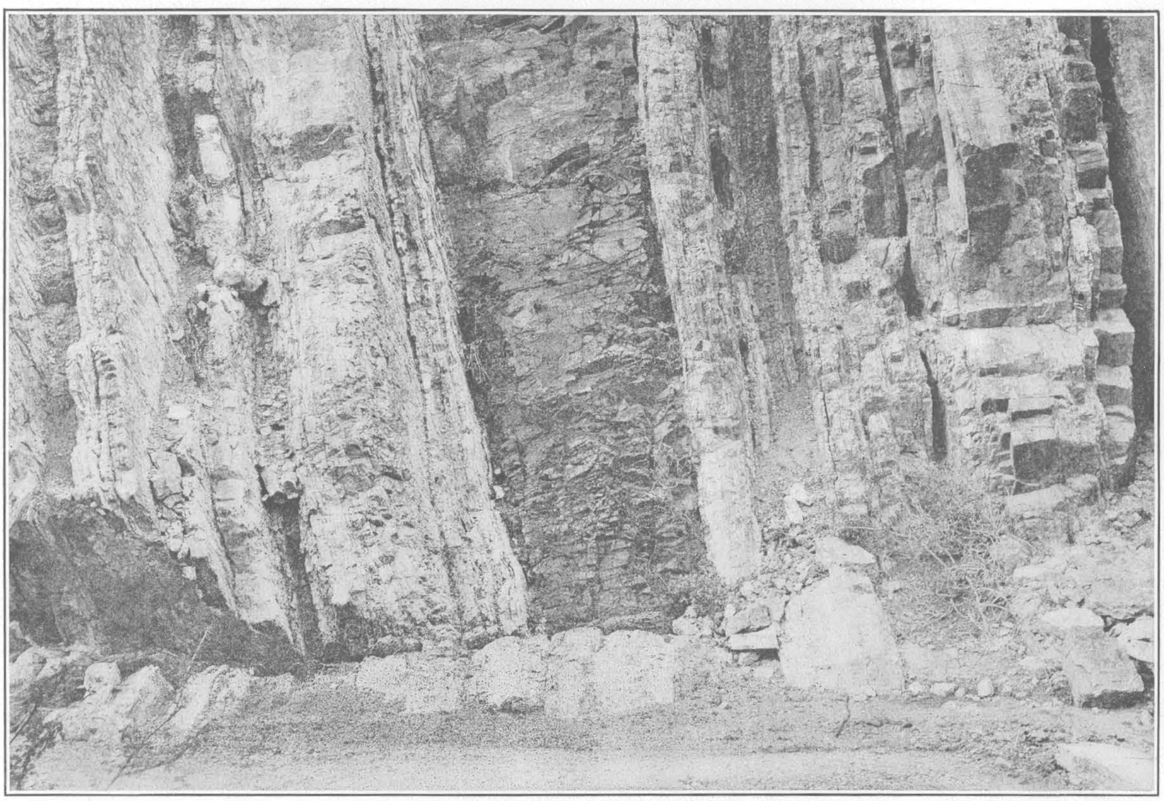
B. VIEW NORTHWEST FROM STAGE ROAD 2 MILES SOUTH OF PIONEER MOUNTAIN, IN THE RAY QUADRANGLE.

The bold hill on the left is composed, in ascending order, of diabase, Troy quartzite, Martin limestone, and Tornado limestone. The broad saddle to the right of this hill is occupied by a great diabase sill which passes beneath the Troy quartzite to the left and laps up onto a dip slope of Dripping Spring quartzite just to the right. The diabase has disrupted the Mescal limestone, which belongs between the two quartzites, and remnants of the limestone strata included in the diabase can be recognized as rather extensive white patches that in the field contrast sharply with the dark olive tint of the diabase surface.

CAMBRIAN BEDS.



A. TYPICAL HILLSIDE EXPOSURE OF THE CHERTY MESCAL LIMESTONE IN THE DRIPPING SPRING RANGE, 2 MILES SOUTH OF DRIPPING SPRING RANCH.



B. STEEPLY UPTURNED MESCAL LIMESTONE WITH INTRUSIVE DIABASE IN THE TORTILLA RANGE, ABOUT 6 MILES SOUTH OF KELVIN.

The diabase sill ends near the bottom of the view but is connected, on the left, with other sheets of diabase by a small dike that cuts across the beds in the lower left corner of the picture.

CAMBRIAN BEDS, MESCAL LIMESTONE.

ences in chemical composition in conjunction with the dissolving action of atmospheric water give rise to such natural ornamentation as is illustrated in Plate XI.

Between the limestone and the overlying quartzite is a layer of decomposed vesicular basalt whose maximum observed thickness is from 75 to 100 feet. Although the basalt is in places much thinner than this, the flow was apparently coextensive with the Mescal limestone throughout the Ray and Globe quadrangles, over an area of at least 500 miles. Where the basalt is in contact with the later intrusive diabase it is difficult to distinguish between the two rocks in the absence of good exposures, and in the earlier work in the Globe quadrangle the altered vesicular basalt was supposed to be merely a contact modification of the diabase.

A section of the Mescal limestone with the overlying basalt flow as exposed on the east side of El Capitan Canyon is as follows:

Section of the Mescal limestone in El Capitan Canyon.

[Thicknesses approximate.]

	Feet.
Base of Troy quartzite.	
Vesicular basalt	75
4. Striped buff and gray dolomitic limestone, weathering in sharp channels and ridges, as illustrated in Plate XI	15
3. Very rough cherty dolomitic limestone with no distinct division into beds; weathers with gnarly dark rusty-brown surface	30
2. Gnarled, knotty cherty limestone, mostly dolomitic, in beds as much as 2 feet thick; some beds light gray and some dark brown; shaly partings	125
1. Thin impure shaly limestone with perhaps some dolomite; splits into thin leaves; mostly light gray	50
Top of Dripping Spring quartzite.	
	295

A partial chemical analysis of a sample from division 2 of the foregoing section is as follows:

Partial chemical analysis of Mescal limestone.

[R. C. Wells, analyst.]

SiO_2	29.93
Al_2O_3	.42
CaO	21.90
MgO	14.90

This rock weathers brown but is nearly white on fresh fracture. The molecular ratio of lime and magnesia is nearly that of dolomite, but as the beds are not all of the same character the foregoing analysis does not represent accurately the composition of the whole formation.

In the narrow gorge just west of Hackberry Spring, in the southwestern part of the Ray quadrangle, the Mescal limestone stands almost vertical and has a thickness of 225 feet. In the section just given the total thickness is recorded as 220 feet, exclusive of the vesicular basalt. This, however, is an estimate based on barometric readings corrected for a dip of about 25°. The average thickness of the formation as mapped in the Ray quadrangle and including the basalt flow may be taken as about 250 feet.

The Mescal limestone has been recognized in the Sierra Ancha and in the Santa Catalina Range. It is in part lithologically identical with and is probably the stratigraphic equivalent of the Abrigo limestone of Bisbee and Tombstone, which contains Middle Cambrian fossils. This correlation, however, is not regarded as sufficiently well established to justify definite application of the name Abrigo in the Ray area.

BASALT.

Throughout the Ray-Globe region where the Mescal limestone and Troy quartzite are exposed in their original relative positions the two formations are separated by a layer of dark decomposed or altered vesicular rock of varying thickness, at most about 100 feet. This is an ancient basaltic flow.

The rock in weathered exposure is generally dark rusty brown to nearly black and contains abundant small vesicles which, as a rule, are flattened parallel with the top and bottom of the flow. Freshly broken material is dark reddish brown and shows that the vesicles are for the most part filled with epidote and calcite. At one locality on Pioneer Creek, about 2 miles south of Pioneer, the basalt has been partly altered to epidote, garnet, and specularite, apparently through the metamorphic action of a diorite porphyry dike.

Under the microscope the basalt is seen to retain much of its primary texture, but the original minerals have been almost entirely altered to aggregates of calcite, epidote, quartz, serpentine, and iron oxide. It was probably a rather coarsely crystalline olivinic basalt.

TROY QUARTZITE.

The Troy quartzite lies conformably above the Mescal limestone and below the Martin limestone. Before the detailed mapping of the Ray quadrangle this quartzite had not been recognized as a formation distinct from the lower or Dripping Spring quartzite, for in the Globe quadrangle there are no sections that show the two quartzites separated by the intervening Mescal limestone, and such brief papers on the geology of the Ray quadrangle as have appeared since the Globe report was published have dealt only with the immediate surroundings of the copper deposits at Ray, where the stratigraphic relations of the sedimentary rocks are less clearly displayed than elswehere in the quadrangle. The name of the formation is derived from Troy Mountain, in the Dripping Spring Range.

The Troy quartzite is one of the most prominent and widely exposed formations in the region, especially in the Ray quadrangle, where it forms the bold crest of El Capitan, in the Mescal Range, and the summits of Scott and Troy mountains, in the Dripping Spring Range. The beds differ greatly in thickness, ranging from thin flaggy or shaly layers to cross-bedded pebbly beds from 25 to 50 feet thick. On the whole the thicker beds are characteristic of the lower and middle parts of the formation. The upper part is invariably composed of thin, generally yellowish or rusty worm-marked shaly quartzite, indicative of a change in sedimentation that preceded the deposition of the Devonian limestone. The most characteristic material of these upper beds consists of layers of fine-grained unevenly colored brown, pink, and green quartzite, an inch or two thick, separated by films of olive-gray shale whose cleavage surfaces are ridged and knotted with numerous worm casts. The quartzite layers appear almost dolomitic in color and texture, but the microscope shows them to consist chiefly of closely fitting quartz grains with specks of flocculent limonite and little nests of a green chlorite mica. The most noteworthy features of the thicker beds are their generally pebbly character, which is a useful means of distinguishing isolated exposures of the Troy quartzite from the pebble-free Dripping Spring quartzite, and their conspicuous cross-bedding. Both of these characteristics are illustrated in Plate XII, *A*. The Dripping Spring quartzite is nearly all arkosic, but the Troy quartzite shows little or no feldspar.

A section of the Troy quartzite as exposed in nearly horizontal attitude 1½ miles southeast of Tam o' Shanter Peak, in the Dripping Spring Range, though not quite complete, is as follows:

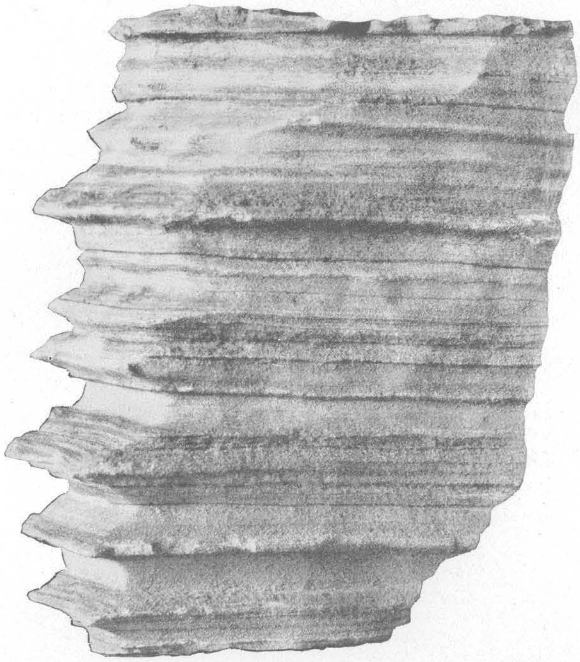
Section of Troy quartzite in Dripping Spring Range.

[Thicknesses approximate.]

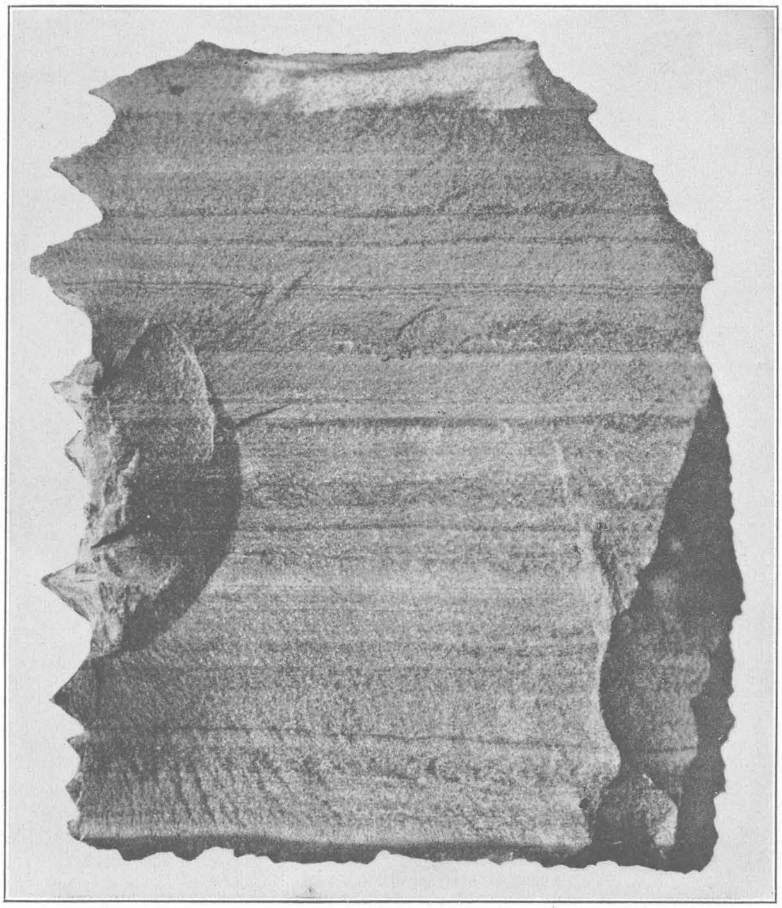
	Feet.
Yellowish, rusty thin-bedded quartzites with olive-gray shale partings roughened by worm casts	50+
Fine-grained quartzite with very regular laminations from 2 to 6 inches thick	1½
Rather thin beds of white fine-pebble quartzite	50
A single bed of massive, cross-bedded fine-pebble, white quartzite, with layers of small quartz pebbles every few feet; forms a cliff	50
Sheet of porphyry, 25 feet. Partly concealed, apparently rather thin-bedded gray pebbly quartzite	35
Two beds of cross-bedded coarse quartzite or grit with scattered pebbles of white quartz 6 inches or less in diameter; forms a scarp	15
Conspicuously cross-bedded gray quartzite with many layers of small quartz pebbles; no distinct separation into beds, but obscure laminations average about 1 foot thick; forms a stepped slope; microscope shows typical quartzite texture with enlarged interlocking quartz grains	75
Conglomerate with fairly well-rounded pebbles, mostly of white quartz, as much as 4 inches in diameter, in an abundant cross-bedded matrix of coarse quartzite	6
Soil-covered slope apparently underlain by a yellowish shale or fine-grained quartzite	25
Cross-bedded pebbly quartzite in beds 4 to 10 feet thick; pebbles quartz, rarely over 2 inches in diameter, in places scattered and in places concentrated in irregular lenticular layers; weathers gray or rusty; forms a stepped slope	25
Bed of irregularly banded gray quartzitic breccia grading up into cross-bedded coarse grit or conglomerate with quartz pebbles; breccia in lower part of bed contains angular fragments of white quartz, the largest 6 inches in diameter; forms a cliff	30
Vesicular basalt at top of Mescal dolomite.	
	362½

Although much of the Troy quartzite is light gray or white on fresh fracture the weathered exposures are generally buff, brown, rusty, or maroon. In the canyon northwest of Tam o' Shanter Peak, where the quartzite is finely exposed, the general tint is reddish brown, but the different parts of the formation vary in color from white or pale buff to dull dark red.

Determination of the exact thickness of the Troy quartzite is difficult, owing to the fact that few of the many fault blocks show a full

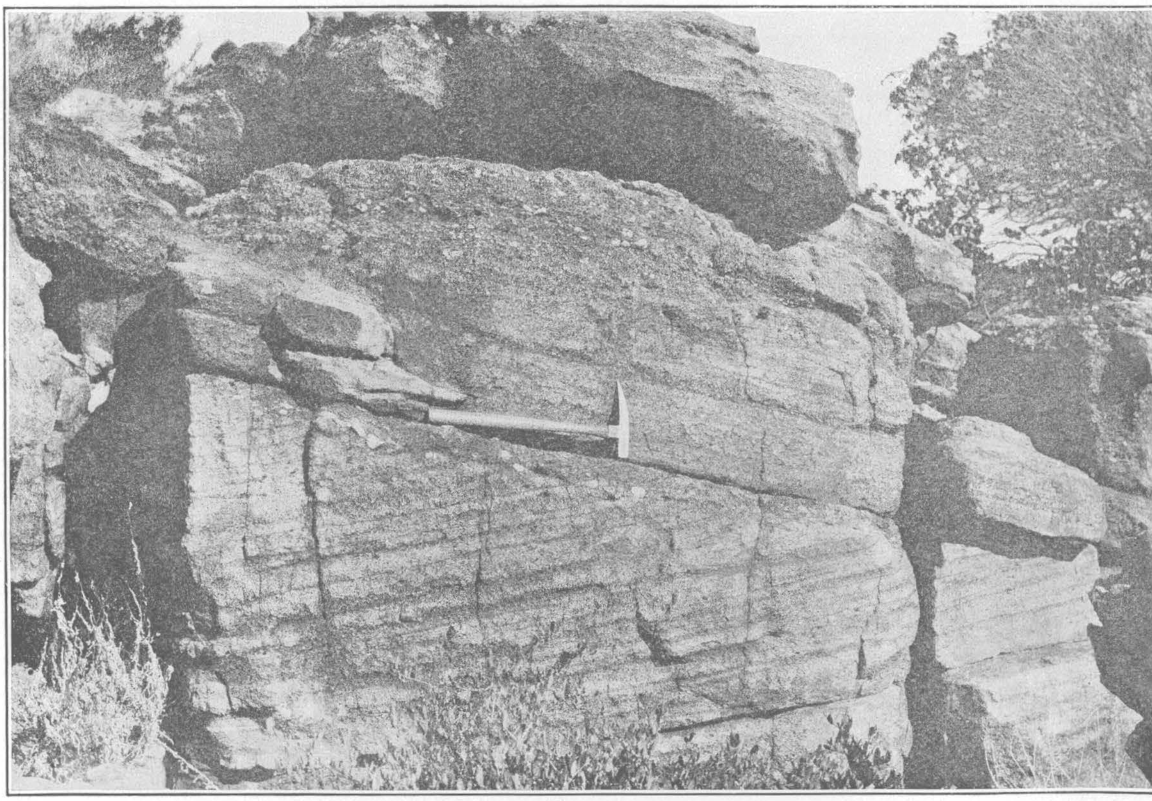


A. EFFECT OF WEATHERING ON CERTAIN BEDS ON EL CAPITAN CREEK, MESCAL RANGE.

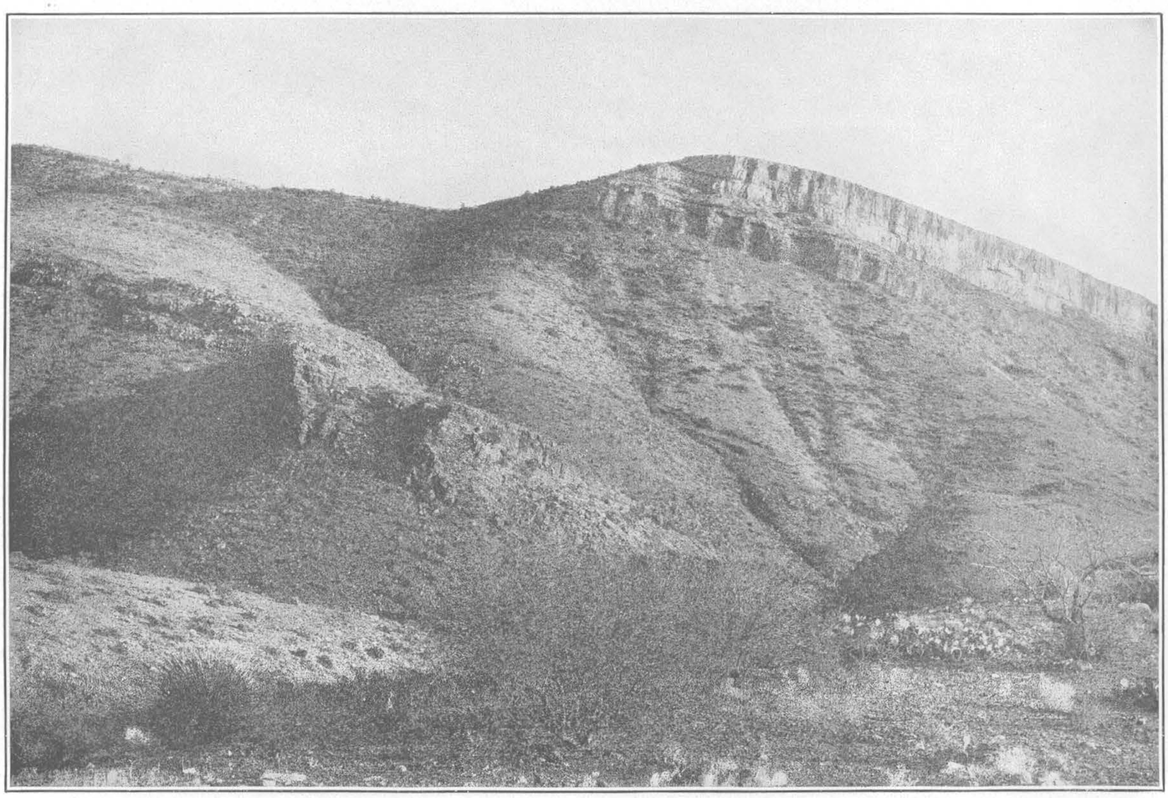


B. FRACTURE SURFACE OF HAND SPECIMEN OF THE SAME ROCK.

CAMBRIAN BEDS, BANDED MESCAL LIMESTONE.



A. CROSS-BEDDED PEBBLY TROY QUARTZITE, DRIPPING SPRING RANGE.



B. A TYPICAL HILLSIDE EXPOSURE OF THE DEVONIAN ON EL CAPITAN CREEK, MESCAL RANGE.

The Devonian limestone forms the smooth slope between the bluff of Troy quartzite in the middle ground and the cliffs of Tornado limestone above.

PALEOZOIC BEDS.

section of the formation or give opportunity for detailed measurements. The section recorded on page 44 gives a total thickness of about 362½ feet but probably does not include quite all the upper beds. In the gorge west of Hackberry Spring a measurement across the edges of the nearly vertical beds gave 300 feet, but here also there are beds missing from the top of the formation. A little less than 2 miles northwest of Tam o' Shanter Peak the formation, here nearly horizontal, is exposed in full section between the Mescal dolomite and the Devonian limestone. The mapping indicates a thickness at this place of a little more than 350 feet. On Troy and Scott mountains the quartzite as mapped appears to be unduly thick, the distribution on Scott Mountain calling for a thickness of about 1,000 feet. This is clearly in excess of any possible real increase in the formation and probably is to be accounted for by faulting or flexing that is not distinctly shown at the surface. From all available information the average thickness of the formation is estimated to be about 400 feet. In the Ray and Globe quadrangles the name quartzite is generally applicable to this formation, but farther north, near Roosevelt and in the Sierra Ancha, the rock is essentially a sandstone.

A rather striking effect of weathering in the Troy quartzite is shown in Plate XIV, *A*. The coloring matter of the concentric rings is iron oxide, and the pattern was apparently produced by rhythmic alternations of solution and precipitation of the iron along joints in the quartzite.

MARTIN LIMESTONE.

The Martin limestone occupies conformably the stratigraphic interval between the underlying quartzite and the overlying Tornado limestone, and with the possible exception of some of its unfossiliferous lower beds is of Devonian age. The name was originally applied to the Devonian limestone of the Bisbee district,[1] with which the formation here described is correlated. The beds now separated as the Martin limestone were in the Globe report and folio mapped with the overlying Carboniferous under the name "Globe limestone."

As a whole the Martin limestone is comparatively thin-bedded and weathers into slopes, broken here and there by a low scarp that marks the outcrop of some bed a little harder or thicker than the rest.

Typical natural sections of the formation are reproduced in Plates VIII, *A*, and XII, *B*. Distant views of such slopes show that the formation is divisible on the basis of color into two nearly equal parts. The prevailing hue of the lower division is light yellowish gray; the upper division, which is less uniform in tint, displays alternations of deeper yellow and darker gray. Detailed examination proves the lower division to consist mainly of very compact, hard gray limestone in beds rarely more than 2 feet thick and, at the base, a bed of impure yellow limestone containing abundant grains of quartz. This lowest bed, which in places is cross-bedded and contains so much detrital material that it might be classed as a calcareous grit, weathers to a rough sandy surface, but the overlying gray beds are characterized by solution surfaces that although uneven in general are smooth in detail. A characteristic feature of these compact lower limestones is the presence of little spherical, oval, or irregular concretions of dark chert, which as a rule are about the size of peas. No identifiable fossils have been found in this lower division of the Martin limestone, although it contains traces of organic life.

About midway in the section is a bed about 15 feet thick of rusty-yellow impure sandy limestone with flaggy lamination. Above this are dark-gray and yellowish limestones in beds of different thicknesses, with shaly partings. These strata are generally fossiliferous, some of the shaly partings particularly being crowded with *Atrypa reticularis* and other small Devonian brachiopods. Some very dark beds in this upper division of the formation are marked with an obscure mottling, suggestive of the former presence of some of the corals, which are abundant in certain beds of the Martin limestone at Bisbee, but which in the Ray-Globe region have been less perfectly preserved. The top bed of the Devonian is a yellow calcareous shale that breaks up on exposure into minute thin flakes and consequently has no prominent outcrops. The yellow color is characteristic of all natural exposures, although before weathering the shale is gray. Being overlain by the massive cliff-making Carboniferous limestone, the bed

[1] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 33, 1904.

of shale is in many places concealed by talus, and its thickness was not exactly determined. It may be from 15 to 20 feet thick, but its base is not very clearly defined, for layers of similar shale occur between some of the limestone beds in the upper part of the formation.

The Devonian limestone is generally magnesian and does not effervesce freely in cold dilute acid. A partial chemical analysis of a typical specimen from the lower division of the formation is as follows:

Partial chemical analysis of Martin limestone.

[R. C. Wells, analyst.]

SiO_2	3.11
Al_2O_3	.33
Fe_2O_3, FeO	1.22
CaO	31.65
MgO	18.65

Measurements and estimates of the thickness of the Martin limestone in different parts of the region range from 300 to 350 feet. The average thickness is considered to be 325 feet.

In contrast with the older formations, which have yielded no determinable organic remains, the Martin limestone contains fossils at many horizons in the upper division, from the top of the rusty bed at its base to the lower layers of the yellow shale. In all 18 lots of fossils were collected and were referred to E. M. Kindle, then of the United States Geological Survey, who lists the following species:

Zaphrentis sp. undet.
Productella hallana.
Stropheodonta arcuata.
Stropheodonta demissa.
Stropheodonta varistriata.
Stropheodonta sp.
Leptostrophia cf. L. interstrialis.
Strophonella cf. S. ampla.
Schuchertella chemungensis.
Schizophoria striatula.
Atrypa reticularis.
Atrypa hystrix occidentalis.
Atrypa spinosa.
Camarotoechia sp.
Pugnax pugnus.
Spirifer orestes.
Spirifer hungerfordi.
Cyrtia cyrtiniformis.
Schizodus sp.
Paracyclas cf. P. elliptica.
Euomphalus cyclostomus?
Euomphalus sp.
Bellerophon sp. undet.

Dr. Kindle remarks with reference to this fauna:

On the ground of its close relationship to an Upper Devonian fauna of Iowa and its stratigraphic relations to the Carboniferous fauna of the Arizona section, I would place the fauna of the Martin limestone and its equivalent, the Devonian fauna of the Ray quadrangle, in the Upper Devonian. It is of course possible that the time range of this fauna in Arizona may include Middle as well as Upper Devonian, but that it includes the Upper Devonian in any event seems well established by the available evidence.

As the Devonian portion of the "Globe limestone" in the Globe quadrangle is continuous and identical with what is now distinguished as the Martin limestone, fossils collected from it should be included in the Martin fauna. For convenience, therefore, the list of determinations made by H. S. Williams [1] on the older collections, with slight changes by Dr. Kindle to bring it into accord with present nomenclature, is given below:

Cf. sponge.
Cf. Rhodocrinus, crinoid stems and plates.
Atrypa reticularis Linné.
Productella hallana Walcott.
Stropheodonta calvini Miller.
Cyrtia cyrtiniformis (Hall and Whitfield).
Spirifer hungerfordi Hall.
Spirifer orestes Hall and Whitfield.
Spirifer whitneyi Hall.
Reticularia fimbriata (Conrad).
Cyrtina hamiltonensis Hall.
Martinia subumbona (Hall); cf. Spirifer infima Whidborne.
Pugnax pugnus (Martin).
Schuchertella chemungensis (Conrad) var.
Dielasma cf. D. calvini (Hall and Whitfield).

Devonian rocks, presumably the Martin limestone, have been found by C. F. Tolman, jr.,[2] in the Santa Catalina Range. The presence of the Martin limestone in the Roosevelt section also has been fully established by the finding, in 1914, of sufficient fossils to confirm a lithologic and indecisive paleontologic identification made a year earlier. A list of the fossils from Roosevelt, as determined by Edwin Kirk, is as follows:

Spirifer whitneyi var. animasensis (Girty).
Camarotoechia contracta Hall?
Camarotoechia sp.
Schuchertella sp.
Modiomorpha sp.
Atrypa spinosa Hall.
Schizophoria striatula var. australis Kindle.
Cladopora sp.

Mr. Kirk remarks that this fauna can be correlated with that of the Martin limestone of

[1] Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, pp. 40–42, 1903.
[2] Unpublished manuscript of Tucson folio.

Bisbee and that of the lower or Devonian part of the Ouray limestone of Colorado. He states that there can be no doubt as to the Devonian age of the material.

TORNADO LIMESTONE.

The Tornado limestone, named from Tornado Peak, in the southeastern part of the Ray quadrangle, where it is extensively exposed, overlies with apparent conformity the Martin limestone and is equivalent to the Carboniferous portion of the "Globe limestone" as originally mapped in the Globe quadrangle. Its local upper limit is a surface of erosion upon which in general rests the Quaternary Gila conglomerate, although in the southeastern part of the Ray quadrangle there is an intervening andesitic formation, probably of Mesozoic age.

The Tornado limestone is generally light lead-gray in color and is divisible with respect to thickness and character of bedding into at least three members.

The basal division, directly overlying the Devonian, is about 75 feet thick and forms the lower part of the scarp that is so prevalent a feature of the Carboniferous outcrops in central and southern Arizona. Under the action of erosion this division behaves as a single massive bed, but in reality it is made up of alternating dark and light gray layers, a foot or two thick, which in cliff faces give it a banded appearance, as may be seen in Plate XII, *B*. This banded division, with a few transitional beds at its top, is succeeded by a very massive member, fully 100 feet thick, within which, as exposed in cliff faces, there is as a rule little more than a suggestion of divisional bedding planes. This massive member, as may be seen from Plate XII, *B*, is of lighter and more uniform tint than the basal member. The two together constitute the principal cliff-forming part of the Carboniferous limestone. The third division consists of beds generally thinner than those in the other two divisions but not separable from them by any marked lithologic distinction.

Thin layers of calcareous shale separate some of the beds, but these are a very subordinate part of the formation.

The Tornado limestone consists essentially of calcium carbonate and effervesces freely in dilute acid. A partial analysis of a typical sample is as follows:

Partial chemical analysis of Tornado limestone.

[W. T. Schaller, analyst.]

SiO_2	1.36
Al_2O_3	.22
CaO	54.91
MgO	.21

Although nearly all the Carboniferous limestone contains fossil remains, there are few localities where full and satisfactory collections can be made. The beds of the two lower divisions carry abundant fragments of crinoid stems and less numerous rugose corals, with long-winged spirifers and *Rhipidomella*. These appear in silicified form on weathered surfaces of the rock, but they can not readily be separated from their matrix. In the upper division appear different species of *Productus* and *Spirifer*, *Derbya crassa*, *Composita subtilita*, and *Fusulina*.

Of seven collections made at as many different localities in the Ray quadrangle, four, according to George H. Girty, of the Geological Survey, consist of Mississippian forms and three of Pennsylvanian forms. His determinations of these fossils are as follows:

Mississippian fauna.

Syringopora aculeata Girty?
Menophyllum sp.
Amplexus? sp.
Rhipidomella aff. R. oweni Hall and Clarke.
Rhipidomella dubia Hall?
Leptaena analoga Phillips.
Schuchertella inflata White and Whitfield?
Chonetes sp.
Avonia arcuata Hall?
Camarotoechia metallica White.
Dielasma burlingtonense White.
Spirifer centronatus Winchell.
Brachythyris peculiaris Shumard.
Spiriferina solidirostris White.
Syringothyris sp.
Composita humilis Girty?
Cliothyridina sp.

Pennsylvanian fauna.

Fusulina sp.
Derbya crassa Meek and Hayden.
Productus semireticulatus Martin.
Productus cora D'Orbigny.
Pustula semipunctata Stevens.
Spirifer cameratus Morton.
Spirifer boonensis Swallow?
Composita subtilita Hall.
Myalina subquadrata Shumard.

According to Mr. Girty the older of these two faunas is early Mississippian, and the other is early Pennsylvanian. He notes that the conditions exhibited in the Ray quadrangle are apparently similar to those at Bisbee, where a limestone of probable early Pennsylvanian age (the Naco) rests directly on a limestone of early Mississippian age (the Escabrosa). The Mississippian in the Ray quadrangle therefore corresponds to the Escabrosa limestone at Bisbee, and the Pennsylvanian limestone near Ray to the lower part of the Naco limestone.

In the Bisbee quadrangle the distinction between the Mississippian and Pennsylvanian limestones proved practicable, although the plane of demarcation is not definite. In the Ray quadrangle a similar distinction might possibly be made, but no satisfactory basis for it appeared in the course of the field work, and it is doubtful whether its accomplishment would be worth the additional labor involved The cliff-making lower members of the Tornado limestone are certainly Mississippian, and probably a considerable part of the upper member also belongs to that epoch.

The original thickness of the Tornado limestone is unknown, for the formation was extensively eroded before the eruption of the andesitic lavas and before the deposition of the Gila conglomerate. In the vicinity of Tornado Peak and along the east flank of the Tortilla Range the limestone at present must be fully 1,000 feet thick, and it may at one time greatly have exceeded this thickness.

CONDITIONS OF DEPOSITION.

The Tornado limestone and the Martin limestone, as shown by their fossils, are unquestionably marine. Ten or fifteen years ago most geologists would probably have had no hesitation in classing the sediments of the Apache group also as marine deposits, although no marine fossils have been found in them. They were so considered in the Globe professional paper, written in 1902, and in the Globe folio, prepared about the same time. Modern studies, however, particularly those of Barrell,[1] have shown the necessity of taking into account continental and, especially, fluviatile deposition.

That the beds of the Apache group were laid down in water there can be no question. They have none of the characteristics of eolian deposits. The evidence as to marine or fluviatile deposition, however, is less conclusive.

The Scanlan conglomerate, with its pebbles of local origin, appears to be most reasonably accounted for as a basal marine conglomerate, although this interpretation has little definite evidence in its favor. The succeeding Pioneer shale gives no clear indication whether it is of marine, lacustrine, or fluviatile origin. It contains no fossil remains or mud cracks, so far as known. The most puzzling feature of the succeeding Barnes conglomerate is its relation to the Pioneer shale. A coarse conglomerate with well-rounded pebbles, indicative of vigorous abrasion and powerful currents, rests on material that when the pebbles accumulated was presumably a sandy mud. The pebbles evidently could not have been shaped near their present resting place but must have come from a distance. The surface of contact between conglomerate and shale, in the very few places where it is well exposed, is undulatory, but the shale layers, instead of being cut by the uneven surface, conform to it, as if the conglomerate had been deposited gently on a soft, yielding foundation.

A similar relation appears to hold between the conglomerate of the Eastern Rand, South Africa, and the underlying formation. E. T. Mellor [2] says:

> One of the most remarkable features of the principal conglomerate bed of the Eastern Rand is that it was laid down over many hundreds of square miles directly upon a wide sheet of muddy or very fine sandy material, which over the whole of that area formed the uppermost portion of a sequence of similar strata some hundreds of feet in thickness. That this abrupt change in the character of the sedimentation was probably brought about simultaneously over the whole area is to some extent shown by the considerations already alluded to. Among further indications may be mentioned the fact that nowhere do we find evidence of that type of erosion of the underlying muddy deposits which might be looked for with the gradual extension of pebbly deposits over them. On the other hand, we do find evidence of such erosion as might be expected to occur with the rapid sweeping of the peb-

[1] Barrell, Joseph, Relative geological importance of continental, littoral, and marine sedimentation: Jour. Geology, vol. 14, pp. 316–356, 430–457, 524–568, 1906; Criteria for the recognition of ancient delta deposits: Geol. Soc. America Bull., vol. 23, pp. 377–446, 1912.

[2] Conditions of deposition of the Witwatersrand system: Mining Mag., vol. 13, pp. 255–262, 1915 (from advance proofs of an article on "The upper Witwatersrand system" read before the Geological Society of South Africa).

bly deposits over a previously existing expanse of hardened silt. Thus in the Kleinfontein mine I recently found numerous examples of the inclusion of fragments of the footwall in the overlying conglomerate, particularly its lower portion. One of these fragments was a foot in length and about 2 inches in thickness and of irregular tabular form, with angular edges. It appeared to be one of many pieces of partly consolidated sediment which had been torn from the underlying muddy material and immediately included in the pebbly mass which had swept over it.

Other conglomerates in the Witwatersrand series, according to Mellor, show similar relations to underlying shales. The evidence of erosion of the shale found by him in South Africa is lacking, so far as known, in Arizona. Mellor's conclusion, that the Witwatersrand series is a delta deposit, accords with an earlier suggestion by De Launay.[1]

On the whole such meager evidence as is obtainable appears to indicate that the Barnes conglomerate represents stream action rather than shore (littoral) or marine action.

The unfossiliferous Dripping Spring quartzite contains some mud cracks in its thin upper beds, showing that these layers must have been exposed to the air during the period of deposition. The formation is tentatively regarded as of delta origin.

The deposition of the impure dolomitic Mescal limestone marks a change of conditions of sedimentation—apparently a subsidence of the land and an incursion of shallow marine waters. On the other hand, the overlying rusty vesicular basalt appears to have been exposed to the air before it was covered by the sands that are now the Troy quartzite.

The Troy quartzite with its abundant pebbly layers and conspicuous cross-bedding (see Pl. XII, *A*) is suggestive of fluviatile or deltaic deposition. The upper part of this formation shows gradation into the undoubtedly marine deposition of the Devonian Martin limestone, although the grit beds and gritty limestones in the Martin show that that formation was laid down in shallower water than the overlying Tornado limestone.

On the whole the evidence bearing on the mode of deposition of the pre-Devonian beds is to some extent conflicting and is inconclusive. They are fluviatile or shoal-water marine deposits, but it does not appear possible at present to determine definitely to which class they belong, or, if both classes are represented, where the deposits of one class give place to those of the other.

[1] De Launay, L., Les richesses minérales de l'Afrique, p. 72, footnote, Paris, 1903.

CORRELATION.

As has been shown in the preceding pages, there is little difficulty in correlating the Devonian and Carboniferous formations of the Ray-Miami region with those of other parts of Arizona. As regards the unfossiliferous formations embraced within the Apache group and provisionally assigned to the Cambrian, the problem is more perplexing.

Inasmuch as in the Grand Canyon there is a profound unconformity between the Algonkian sediments (Unkar and Chuar groups) and the Cambrian beds of the Tonto group, and as in the Globe region all the beds from Carboniferous down to the Scanlan conglomerate are apparently conformable, the Apache group was in the Globe report and folio treated provisionally as Cambrian. At the same time, it was recognized that the Apache group had lithologically little in common with the Cambrian Tonto group of the Grand Canyon.

In 1905 Willis T. Lee[2] briefly described and figured the section of beds exposed in the gorge of Salt River below the Roosevelt Dam. He quotes a statement from a letter to him from Dr. Charles D. Walcott to the effect that at this locality the Carboniferous limestones rest directly and unconformably upon the quartzites and argillites of the Algonkian. He mentions the fact that the same supposedly Algonkian formations occur in the Sierra Ancha. Two years earlier A. B. Reagan[3] also appears to have included in the Algonkian most of the beds that make up the Sierra Ancha, although he stated that the sandstone of the Tonto group overlies these beds unconformably on the crest of the range.

Later reconnaissance work by me has shown conclusively that the Roosevelt section contains the same formations that have been recognized in the Ray-Miami region. The beds dip upstream and in ascending order are the Scanlan conglomerate, resting on granite, the Pioneer shale, the Barnes conglomerate, the Dripping Spring quartzite, the Mescal limestone (at the dam), and the Troy quartzite,

[2] Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, pp. 96-97, 1905.

[3] Geology of the Fort Apache region, Ariz.: Am. Geologist, vol. 32, p. 277, 1903.

here perhaps more properly referred to as a sandstone. These formations constitute the Apache group. As usual, there is a thick sheet of diabase, which in this locality has invaded the Pioneer shale.

This reconnaissance has shown also that the Devonian (Martin limestone) is not missing at Roosevelt but is well represented by about 300 feet of thin-bedded limestones, which as stated on page 46 contain a characteristic Devonian fauna. As in the Ray-Miami region, the entire Paleozoic sequence from the Scanlan conglomerate to the Carboniferous limestone appears to be conformable. Certainly there is no unconformity present that brings the Carboniferous limestone against the Apache group.

The same reconnaissance showed that, as Reagan and Lee have both stated, the Sierra Ancha, in its southern part, where they saw it, is composed chiefly of these same Apache rocks, with a sheet of diabase, probably at least 1,000 feet thick, intruded in the Mescal limestone. No trace was found, however, of an unconformably overlying "Tonto" (Tapeats) sandstone. As far north as Gun Creek, an east tributary of Tonto Creek, the sedimentary rocks of the Sierra Ancha can readily be interpreted in terms of the Globe-Ray section and are recognizable as belonging to the Apache group.

From the mouth of Gun Creek north to Payson and East Verde River the distance is only about 20 miles, but in this interval a striking change takes place in the character of the older Paleozoic rocks. Where the road from Payson to Pine crosses the East Verde, the following section was somewhat roughly measured on the south bank of the river:

Section on East Verde River.

	Feet.
Top of bluff.	
Rather thin-bedded, in part flaggy light-gray compact limestone with some intercalated thin sandstone beds near top	130
Pinkish and grayish sandy limestone, grading upward into overlying limestone	50
Hard compact gray limestone in beds 2 to 3 feet thick	50
Red shale with 2 to 3 feet of gray laminated quartzite near top	20
Thin-bedded gray limestone with some pink limestone near top and flaggy, somewhat sandy limestone in lower 25 or 30 feet	100
Thin-bedded reddish sandstone with one gray bed near top, overlain by a layer of shale which grades into limestone above	30
Pebbly cross-bedded red-brown sandstone, with some irregular horizontal lamination in cliff exposures but no distinct division into beds	80
	460
Moderately coarse crumbling red granite, probably Archean.	

The foregoing section is entirely different from the Paleozoic section of the Ray-Miami region, and although the section as a whole probably can not yet be fully correlated with the Grand Canyon section, the basal sandstone is without much doubt the Tapeats sandstone of the Tonto group. The southernmost point to which this sandstone has been traced is a ridge just south of Payson, where it rests on a gray dioritic rock belonging to the pre-Cambrian complex. To the north, along the Mogollon escarpment, the beds just described pass under other limestones, probably including the Redwall, and a thick series of red beds that are probably Supai, overlain by the Coconino sandstone.

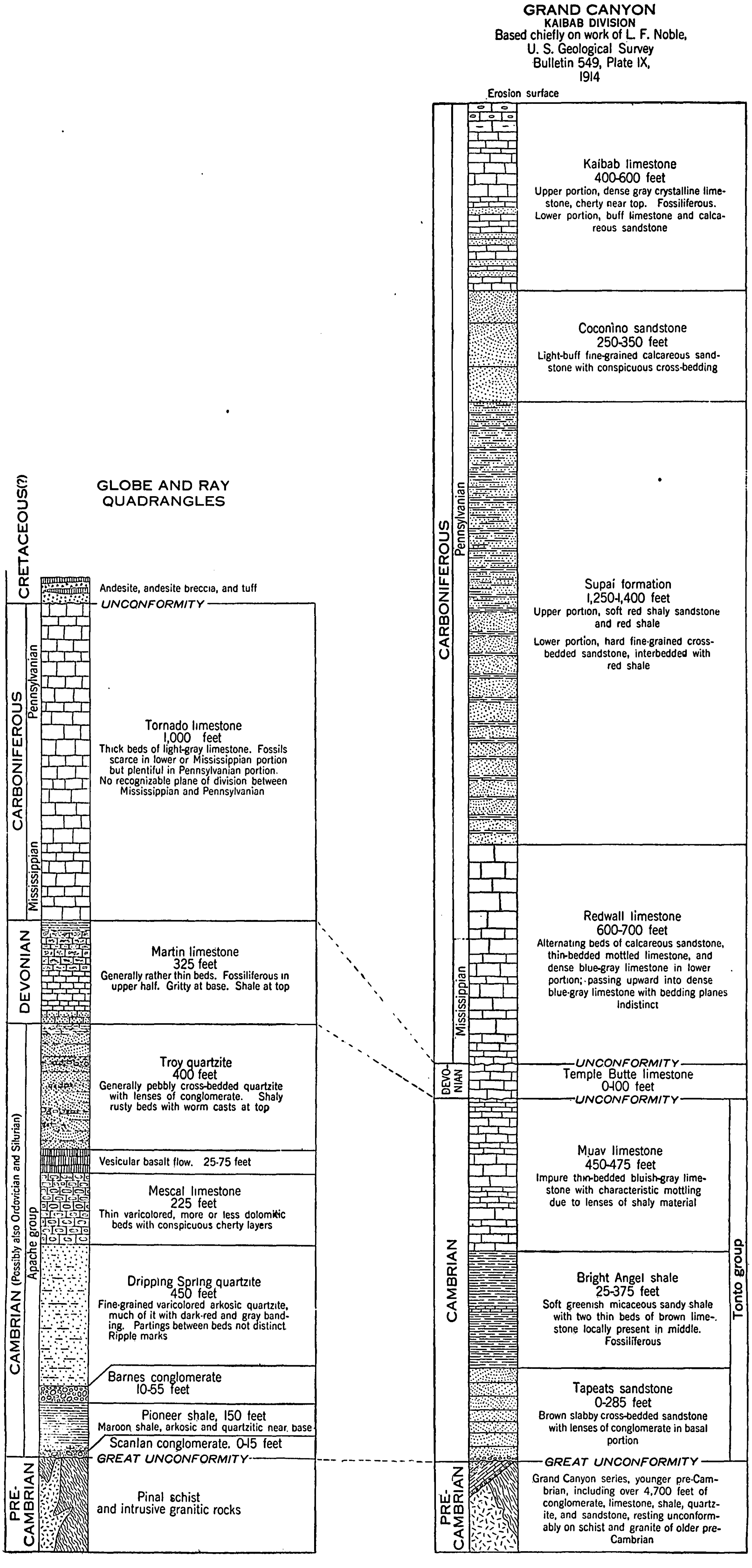
At Jerome, 65 miles northwest of Payson, the same basal sandstone, 75 to 80 feet thick, rests on pre-Cambrian schist. It is overlain by limestones which about 350 feet above the top of the sandstone carry Devonian fossils. A small collection made in 1912 was submitted to E. M. Kindle, then of this Survey, who furnished the following list:

Aulopora sp. undet.
Zaphrentis sp. undet.
Camarotoechia sp. undet.
Spirifer orestes.
Cyrtia cyrtiniformis.
Bellerophon maera.

Dr. Kindle notes: "These species represent an Upper Devonian fauna of the same general facies as that previously collected by you at various points in Arizona." In other words, they represent the fauna of the Martin limestone.

In another publication [1] the correlation of the Paleozoic strata in Arizona has been considered more at length. The facts here presented, however, are probably sufficient to show that below the Devonian beds, which are fossiliferous and are readily identified from Bisbee to the Grand Canyon, there are in central Arizona two markedly dissimilar groups of strata. On the north is the Tonto group,

[1] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 133-166, 1916.



COMPARISON OF GENERALIZED COLUMNAR SECTIONS OF THE ROCKS OF THE GLOBE-RAY REGION AND OF THE GRAND CANYON.

consisting in the Grand Canyon, from the base up, of the Tapeats sandstone, the Bright Angel shale, and the Muav limestone. The Tapeats sandstone can be followed with a few interruptions from the mouth of the Grand Canyon along the base of the cliffs bounding the Arizona Plateau on the southwest to the vicinity of Payson, in Tonto Basin. The Bright Angel shale and Muav limestone apparently do not maintain their characteristic features south of the Grand Canyon and have not been definitely recognized at Jerome or in Tonto Basin.

South of Tonto Basin, from the northern portion of the Sierra Ancha at least as far south as the Santa Catalina Range, there are, in ascending order beneath the Devonian, the Scanlan conglomerate, the Pioneer shale, the Barnes conglomerate, the Dripping Spring quartzite, the Mescal limestone, and the Troy quartzite. For the sake of comparison Plate XIII shows, side by side, generalized typical sections of the Paleozoic rocks of the Grand Canyon and of the Globe-Ray region.

POST-PALEOZOIC ROCKS.

GENERAL CHARACTER AND SEQUENCE.

The post-Paleozoic rocks of the Globe-Ray region comprise both igneous and sedimentary kinds. The igneous rocks occur as intrusive sheets and irregular masses, as lava flows, and as accumulations of volcanic fragments. The sedimentary rocks comprise stony land detritus that has been only slightly moved from its place of origin, and coarse stream deposits that grade away from the mountains into finer material and even into lake sediments; they are essentially fluvio-lacustrine deposits of continental as opposed to marine deposition.

It is a common practice in geologic reports to describe all the sedimentary rocks separately from the igneous rocks. That practice has not been followed in the present work. It is thought that, in this field at least, greater clearness can be attained and descriptive matter can be made more interesting to the reader by following a historical sequence, the rocks, of whatever kind, being described in the order of their appearance on the geologic scene. This plan has already been followed as regards the basalt overlying the Mescal limestone and will receive more conspicuous exemplification in what now follows.

The first recorded addition to the rocks of the Ray-Globe region after the disposition of the Tornado limestone in Carboniferous time appears to have been the quartz monzonite of Lost Gulch, in the Globe quadrangle. This was succeeded by intrusive olivine diabase. Then followed the accumulation, in the southern part of the area, of andesite breccia and lava flows and the irruption of closely related dikes. These igneous rocks are probably all of Mesozoic age. Tertiary time was marked by the intrusion of (1) quartz diorite, in small irregular masses and a few dikes of considerable size; (2) granite, quartz monzonite porphyry, and granodiorite in masses, some of which, as the Schultze granite, are now exposed over areas several miles in diameter; and (3) quartz diorite porphyry, in dikes, sills, and small intrusive masses. After some erosion, the coarse detrital Whitetail formation was accumulated and then followed extensive outpourings of dacite. After much deformation and during consequent vigorous erosion the Gila conglomerate was laid down during early Quaternary time. There was at least one minor eruption of basalt during the accumulation of the conglomerate, which was followed by erosion and the deposition of younger sediments of no great areal importance. All these rocks will now be described in chronologic order.

LOST GULCH MONZONITE (QUARTZ MONZONITE).

OCCURRENCE, DISTRIBUTION, AND AGE.

The Lost Gulch monzonite forms a roughly quadrangular area about 4 square miles in extent, which occupies the greater part of the drainage basin of Lost Gulch north of Miami and stretches northeastward toward Pinal Creek. The area of exposure, save where the rock is overlapped on the east by the Gila conglomerate, is bounded chiefly by faults, and the age relations of the mass are not entirely clear. On the basis of observations made in 1902 the monzonite is supposed to be cut by diabase and therefore to be older than that rock. The evidence, however, should be reexamined in the light of later acquired knowledge of the intrusive rocks of Arizona and of the suggestion that it may belong with petrographically related rocks that are probably of Tertiary age. Until this can be done, the Lost Gulch monzonite is provisionally regarded as older than the diabase and of early Mesozoic age. In the Globe folio it was considered as probably of pre-Cambrian age, but its petrographic character renders this earlier assignment doubtful.

PETROGRAPHY.[1]

The quartz monzonite is a fine-granular gray rock containing scattered crystals of potassium feldspar and smaller ones of plagioclase. Toward the eastern part of the area the rock becomes more finely crystalline and the gray medium-granular groundmass is made up of potassium feldspar, plagioclase, quartz, and biotite. Under the microscope quartz is apparently the most abundant constituent, followed by oligoclase-andesine feldspar, microcline, and biotite. A chemical analysis of a fresh specimen from Lost Gulch, about 2 miles northwest of the Inspiration mill, is as follows:

Analysis of quartz monzonite from Lost Gulch.

[W. F. Hillebrand, analyst, 1902.]

SiO_2	68.63
Al_2O_3	13.68
Fe_2O_3	2.53
FeO	1.81
MgO	1.10
CaO	2.51
Na_2O	2.94
K_2O	4.04
H_2O below 110° C	.70
H_2O above 110° C	.87
TiO_2	.69
ZrO_2	.01
CO_2	None.
P_2O_5	.24
Cl	Not determined.
F	Not determined.
S	[2] (.06)
NiO	None.
MnO	.15
BaO	.05
SrO	Trace.
Li_2O	Faint trace.
FeS_2	.11
	100.06

In the norm system of classification and nomenclature the rock is toscanose.

The mineral composition of the Lost Gulch monzonite as calculated from the chemical analysis, checked by microscopical examination, is as follows:

Approximate mineral composition of Lost Gulch monzonite.

Quartz	31.67
Microcline and orthoclase	19.79
Andesine (Ab_4An_3)	35.74
Biotite	8.33
Magnetite	2.69
Titanite	1.23
Apatite	.44
Pyrite	.11
	100.00

It will be observed that although the rock is chemically a quartz monzonite, the grouping of the molecules is such as to give a high proportion of plagioclase for rocks of this class. It lies almost on the line between granodiorite and quartz monzonite according to the distinction made by Lindgren.[3]

WILLOW SPRING GRANITE.

OCCURRENCE AND DISTRIBUTION.

The Willow Spring granite forms a small isolated mass lying just north of Webster Gulch and occupying an area of less than a square mile. It is intrusive into the Pinal schist, and, like the Lost Gulch monzonite, is bounded in part by faults.

PETROGRAPHY.

The Willow Spring granite is gray and is as a rule fine grained for a rock of granitic composition, the average size of the grains being less than a millimeter. A few phenocrysts of orthoclase or microcline, as much as 2 inches long, are scattered through this groundmass, which is in places nearly aphanitic.

The microscope reveals a hypidiomorphic granular aggregate consisting of abundant quartz and microcline, with oligoclase, muscovite, and biotite. The exact nature of the oligoclase is not readily determinable, owing to the general decomposition of this constituent into nearly cryptocrystalline aggregates that apparently consist principally of kaolin. The accessory minerals are apatite, iron ore, and tourmaline, none of them abundant. The secondary minerals are kaolinite, epidote, and chlorite.

AGE AND AFFILIATIONS.

The age of the Willow Spring granite is even more uncertain than that of the Lost Gulch

[1] Condensed from U. S. Geol. Survey Prof. Paper 12, pp. 76-78, 1903.
[2] Included with pyrite.
[3] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, pp. 277-281, 1900.

monzonite. All that can be said is that considerable doubt now attaches to its original assignment to the pre-Cambrian. No thorough field examination has been made of it since the work was done for the Globe folio. It is described in this place because it may have been irrupted at about the same time as the Lost Gulch monzonite.

DIABASE.

OCCURRENCE AND DISTRIBUTION.

The diabase of the Ray quadrangle is identical in age, geologic relations, and general character with the rock in the Globe quadrangle described some years ago under that name, and many of the descriptive petrographic details here presented have been taken with slight modification from the Globe folio.

The diabase is intrusive, and although it is highly probable, in view of the great disturbance which accompanied the intrusion, that at the time of irruption some of the magma reached the surface, there are now in the region no effusive or pyroclastic rocks referable to this period of igneous activity. The magma forced its way between the sedimentary strata as sills, but these are not persistent sheets of uniform thickness; the magma broke across the bedding at so many places and followed so many different planes of stratification that the resulting structure, in spite of the fact that the blocks of strata retain a common strike and dip, is highly irregular, and great masses of the sediments are now surrounded by and immeshed in the intrusive rock. The intruded sheets range from a few inches to many hundreds of feet in thickness, and the sizes of the included blocks of strata are equally diverse. The main zone of intrusion in the Globe-Ray region was along the Mescal limestone, but the diabase is not confined to that horizon.

The relations of the diabase to the sedimentary rocks are remarkably well displayed in the northeastern part of the Ray quadrangle, in the Mescal Range, where blocks of quartzite and more or less altered limestone, all dipping about 20° SW., are dispersed through the diabase, which in this part of the area has invaded all the rocks older than the Devonian. (See Pls. II, III, *A*, and IX, *B*.) One sill, roughly parallel with the bedding of the sediments, traverses the Madera diorite north of Pioneer Mountain and Old Baldy.

Into the beds now forming the Dripping Spring Range the diabase was intruded in the same manner as in the Mescal Mountains, but faulting has here introduced much greater structural complexity. In the Dripping Spring Range also the principal zone of intrusion was the Mescal limestone, but in a few places, as at Steamboat Mountain, small bodies or dikes of the diabase cut the Martin and Tornado limestones.

In the Tortilla Mountains the diabase cuts all rocks up to and including the Tornado limestone. Some of the intrusions in the granite are curiously irregular, as may be seen in the vicinity of Kelvin. (See Pl. II.) Although in some parts of the area diabase to the thickness of several hundred feet has been injected at the horizon of the Mescal limestone, the same limestone where upturned in the gorge west of Hackberry Spring has been only slightly invaded by the igneous rock in the form of thin sills and small dikes. One of these sheets, now nearly vertical, is shown in Plate X, *B*. As may be seen from the illustration, the sheet does not extend quite to the bottom of the gorge but connects with a narrow crosscutting dike.

In many places the diabase of the intruded sheets is divided by close joints parallel with the stratification of the sediments above and below. The effect is that the diabase, when viewed at a distance, resembles a bedded rock, as may be seen in the gorge of Pioneer Creek.

Diabase of the same kind as that in the Globe-Ray region and undoubtedly belonging to the same period of intrusion is abundant to the north, in the vicinity of Roosevelt and in the Sierra Ancha. Near Roosevelt the diabase forms a thick sill in the Pioneer shale. In the Sierra Ancha a sheet fully 1,000 feet thick has invaded the Mescal limestone. Diabase also correlated with that of the Globe-Ray region occurs in the Santa Catalina Range, northeast of Tucson.

PETROGRAPHY.

When fresh, the diabase typical of all the larger areas in the region is a tough, heavy dark-gray holocrystalline rock of medium grain as a whole but grading here and there into fine-grained (aphanitic) varieties or into coarser, exceedingly tough facies with large tabular plagioclase crystals and abundant magnetite. Some of the finer-grained varieties are younger than the mass of the diabase, which they cut as dikes. The minerals readily visible to the unaided eye are plagioclase, augite, and magnetite. The augite is particularly noticeable on many natural surfaces of the rock, as it forms brilliantly flashing spots, some of which are 2 centimeters in breadth. Close examination of these reflecting cleavage surfaces show that the augite is crowded with inclusions of the other minerals composing the diabase, giving what the petrographer calls poikilitic texture. The weathered rock is greenish, and the diabase masses can ordinarily be distinguished from a distance by the very characteristic dark olive hue of their bare slopes. Hard residual boulders or pebbles of various sizes, with curiously nodular surfaces, are extremely characteristic of the disintegration of the typical diabase. The rock crumbles to a greenish sandy soil (saprolite). Embedded within this material are residual kernels of sound rock, ranging in diameter from that of a pea up to a foot or more. The larger masses have the characteristic lumpy or warty surfaces, and with the further progress of disintegration these lumps separate as small nodules. Close examination of these little bodies shows that their form and resistance to disintegration are dependent on the presence of rounded poikilitic crystals of augite. The various steps in this process of disintegration are clearly displayed along the Globe-Kelvin stage road where it crosses the main diabase belt south of Pioneer station (see Pl. XIV), and an excellent opportunity for study of the rock in fresher condition is afforded by the narrow gorge of Pioneer Creek, south of the road, and by the road from Troy down to the mouth of the Pratt tunnel, southwest of Troy. In addition to the excrescences with which exposed surfaces of the diabase are usually studded there are in some localities well-marked projecting ribs or ridges an inch or two in height. These are due to the development of secondary hornblende along minute fissures in the rock and the resistance of this mineral to weathering.

Thin sections of the typical diabase examined under the microscope show a fresh ophitic aggregate of calcic labradorite or bytownite, faintly brownish augite, olivine, and a little biotite, magnetite, apatite, and titanite. In many places the diabase is so fresh that the olivine, which occurs in the usual rounded forms more or less inclosed in the augite, shows scarcely a trace of serpentinization. The augite is broadly poikilitic, the apparently isolated angular areas between the subhedral crystals of plagioclase showing optical continuity over large areas of the microscopic slides. The angle $c \wedge c$ is approximately 45°.

A chemical analysis of a fresh typical specimen from a hilltop 1 mile northwest of Black Peak, in the Globe quadrangle, is given below:

Chemical analysis of diabase.[1]

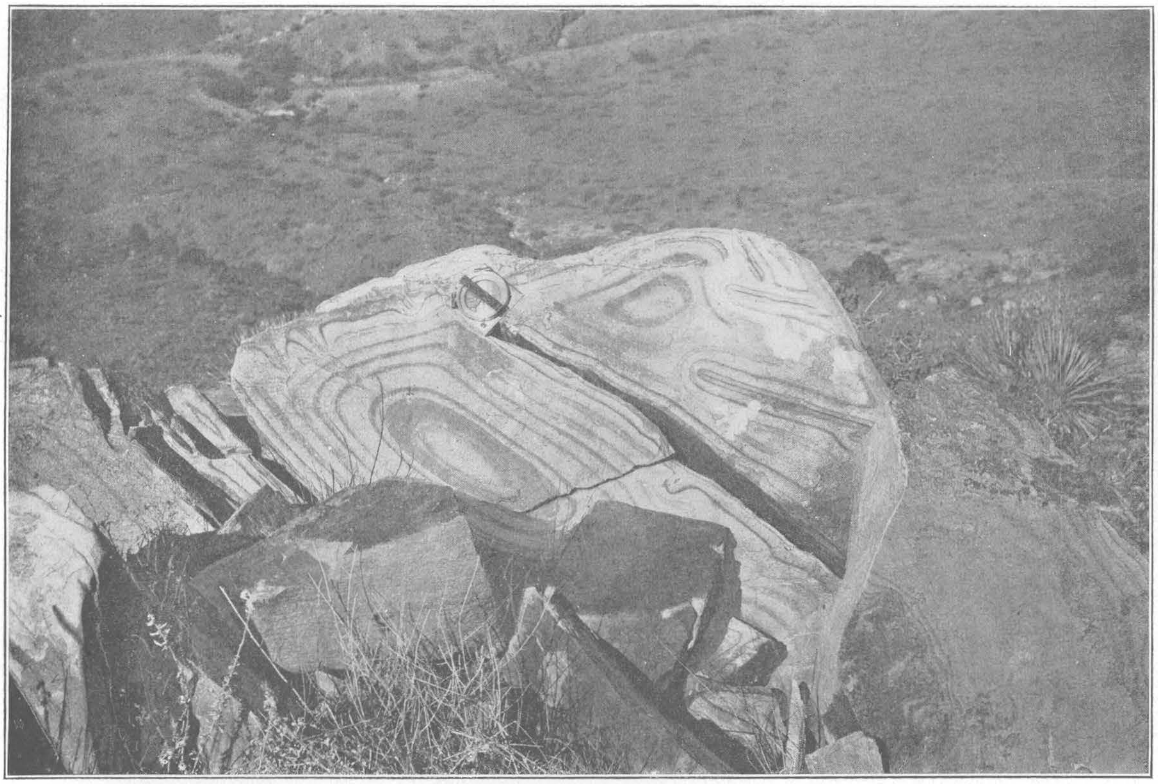
[E. T. Allen, analyst.]

SiO_2	49.00
Al_2O_3	16.87
Fe_2O_3	2.09
FeO	8.50
MgO	6.70
CaO	10.21
Na_2O	2.57
K_2O	.66
H_2O below 110° C	.72
H_2O abeve 110° C	1.00
TiO_2	1.11
ZrO_2	.02
CO_2	None.
P_2O_5	.13
SO_3	None.
Cl	.05
F	Undetermined.
S	None.
Cr_2O_3	.02
NiO	None.
MnO	.10
BaO	Trace.
Li_2O	Undetermined.
SrO	None.
V_2O_3	Trace.
	99.75

Without knowledge of the exact composition of the augite, it is impossible to make from the chemical analyses an accurate calculation of the quantitative mineral composition of the rock. Rough calculation, however, checked by optical estimation in thin sections, indicates about 55 per cent of bytownite, 30 per cent of augite, 10 per cent of olivine, and 5 per cent of biotite, magnetite, titanite, and apatite. The rock may be considered a typical olivine diabase and in the norm quantitative system of classification is auvergnose.

In the Globe report[2] attention was called to the occurrence here and there within the diabase of the larger areas of rather coarsely crystalline

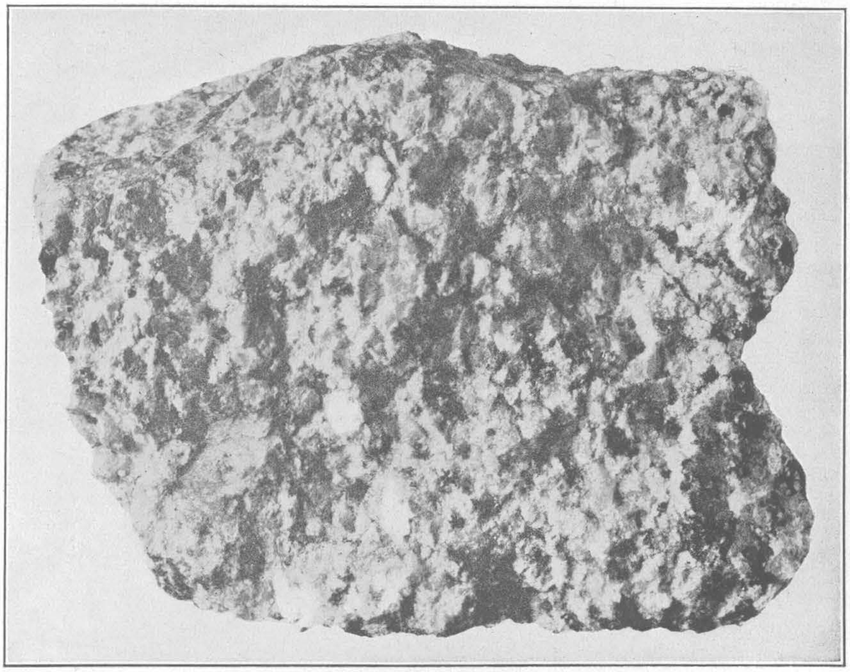
[1] U. S. Geol. Survey Prof. Paper 12, p. 84, 1903.
[2] Idem, p. 85.



A. DIFFUSION RINGS AS A RESULT OF WEATHERING IN TROY QUARTZITE, TOP OF HILL 2 MILES SOUTH-SOUTHWEST OF OLD BALDY, ON THE WEST SIDE OF EL CAPITAN CREEK.

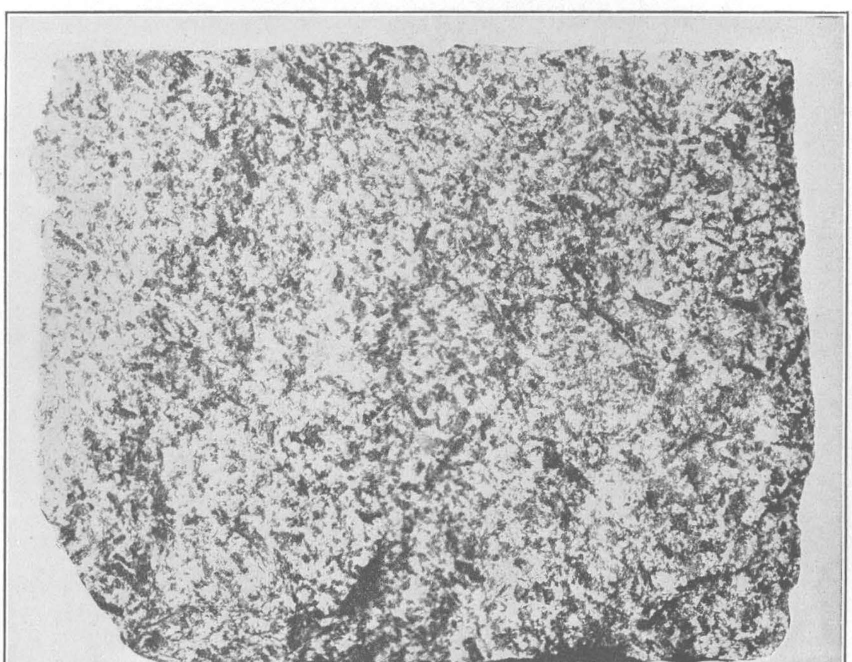
B. CHARACTERISTIC WEATHERING OF DIABASE ON STAGE ROAD JUST SOUTH OF PIONEER.

WEATHERING PHENOMENA.



A. PRE-CAMBRIAN GRANITE OF THE TORTILLA RANGE, SOUTH OF KELVIN.

Natural size.



B. QUARTZ DIORITE 1 MILE NORTH OF TROY MOUNTAIN.

Natural size.

IGNEOUS ROCKS.

reddish rock having the general composition of a hornblende syenite. At a few places in the Ray quadrangle the diabase shows similar differentiation facies. Thus in the crest of a ridge 1.6 miles northwest of the summit of Scott Mountain the diabase grades into an exceedingly tough fine-grained rock of which the obvious minerals are dull-green hornblende and pink feldspar. The microscope shows that the essential constituents are hornblende, quartz, and orthoclase, micropegmatitically intergrown, and decomposed plagioclase. A part of the hornblende appears to have been derived from pyroxene by uralitization, but none of the original mineral remains. This rock, which is apparently nothing more than a local facies of the normal diabase, may be called a "basic" or more accurately a mafic quartz monzonite.

Although there is generally no difficulty in procuring specimens of fresh diabase from most of the larger areas, greenish uralitic varieties are common, even where ravines have cut deeply into the diabase and the rock exposed is firm and hard. Such facies illustrate all stages of alteration from those in which the augite is only partly altered to those in which the augite is completely changed to aggregates of green hornblende.

The diabase occurring as dikes in the pre-Cambrian complex or in the Martin and Tornado limestones is as a rule more finely crystalline than that of the larger sills and in places is nearly aphanitic.

CONTACT METAMORPHISM.

In general the contact metamorphism effected by the diabase is inconspicuous. In the vicinity of the large intrusions the quartzites, especially the Dripping Spring quartzite, are exceptionally hard and well indurated, and near the contact the Pioneer shale is in places baked and hardened. The Mescal limestone, which is in contact with the diabase at so many places, shows, as might be expected, more noticeable metamorphism than the shale and quartzite. Three-fourths of a mile southwest of Walnut Spring, in the northern part of the Ray quadrangle, the Mescal limestone near the diabase contains abundant tremolite. In the bed of Pioneer Creek, 1½ miles south of bench mark 4504 on the stage road near Pioneer, in the northeastern part of the Ray quadrangle, the limestone near the diabase contains nodular segregations of silicate minerals. These include a member of the olivine group having an index of refraction higher than that of pure forsterite, tremolite, and diopside, associated with calcite and abundant serpentine, the latter derived for the most part from the olivine.

In connection with the discussion of the contact metamorphism effected by the diabase attention may be called to a small body of peculiar granitic rock that is exposed on the stage road nine-tenths of a mile south of bench mark 4504, near Pioneer, in the northeastern part of the Ray quadrangle. The mass is about 200 yards long and is surrounded by diabase. The rock composing it is strikingly variable in color and texture. Some parts are fine granular, show conspicuous although rather vaguely defined pink and greenish-gray mottling, and suggest in appearance and texture a metamorphosed quartzite. Other parts are greenish gray and evidently contain considerable chlorite. Such material is suggestive of an altered quartz diorite. Still other varieties are more granitic in appearance. One of these, a fine-grained pink rock, evidently contains abundant pink orthoclase with specks of green-brown chlorite. This rock is miarolitic, and the cavities contain partly free crystals of quartz and orthoclase. Another variety resembling this, but finer grained, is traversed by cracks whose walls are lined with small crystals of orthoclase and quartz.

The microscope confirms the impression gained in the field that the varieties are all parts of one rock mass. The feldspar is in part microcline and in part orthoclase. It poikilitically incloses the other constituents or, less commonly, is in micropegmatitic intergrowth with quartz. The characteristic occurrence of the quartz is as rounded but minutely irregular grains, about 0.6 millimeter in greatest diameter, embedded in the feldspar. As seen in thin section the boundaries of these grains are irregularly scalloped, much as would be those of a section through a blackberry. The dark constituent in most of the specimens is chlorite, but in one thin section was noted a little pale biotite, and from this mineral the chlorite was evidently derived. All thin sections show rather abundant titanite and a little zircon.

The origin of this mass of rock is not clear. The material has little in common with the other granitic rocks of the region and has an unusual texture for a normal igneous rock. If the mass is regarded as a product of local differentiation of the diabase magma, it is difficult to understand why differentiation should have taken place at this particular spot in the molten material, unsubjected apparently to any conditions favoring a departure from homogeneity. The mass may represent an included block, or xenolith, of arkosic quartzite that has been metamorphosed by reaction with the diabasic magma, although there is admittedly no conclusive evidence for this suggestion.

AGE.

Intrusive relations show very clearly that the diabase is younger than the Troy quartzite. The Mescal and Tornado limestones have been cut only here and there by small bodies of diabase, but these are supposed to represent parts of the same magma that solidified in the larger masses. The diabase is thus younger than the Pennsylvanian epoch of the Carboniferous. The relation of the diabase to the andesite in the vicinity of Tornado Peak is not definitely determinable within the area studied but the diabase is thought to be probably the older rock. Campbell's reconnaissance of the Deer Creek coal field[1] showed that the andesite is probably Cretaceous, which would make the diabase assignable to the early Mesozoic or late Paleozoic.

CRETACEOUS SEDIMENTARY ROCKS.

The Tornado limestone constitutes the latest record of marine sedimentation preserved in the Globe-Ray region. The Deer Creek coal field,[2] which lies about 12 miles east of the Ray quadrangle, contains several hundred feet of coal-bearing sandstone and shale from which were collected plant remains whose forms, according to F. H. Knowlton, are suggestive of Upper Cretaceous age, and at a lower horizon in the same beds were obtained imperfect specimens of *Ostrea* and *Exogyra*, which, according to T. W. Stanton, are also indicative of Cretaceous time. Campbell described the major portion of the sediments as overlain by a thick mass of andesitic volcanic rocks within which are intercalated some sedimentary layers. According to him, the main body of coal-bearing sediments under the andesite thins rapidly to the west. These beds are not represented in the Ray-Globe region, although the andesitic formation, presumably also of Cretaceous age, extends into the southeastern part of the Ray quadrangle, east of Tornado Peak, and will be next described.

ANDESITE TUFF AND BRECCIA.

OCCURRENCE AND DISTRIBUTION.

In their reports on the Deer Creek coal field both Walcott[3] and Campbell[4] refer briefly to the occurrence of large masses of andesite overlying the Cretaceous sediments and connected with them by the intercalation of sedimentary layers containing a little coal.

Southeast of Tornado Peak and stretching as a broad belt in that direction across Gila River is an area of somber-colored hills composed of andesitic tuff. This material is undoubtedly the andesite referred to in the Deer Creek reports, although in the Ray quadrangle it rests, not on the Cretaceous but directly on the Pennsylvanian limestone. In part the material may consist of lava flows, and certainly it is traversed by many porphyry dikes of andesitic to dioritic or monzonitic character, but in the main it is an indurated, more or less decomposed tuff or tuff-breccia. It caps the high ridge between Tornado Peak and Christmas and thins out to disappearance toward the north but thickens greatly toward the southeast, where the general dip carries its base down to and under the river. The most northerly occurrence of the andesite tuff within the Ray quadrangle is at the edge of Dripping Spring Valley, 2 miles northeast of the London-Arizona mine, where it has been dropped by faulting against the Tornado limestone. Southeast of the quadrangle, on the other hand, the formation, as may be seen from any high point near Christmas, is the prevailing rock for many square miles.

In some places the ordinary andesitic breccia, as a rule green because of the large amount of epidote near its base, rests directly on the limestone. South of O'Carroll Canyon, however, the limestone is unconformably overlain by a layer of angular cherty fragments,

[1] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, pp. 240-258, 1904.

[2] Campbell, M. R., op. cit.

[3] Walcott, C. D., Description of the [Deer Creek] coal field: 48th Cong., 2d sess., S. Ex. Doc. 20, Appendix I, pp. 5-7, 1885.

[4] Op. cit.

derived from the limestone, embedded in a gray clayey matrix. Above this is a layer, a few feet thick, of clay and fine soft tuff succeeded in turn by the prevailing indurated tuff-breccia. The coarse conglomerate mentioned by Campbell as lying at the base of the andesite was not seen within the Ray quadrangle but was observed at a few places along the Gila between Winkelman and the mouth of Dripping Spring Valley. It consists of large partly rounded fragments of granite, quartzite, and andesite in an andesitic matrix. No close study was made of it, but it probably represents material thrown out by explosive eruptions early in the andesitic epoch. The fact that the andesite rests on Carboniferous limestone in the Ray quadrangle, whereas, according to Campbell, its eruption followed the deposition of the Cretaceous sediments of the Deer Creek field without any marked interval of erosion, indicates that those sediments were deposited in a local basin and that the area of the Ray quadrangle was then land.

The tuff-breccia is cut by many dikes ranging from dark-gray andesitic porphyries with sharp lustrous phenocrysts of hornblende to more coarsely crystalline and lighter-colored quartz diorite or quartz monzonite porphyries.

THICKNESS.

The relations of the andesitic rocks to the underlying limestone and to the surface east of Tornado Peak indicate a thickness of at least 1,000 feet.

PETROGRAPHY.

The general color of the andesite is dark greenish or reddish gray. The texture is minutely porphyritic, small phenocrysts of plagioclase being embedded in a fine-grained or aphanitic groundmass. The clastic character is not everywhere apparent, but on many weathered surfaces the faint outlines of the constituent fragments are visible on close inspection. A large proportion of the rock is so jointed and cracked that specimens of the ordinary shape and size are difficult to obtain, and the material as a whole has undergone considerable decomposition. In some localities, especially north of the latitude of Tornado Peak, the basal portion of the tuff-breccia contains much secondary epidote and in places is altered to a hard, dense yellow-green aggregate which under the microscope shows the outlines of feldspars and ferromagnesian minerals, although these minerals have been completely replaced by epidote with a little quartz and iron oxide.

The freshest obtainable specimens of the andesite tuff-breccia show more or less decomposition, as seen in thin section. The fragments were originally an ordinary feldspathic hyalopilitic pyroxene andesite. The pyroxene, so far as could be determined in partly decomposed material, is all augite, and the few thin sections examined contain no hornblende.

The dikes that traverse the pyroclastic andesite fall into two main classes—hornblende andesite and holocrystalline dioritic or monzonitic porphyries. Those of the first class appear to be restricted to the andesitic area and to belong to the same epoch of eruptive activity as the tuffs. Many of them are handsome rocks, showing sparkling black phenocrysts of hornblende, generally about half a centimeter in length, and less conspicuous crystals of plagioclase in a partly glassy gray groundmass of ordinary andesitic character. Augite occurs sparingly as phenocrysts and in the groundmass. Although the rocks of this type are certainly in part dikes, some of the material may possibly represent flows. At all events they are an integral part of the volcanic complex. The porphyries of the second class are not limited to the andesitic area but belong to a group of rocks widely distributed over the quadrangle and will be described in another place.

AGE.

Beyond the fact that the andesitic rocks rest on an erosion surface of the Pennsylvanian limestone, the Ray quadrangle supplies no clue to their age. The work of Campbell in the Deer Creek coal field, however, shows that they are late Cretaceous or Tertiary. They are provisionally assigned to the close of the Cretaceous and are thought to be younger than the diabase. Their altered condition, moreover, suggests that they are older than the dacite.

QUARTZ DIORITE.

DISTRIBUTION AND OCCURRENCE.

The quartz diorite forms small irregular intrusive masses and a few dikes of considerable size. The largest mass in the Ray quadrangle lies about a mile northwest of Kelvin and is intrusive in granite and diabase, but is itself cut by dikes of quartz diorite porphyry similar to the rock of some of the dikes near Troy. Another mass southwest of Ray is intrusive into Pinal schist. This mass in turn is cut by a dike of quartz diorite porphyry and probably also by the Granite Mountain porphyry. Two smaller bodies on the north side of Rustler Gulch have invaded the Dripping Spring quartzite.

Three miles northeast of Kelvin, near the head of Elder Gulch, the quartz diorite is intrusive into the Tornado limestone, within which it has effected some local metamorphism. Other small bodies of the same igneous rock lie north and east of Troy Mountain. An irregular mass about one-fourth of a square mile in area cuts granite, diabase, and the Paleozoic formations up to the Mescal limestone just west of Hackberry Spring, in the southwestern part of the Ray quadrangle. Three dikes and a small intrusive body of the same rock cut granite and diabase northeast of Ripsey Spring. Finally, a small body of the quartz diorite in diabase is exposed on Pioneer Creek in the Mescal Range.

As bearing on the age of the quartz diorite intrusions, the fact should be noted that dikes of this rock are fairly abundant in the andesite breccia southeast of Tornado Peak. Most of these dikes are east of the Ray quadrangle.

PETROGRAPHY.

The obvious characteristics of the typical quartz diorite (see Pl. XV, *B*) are light to dark gray color, even fine-grained texture, and general freshness as compared with most of the dioritic porphyries. The constituent minerals are generally not more than 3 millimeters across, and phenocrysts as a rule are very sparsely disseminated or lacking. On fresh fracture the rock sparkles with small crystals of hornblende, augite, or biotite; all three minerals are present in some varieties.

Although the foregoing description applies to the prevalent variety the rock is not wholly uniform in general appearance. In certain local facies the crystals of hornblende may be 2 centimeters or more in length, with the feldspars of proportional size. The mineral composition of the rock is also somewhat variable. Under the microscope the normal rock appears as a fresh aggregate of subhedral to euhedral plagioclase and hornblende, anhedral interstitial quartz and orthoclase, together with the usual accessories—titanite, magnetite, and apatite. The hornblende is generally intergrown with biotite and with colorless or faintly greenish augite. The proportions of these three minerals vary in different facies, although it is rare to find any one of them wholly absent, The plagioclase is not of uniform composition, many of the crystals being decidedly zoned. but a number of optical determinations gave compositions near Ab_1An_2, so that the feldspar is chiefly a calcic labradorite. The quantities of quartz and orthoclase vary in different facies, even to the point of absence in certain porphyritic marginal varieties.

A typical specimen of the quartz diorite from the mass northwest of Kelvin was chosen for chemical analysis, with results as follows:

Chemical analysis of quartz diorite.

[George Steiger, analyst.]

SiO_2	60.42
Al_2O_3	17.27
Fe_2O_3	2.60
FeO	3.47
MgO	2.30
CaO	6.36
Na_2O	3.14
K_2O	2.34
H_2O below 110° C	.40
H_2O above 110° C	.86
TiO_2	.83
ZrO_2	None.
CO_2	None.
P_2O_5	.20
SO_3	None.
S	.05
MnO	.13
BaO	.03
SrO	.06
	100.46

This rock is a tonalose in the norm system of classification and nomenclature.

In a few places the quartz diorite grades into local coarsely crystalline facies, some of which are highly hornblendic.

CONTACT METAMORPHISM.

Quartz diorite which crops out in a small triangular area about a mile northwest of Troy contains an included block of Mescal limestone. This has been strongly metamorphosed, and the igneous rock near the limestone is more coarsely crystalline and more conspicuously hornblendic than elsewhere. The principal minerals developed by metamorphism in the limestone are vesuvianite, clinochlore, diopside, epidote, hornblende, and garnet. The vesuvianite is in stout, nearly sulphur-yellow crystals which, according to W. T. Schaller, who verified the determination of the mineral, present no unusual faces. The garnet is a yellow-brown variety in crystals as much as a centimeter in diameter.

Similar metamorphism has been undergone by a block of limestone included in quartz diorite 2 miles northwest of Troy. Here the garnet shows no crystal faces and is full of inclusions of diopside. The rock in places is a fine-grained aggregate of colorless anhedral diopside.

Another locality where limestone, in this place the Tornado limestone, has been metamorphosed by the quartz diorite is in Elder Gulch, 3 miles northeast of Kelvin. At the contact wollastonite has been developed in coarsely crystalline masses and occurs also associated with diopside, vesuvianite, and garnet

SCHULTZE GRANITE.

EXPLANATORY NOTE.

The Schultze granite was rather fully described in the professional paper on the Globe district and in the Globe folio, but as these publications are no longer readily obtainable and as the granite, particularly its porphyry facies, has been found to be of additional economic importance since those reports were published, much of the description will here be repeated in substance. At the time the reports mentioned were written the Schultze granite was provisionally included with other granitic rocks in the pre-Cambrian. Although its relations to adjacent formations afford no conclusive evidence for a change of assignment, the character of the rock and its similarity to other granitic rocks in the region now known to be younger than the diabase and probably of Tertiary age make it reasonably certain that the Schultze granite is post-Cambrian and probable that it is Tertiary.[1]

The chief interest of the Schultze granite in connection with the present report lies in its intimate relation to the disseminated copper ores of the Miami district.

OCCURRENCE AND DISTRIBUTION.

The Schultze granite occupies an irregular area in the west-central part of the Globe quadrangle, extending from the vicinity of Miami on the northeast to the Pinal ranch on the southwest, a distance of about 10 miles. As a rule, erosion in this area tends toward the development of broad basins and moderate slopes, which, however, may be very rugged in detail. The surface of the granite is but poorly screened by vegetation, so that the rounded outcrops and smoother slopes covered by loose particles of feldspar, quartz, and mica give a pale-yellow tint to the landscape.

PETROGRAPHY.

The granite is characterized by a prevalent porphyritic texture and a generally light tint. The usual color of slightly weathered surfaces is pale yellow, but fresh specimens are nearly white, speckled with small flakes of black mica. The constituents visible to the unaided eye are porphyritic crystals of a fresh, white feldspar as much as 2 inches in length, showing the brilliant cleavage faces and Carlsbad twinning characteristic of orthoclase. These phenocrysts lie in a medium granular groundmass whose constituent grains range from 1 or 2 millimeters to 1 centimeter in diameter and comprise quartz, white feldspar, and biotite. Close inspection of cleavage faces shows that the feldspar of the groundmass is predominantly plagioclase. Such is the rock in which the kettle-like holes are eroded at Bloody Tanks and which is well exposed around the Schultze ranch, on Pinto Creek, and along the trail from this creek to the Pinal ranch.

Under the microscope thin sections (which as a rule illustrate chiefly the groundmass or granular portion of the rock) show a hypidiomorphic granular aggregate of oligoclase, quartz, orthoclase, and biotite, with accessory muscovite and a very little iron ore, apatite, and zircon. Small quantities of epidote and chlorite are present here and there as alteration products of biotite.

The oligoclase, which is a calcic variety, although containing a little brownish microscopic dust, is generally fresh and has a tendency toward idiomorphic form.

[1] Ransome, F. L., Geology at Globe, Ariz.: Min. and Sci. Press, Feb. 12, 1910, pp. 256-257.

The orthoclase occurs as phenocrysts, many of which are irregularly bounded or peripherally intergrown with oligoclase and quartz, and also allotriomorphically crystallized with quartz between and around the oligoclase in the groundmass. It is fresh and fairly clear and is not nctlceably microperthitic, although it contains numerous inclusions of oligoclase, quartz, and biotite.

The biotite shows the usual microscopic characteristics.

A chemical analysis of a typical sample of the Schultze granite, collected about a mile west of the Schultze ranch, in the Globe quadrangle, is given in column 1 of the following table; in column 2 is the analysis of a porphyritic marginal facies obtained 2 miles south of the Schultze ranch.

Chemical analyses of granite and granite porphyry.

[E. T. Allen, analyst, 1902.]

	1	2
SiO_2	70.95	69.35
Al_2O_3	16.30	15.71
Fe_2O_3	1.01	1.18
FeO	.36	.43
MgO	.23	.36
CaO	1.85	1.79
Na_2O	5.16	4.78
K_2O	3.34	3.63
H_2O below 110° C	.26	1.17
H_2O above 110° C	.37	.97
TiO_2	.23	.19
ZrO_2	Trace.	Trace.
CO_2	None.	None.
P_2O_5	Trace.	.08
SO_3	Trace.	....
Cl	Undet.	....
F	Undet.	....
S	Trace.	Trace.
Cr_2O_3	None.	None.
NiO	Undet.	....
MnO	Trace.	Trace.
BaO	.04	.07
SrO	Undet.	....
Li_2O	Undet.	....
	100.10	99.71

In the norm quantitative system the two rocks analyzed correspond to lassenose. In their high silica, low iron oxides, magnesia, and lime, and moderately high potash and soda, they correspond in the familiar system of classification to a granite, and the preponderance of soda over potash points to a soda granite, in which might be expected an alkalic feldspar rich in the albite molecule. The optical examination, on the other hand, shows that the chief constituent of the rock is oligoclase. By calculating the magnesia, all of the ferrous oxide, and most of the ferric oxide as biotite, and proportioning the remaining potash to the remaining alumina for orthoclase and muscovite after the subtraction of enough of the alumina to form titanite, albite, and anorthite, the approximate mineral composition of the rock may be arrived at, as follows:

Mineral composition of granite.

Oligoclase (Ab_8An_3)	52.24
Orthoclase	16.82
Quartz	24.09
Biotite	4.50
Muscovite	1.28
Titanite	.43
Iron oxides	.64
	100.00

Some of the albite molecule is probably combined with the orthoclase molecule to form alkalic feldspar, but as the orthoclase is not microperthitic, and as the composition of the oligoclase as above calculated agrees well with the optical determinations, this amount is probably not large. It thus appears that about half the rock is composed of oligoclase.

It was found in making the foregoing calculation that if all the alumina, after taking out sufficient for the biotite, anorthite, and albite, were combined with the available potash it would give nearly as much muscovite as biotite. This result, as microscopic examination shows, is plainly erroneous, and as the alumina in the analysis is rather higher than is common in rocks of this general chemical character, 0.5 per cent of this oxide was assumed as excessive and thrown in with the remaining iron oxide as iron ore. This is in accord with the well-known fact that small and often unavoidable errors in analysis, especially any occurring in the iron determinations, are cumulatively thrown upon the alumina.

Upon consideration of the chemical and mineral compositions together it appears that the rock does not fit into existing mineralogic schemes of classification. Chemically it is a sodium-rich granite, but mineralogically it is about half plagioclase. It is conceivable that under slightly different conditions the calcium might have gone into mineralogic combination to form pyroxene or amphibole instead of oligoclase, and the rock would then have been made up chiefly of alkalic feldspar, and could be placed without hesitation among the sodium-rich granites. All things considered, it appears to belong somewhere between the quartz monzonites and the alkalic granites. It is placed provisionally with the latter for the reason that chemical composition is considered more important in deciding petrologic relationship than the particular manner in which the potassium, sodium, and calcium of a given magma enter into mineralogic combination.

The foregoing description applies to the rock characteristic of the mass as a whole, particularly at some distance from its periphery. Near the periphery the typical porphyritic granitoid rock may pass into facies which, in the absence of a more appropriate name, may be called biotite granite porphyry. Such porphyry (Pl. XVI, *A*) is characteristic of the copper-bearing area north of Bloody Tanks, drained by Liveoak Gulch, and of the southern border of the granitic area near the schist contact south of the Schultze ranch. The lobe-like projection of the biotite granite extending northward past Needle Mountain, west of Miami, shows much textural variation, passing into facies in which very conspicuous orthoclase phenocrysts lie in a medium granular to fine granular, rather biotitic groundmass. A few of the orthoclase phenocrysts are 4 or even 5 inches in length, and such large crystals always show rounded outlines and more or less peripheral poikilitic texture.

A typical specimen of the granite porphyry near the schist contact, 2 miles south of the Schultze ranch, shows idiomorphic phenocrysts of orthoclase and quartz in a fine-grained groundmass consisting chiefly of white feldspar, quartz, and biotite. The orthoclase phenocrysts occur in apparently untwinned individuals of the usual orthoclase habit and have a maximum length of about 2 centimeters. The quartz phenocrysts are of slightly rounded bipyramidal form and rarely exceed 5 millimeters in length.

Under the microscope the rock shows a typical porphyritic texture. Phenocrysts of orthoclase, quartz, plagioclase (mostly oligoclase), and biotite lie in an extremely fine granular groundmass, such as is common in "quartz porphyries" but was hardly expected in a facies of so crystalline a plutonic rock as the granite of the Bloody Tanks area. The quartz phenocrysts, too, are embayed, as is common in rhyolitic effusive rocks. The orthoclase is usually untwinned, idiomorphic, and fairly fresh, although all the feldspars contain some sericite and indeterminable alteration products. The biotite is almost wholly altered to chlorite, epidote, and iron ore.

A chemical analysis of this porphyry is given in column 2 of the table on page 60. The practical identity of the magma which solidified as porphyritic biotite granite in the middle of the batholith and as granite porphyry at the contact with the schists is apparent from a comparison of analyses 1 and 2. The modification is textural and perhaps to some degree mineralogic, but there has been no appreciable magmatic differentiation.

The porphyry of Liveoak Gulch has been much shattered and veined and is extensively stained with salts of copper. In its petrographic character it is similar to that just described, but all gradations may be found along the Western Pass road near Bloody Tanks from porphyries with microcrystalline groundmass to the typical biotite granite of the central portion of the batholith.

QUARTZ MONZONITE PORPHYRY.

DISTRIBUTION AND OCCURRENCE.

The quartz monzonite porphyry is confined to the vicinity of Ray and occurs for the most part west of that town. Two varieties are recognized. One, designated the Granite Mountain porphyry, is intrusive into the Pinal schist southwest of Ray as a number of irregular masses, of which the largest forms part of Granite Mountain. (See Pl. XLV.) There are also two small bodies of this rock east of Ray, shown in Plate XLV. Most of the altered porphyry in the copper-bearing area west of Ray appears to belong to this variety, although, owing to alteration, close identification is not everywhere possible.

The other variety, distinguished as the Teapot Mountain porphyry, occurs chiefly northwest of Ray and north of the recognized copper-bearing area. One small mass only, that about a mile northeast of Ray, is represented on Plate II. But, as shown by the Ray geologic map (Pl. XLV), which covers an area extending west of the Ray quadrangle, there are many dikes and one irregular mass of considerable size exposed on the flanks of Teapot Mountain, a prominent landmark northwest of Ray.

PETROGRAPHY.

GRANITE MOUNTAIN PORPHYRY.

The quartz monzonite porphyry west of Ray is a light-gray, nearly white rock, which on slightly weathered surfaces has generally a faint yellow tint and closely resembles some of the Schultze granite. This lightness of hue is due to the preponderance of feldspar and quartz, the only dark constituent being black mica in small and sparsely disseminated scales.

The texture of the larger masses, such as that intrusive into the schist of Granite Mountain, resembles on casual inspection that of a porphyritic granite of medium grain, with phenocrysts of orthoclase and quartz not, as a rule, sharply differentiated from the groundmass. The microscope, however, reveals a typical porphyritic texture. The most abundant phenocrysts are plagioclase, which probably are not all of the same composition but which are for the most part andesine or calcic oligoclase. These phenocrysts are euhedral to subhedral, and their average length is about 1.5 millimeters. The phenocrysts of quartz, as a rule partly rounded or embayed, are generally larger than the plagioclase, and the orthoclase phenocrysts are still larger, some being 2 or 3 centimeters in length. They are not abundant, however, and do not appear in every thin section. The biotite phenocrysts are of the usual subhedral form. The groundmass is a fine, equigranular aggregate of quartz and clear orthoclase, and is approximately equal in volume to the phenocrysts, or, more briefly, the texture is sempatic. The average diameter of grain in the groundmass is about 0.1 millimeter. In addition to the principal minerals the porphyry contains small quantities of titanite, apatite, magnetite, and zircon.

A chemical analysis of a representative sample from the east base of Granite Mountain, 1 mile southwest of Humboldt Hill, is as follows:

Chemical analysis of quartz monzonite porphyry.

[R. C. Wells, analyst.]

SiO_2	70.52
Al_2O_3	15.54
Fe_2O_3	.77
FeO	1.31
MgO	.66
CaO	2.49
Na_2O	3.96
K_2O	3.72
H_2O below 110° C	.36
H_2O above 110° C	.88
TiO_2	.27
ZrO_2	None.
CaO	None.
P_2O_5	.09
S	Trace.
MnO	.02
BaO	.03
SrO	None.
	100.62

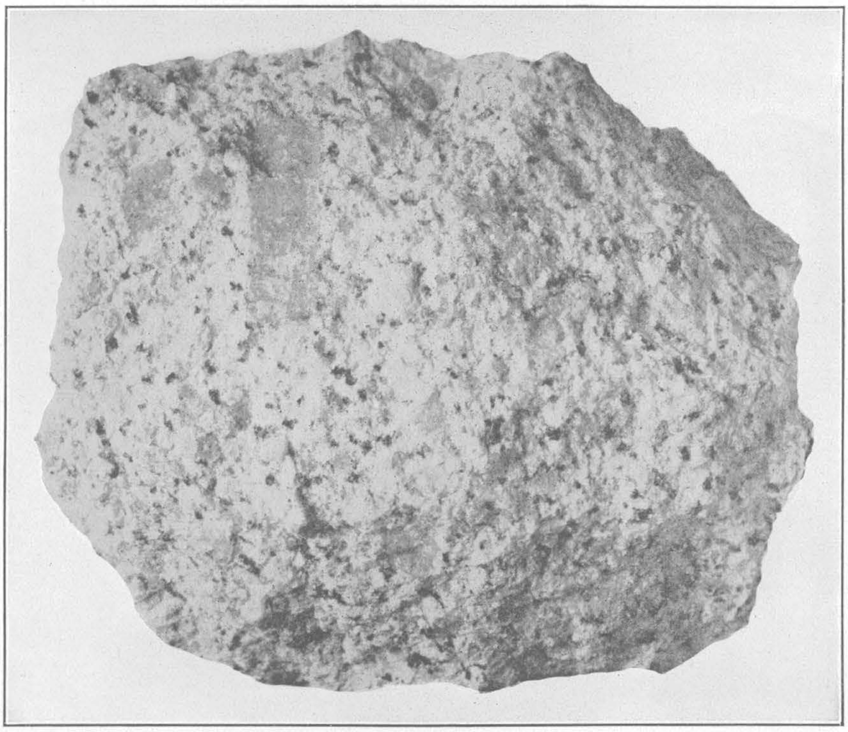
In the norm quantitative system this rock is toscanose.

TEAPOT MOUNTAIN PORPHYRY.

Closely associated with the Granite Mountain porphyry of Ray is a slightly different variety of quartz monzonite porphyry, which occurs for the most part north and west of the copper-bearing area, on the southeast slopes of Teapot Mountain, as dikes and irregular masses in the Pinal schist.

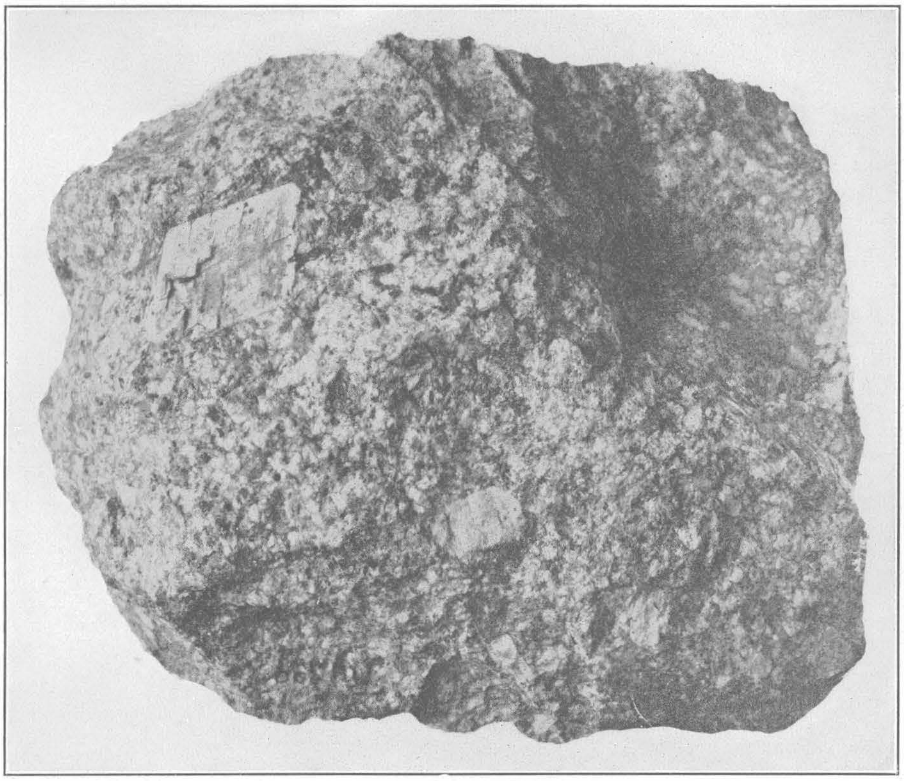
This rock (Pl. XVI, *B*) is, as a rule, a little darker in color than the Granite Mountain porphyry and is more obviously porphyritic. The general color of the fresh rock is gray, but surface exposures are generally light yellowish brown from decomposition. Contrasting sharply with the gray groundmass are phenocrysts of pink orthoclase as much as 3 centimeters in length. These are associated with smaller phenocrysts of quartz and of milky-white feldspar.

Under the microscope the matrix in which occur the large orthoclase crystals itself shows phenocrysts of plagioclase, orthoclase, quartz, and biotite in a very fine grained granular groundmass that is probably chiefly quartz and orthoclase. A single twinned crystal of allanite about 0.65 millimeter long was noted in one thin section. Although this porphyry is younger than the Granite Mountain porphyry, it is more subject to decomposition than that rock, and ordinary exposures do not



A. GRANITE PORPHYRY FACIES OF SCHULTZE GRANITE, LIVEOAK GULCH, HALF A MILE WEST OF LIVE OAK TUNNEL.

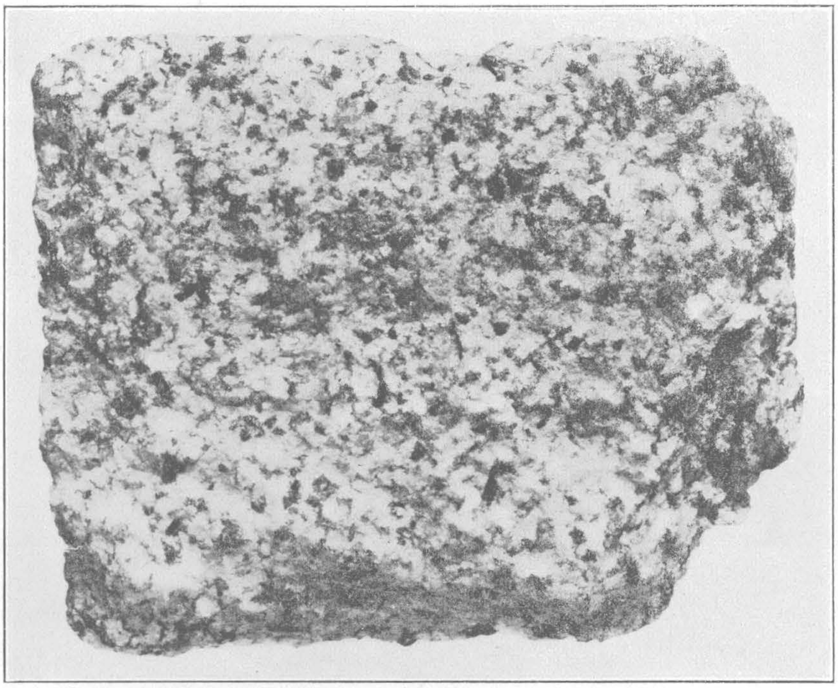
Natural size.



B. TEAPOT MOUNTAIN PORPHYRY (QUARTZ MONZONITE PORPHYRY), SOUTH SLOPE OF TEAPOT MOUNTAIN.

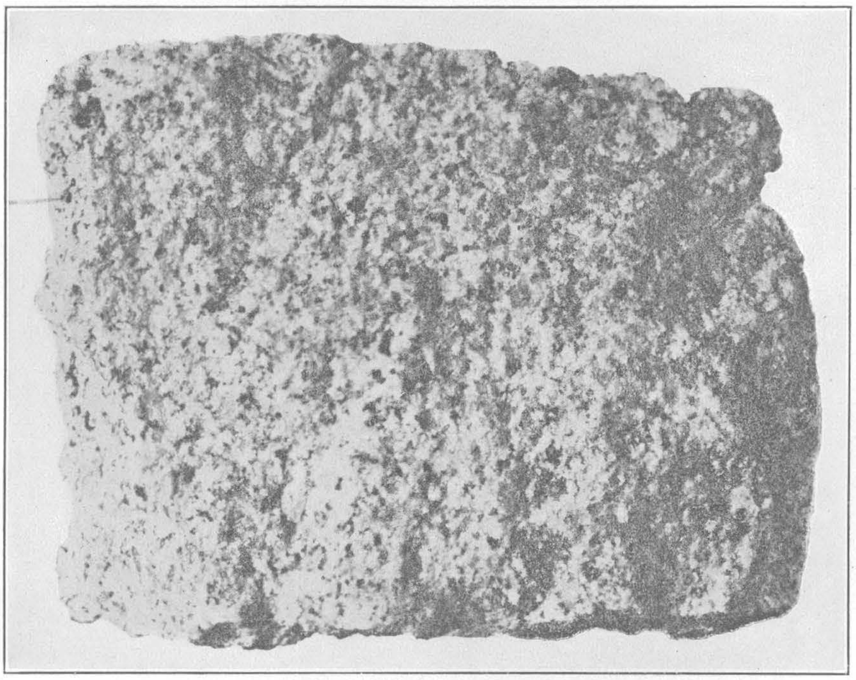
Natural size.

IGNEOUS ROCKS.



A. GRANODIORITE HALF A MILE NORTHEAST OF TROY.

Natural size.



B. GRANODIORITE ON ROAD JUST WEST OF TROY.

Natural size.

IGNEOUS ROCKS.

afford satisfactory material for petrographic and chemical study. The feldspars are largely changed to calcite and sericite and the biotite to chlorite and epidote.

CONTACT METAMORPHISM.

The contact action of the quartz monzonite porphyry near Ray is most apparent on the diabase, which, near the porphyry, glistens with abundant secondary biotite. This alteration is of the same sort as that produced by quartz diorite porphyry in diabase near the London-Arizona mine, and is described on page 64. Altered diabase of the kind referred to may be well seen on the dump of the Blue Bell shaft, southeast of the town of Ray.

GRANODIORITE.

OCCURRENCE AND DISTRIBUTION.

The almost abandoned settlement of Troy, in the Dripping Spring Range, is situated in a small upland basin floored with granodiorite and inclosed by hills of diabase and Paleozoic sediments, into which the granodiorite is intrusive. The principal area of this granite-like rock is roughly pear-shaped in outline, with the point to the east. Its length is 1¾ miles and its greatest width nearly 1¼ miles. A small outlying area half a mile northwest of Troy, although inclosed at the surface by Pioneer shale, is probably part of the main Troy mass.

PETROGRAPHY.

The granodiorite of Troy (Pl. XVII) is a light-gray evenly granular rock whose principal constituents, easily recognized as plagioclase, quartz, and black mica, average about 3 millimeters in diameter. Although over much of the surfaces of the basin the rock is disintegrated and crumbling, it is not difficult to procure material that is fresh or that shows under the microscope only slight development of epidote and chlorite in the biotite or of calcite and sericite in the feldspars.

In thin section under the microscope the rock appears as a granular aggregate of andesine (near Ab_3An_2), quartz, orthoclase, biotite, hornblende, titanite, magnetite, and zircon. With the exception of the quartz and orthoclase, which are anhedral, the principal constituents are subhedral, and some of the hornblende shows automorphic sections in the prism zone. The minerals have the usual character of those found in rocks of this class and call for no detailed description. The orthoclase and hornblende are both rather variable, being fairly abundant in some facies and inconspicuous or absent in others. They are nowhere, however, other than subordinate constituents.

A chemical analysis of a typical sample of the granodiorite, from a point half a mile northeast of Troy, is as follows:

Chemical analysis of granodiorite.

[R. C. Wells, analyst.]

SiO_2	64.84
Al_2O_3	16.49
Fe_2O_3	1.87
FeO	2.28
MgO	1.58
CaO	4.54
Na_2O	4.18
K_2O	2.46
H_2O below 110° C	.19
H_2O above 110° C	.98
TiO_2	.50
ZrO_2	.01
CO_2	Trace.
P_2O_5	.19
S	None.
MnO	.06
BaO	.02
SrO	None.
Li_2O	None.
	100.19

The name in the norm system for a rock of the above composition is yellowstonose.

The rock of the little area half a mile northwest of Troy resembles that of the main mass, although it is slightly finer grained and, as the microscope shows, approaches granodiorite porphyry in texture.

CONTACT METAMORPHISM.

The most noticeable metamorphism near the granodiorite of Troy is on the northwest side of the intrusive mass, where the igneous rock is in contact with fine-grained gray schist. This schist is not unlike some of the finer-grained varieties of the Pinal schist, but its geologic relations at this place show that it is locally metamorphosed Pioneer shale. The schistosity conforms to the bedding of the former shale, dipping about 15° SW.

One specimen of the schist, when examined in thin section, proved to consist of quartz, biotite, and muscovite with andalusite in long ragged prisms and rather abundant corundum in grains, granular aggregates, and larger individuals without external crystal form. The corundum is colorless in thin section but contains numerous dark inclusions. Its index of refraction was determined to be above 1.736 (that of the highest refractive index liquid at hand), while the birefringence is low, only slightly exceeding that of quartz. The mineral gives a uniaxial interference figure and is optically negative. It was found to have a density greater than that of methylene iodide (approximately 3.3) and remains as a residue when the powdered rock is treated with hydrofluoric acid. These properties together establish the identity of the mineral as corundum beyond any reasonable doubt.

Other specimens from the same small area of schist showed neither andalusite nor corundum, although all contain a little dark tourmaline as a microscopic constituent.

The schist is overlain by the Barnes conglomerate, which is so metamorphosed as to be scarcely recognizable. It looks at first glance like a nearly homogeneous white quartzite, and close examination is required to distinguish the shadowy outlines of the original pebbles.

The diabase near the granodiorite in places shows noticeable alteration. It is more glittering than the normal diabase and evidently contains abundant biotite. The microscope shows that this rock, while retaining the general texture of the diabase, has undergone extensive recrystallization. The original feldspars have a reddish turbidity and are full of minute inclusions. The augite and olivine have totally disappeared and are replaced by aggregates of green hornblende and biotite. There is considerable clear secondary feldspar, generally in optical continuity with the original feldspar and containing flakes of biotite and needles of amphibole. The rock is perfectly fresh, and it is clear that the change was produced by a more active agency than those which effect the ordinary uralitization of pyroxenic rocks.

Certain of the ore deposits near Troy are to be interpreted as the results of contact metamorphism by the granodiorite magma. Such are the deposits of the Rattlesnake or Manhattan mine, 1 mile east of Troy, on the South side of the granodiorite area. Here magnetite, chalcopyrite, and pyrite occur as irregular replacement layers in the Mescal limestone, which has been altered to an aggregate of diopside, white mica, and other silicates. The chalcopyrite has been in part changed to chalcocite, and the white mica apparently to a green micaceous mineral of the chlorite group, probably clinochlore. The white mica, although suggestive of muscovite, is probably not that mineral and may be a colorless phlogopite. No detailed study has yet been made of the metamorphic minerals at this locality.

QUARTZ DIORITE PORPHYRY.

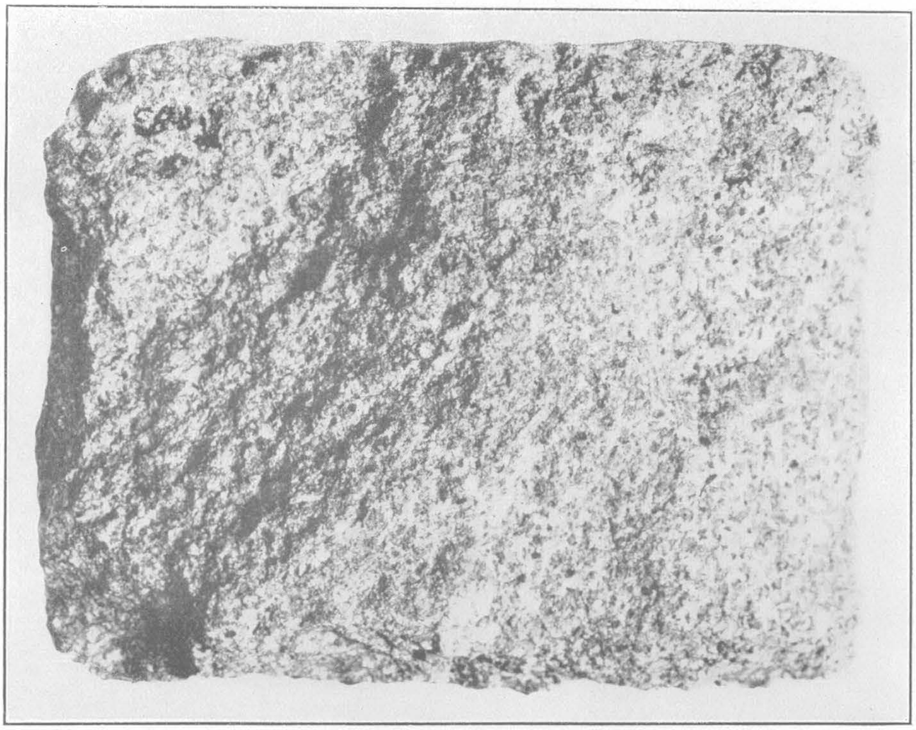
OCCURRENCE AND DISTRIBUTION.

The rocks here included under the heading quartz diorite porphyry are widely distributed over the Ray quadrangle as dikes, sills, and small intrusive masses. In dikes they are abundant in the vicinity of Troy and are likely to attract the attention of a traveler over the stage road, from the fact that they crop out in the granodiorite area as narrow ridges of darker color than the surrounding granitic rock. The general trend of the dikes near Troy is nearly due east, but in the vicinity of the Alice and Buckeye mines, southwest of the settlement, some of the dikes branch into nearly north fault fissures. The width of most of the dikes is between 10 and 100 feet.

Intrusions of this porphyry are abundant also between Tam o' Shanter Peak and Gila River. In this part of the Mescal Range the porphyry cuts the andesite tuff and has invaded the Tornado limestone both as dikes and sills. The ore deposits of the London-Arizona mine and at Christmas appear to be genetically dependent upon the quartz diorite porphyry.

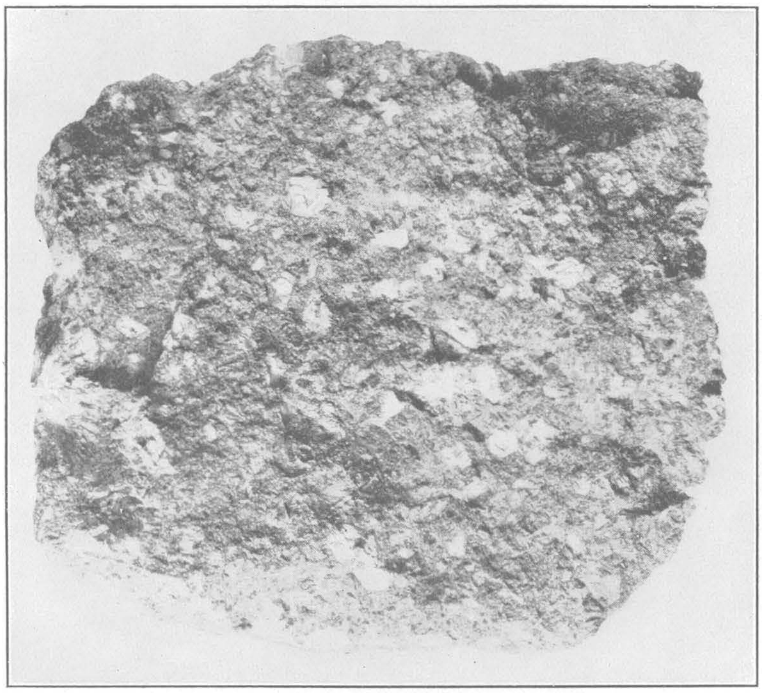
PETROGRAPHY.

More or less decomposition is so prevalent a feature of the quartz diorite as to be one of its chief characteristics, and the crumbling condition of most surface exposures makes it difficult to collect satisfactory petrographic material. Furthermore, in view of the facts that the porphyry in different parts of the same dike may be wholly unlike in color and



A. QUARTZ DIORITE PORPHYRY DIKE HALF A MILE NORTHEAST OF TROY.

Natural size.



B. DACITE 2½ MILES NORTH OF WALNUT SPRING, RAY QUADRANGLE.

Natural size.

IGNEOUS ROCKS.

texture and that the mineralogic and chemical distinction between quartz diorite porphyry and other members of the dioritic and monzonitic families is at best not sharp, it is obvious that among the many intrusive bodies mapped as quartz diorite there are possibly a few that belong to other rock types. Probability, not infallibility, is all that can be claimed for the classification of some of these bodies.

The typical quartz diorite porphyry (Pl. XVIII, *A*), as exemplified by some of the larger dikes near Troy and by the intrusive bodies of various form near the London-Arizona mine and near Christmas, is a rather light gray speckled rock within which may readily be seen phenocrysts of white feldspar, of black mica, and of quartz, whose relative size and abundance of these constituents is generally in the order named. The phenocrysts rarely exceed a centimeter in length and as a rule are smaller. They lie in a gray groundmass apparently composed in part of the same minerals. Some varieties show hornblende, but it is generally not abundant or conspicuous. Small crystals of rosin-yellow titanite have been noted in one or two specimens. With the progress of decomposition the bright granitic gray color changes to various shades of greenish or yellowish gray in consequence of the development of epidote and chlorite.

Under the microscope in thin section the typical fresh porphyry shows subhedral phenocrysts of andesine (near Ab_2An_1) and biotite, with rounded or embayed phenocrysts of quartz and generally a few phenocrysts of hornblende which may be intergrown with the biotite. These lie in a fine granular groundmass consisting chiefly of quartz and plagioclase granules under 0.3 millimeter in diameter, with more or less biotite and hornblende and the usual accessory minerals magnetite, apatite, titanite, and zircon. Allanite appears to be a characteristic though sparsely disseminated constituent of the porphyry, but it is not present in every thin section. The largest crystal seen was a millimeter in length.

Comparatively few thin sections show all the above-mentioned minerals in fresh condition. The feldspars are as a rule partly altered to sericite and calcite, the biotite is partly or wholly changed to chlorite and epidote, and the hornblende is represented by aggregates of calcite, epidote, and chlorite.

Deviations from the type are many and varied. Some facies are finer grained, some show no quartz phenocrysts to the naked eye, others show prominent phenocrysts in an aphanitic groundmass, and still others are almost aphanitic throughout.

A common facies among the dikes in the Troy basin is characterized by abundant phenocrysts of dull, slightly pinkish feldspar and of rounded quartz, the largest 1 centimeter in diameter, with inconspicuous phenocrysts of hornblende and biotite, in a dark greenish-gray aphanitic groundmass. The microscope shows that the pink feldspar is not, as its appearance at first suggests, orthoclase but is plagioclase, probably andesine, largely altered to kaolinite, calcite, and sericite. Hornblende, rather more abundant in the groundmass than in the typical quartz diorite porphyry, has been for the most part changed to epidote and chlorite. Biotite, in this facies less abundant than in the typical variety, has been altered to the usual secondary products.

Dikes, resembling those just described in being more hornblendic than the typical quartz diorite porphyry, occur in diabase, about a mile west of Kelvin.

Some of the wider dikes near Troy grade on their margins into fine-grained facies having very little resemblance to the main rock of the dike. This gradation is shown exceptionally well by the dikes south and west of bench mark 3,644. The marginal facies is generally a compact greenish-gray or brown rock with minute phenocrysts of hornblende in an aphanitic groundmass. Some varieties show also small phenocrysts of plagioclase and biotite. The rock has invariably an original rough cleavage parallel with the sides of the dike and has acquired by weathering a pronounced platy structure. Under the microscope these marginal rocks are seen to be much decomposed and to contain abundant calcite, chlorite, and other secondary products, but there appear to have been originally small phenocrysts of plagioclase and hornblende in a groundmass consisting chiefly of tiny felted laths of plagioclase. Were the rocks fresher the dikes of Troy would provide the material for an interesting study of local magmatic differentiation. As it is, however, little more can be done than to call attention to the marked difference in general character between the medial portions and sides of the dikes and to point out that the marginal facies are more hornblendic and less quartzose than the typical quartz diorite.

Two specimens from a dike 125 feet wide, just south of the settlement of Troy, were partly analyzed, as follows:

Partial chemical analyses of quartz diorite porphyry.

	1	2
SiO_2	68.26	59.90
Al_2O_3	15.91	[a]21.48
Fe_2O_3, FeO	3.04	4.44
MgO	.87	2.16
CaO	2.11	4.02
Ma_2O	3.65	3.38
K_2O	2.80	2.82
TiO_2	.29	....
	96.93	98.20

[a] Includes any P_2O_5 and TiO_2.

1. Quartz diorite porphyry from middle of dike. R. C. Wells, analyst.
2. Marginal facies of above. W. T. Schaller, analyst. Both rocks contain calcite, epidote, and chlorite.

The fine-grained rock that forms a marginal facies of some of the larger dikes also occurs by itself as dikes of considerable width, some of these being wider than the combined width of the two lateral facies of the large differentiated dikes. A specimen from one of these dikes, half a mile north of Troy, being the freshest dike rock obtainable, was selected for chemical analysis. This rock shows small phenocrysts of andesine (less than 5 millimeters) and smaller ones of biotite in a compact slate-gray groundmass. Texturally it is intermediate between the ordinary marginal facies and the porphyry described on page 65. The microscope shows phenocrysts of andesine, hornblende, partly chloritized biotite, apatite, and magnetite in a fine andesitic-looking feldspathic groundmass. Quartz is absent, and the specimen in this respect is representative rather of the marginal facies than of the typical quartz diorite porphyry. The analysis is as follows:

Analysis of diorite porphyry.

[W. T. Schaller, analyst.]

SiO_2	65.30
Al_2O_3	15.92
Fe_2O_3	1.37
FeO	2.19
MgO	1.59
CaO	3.89
Na_2O	4.01
K_2O	3.08
H_2O below 110° C	.34
H_2O above 110° C	.78
TiO_2	.50
ZrO_2	None.
CO_2	.27
P_2O_5	.29
S	.20
Cr_2O_5	None.
MnO	.05
BaO	.12
SrO	None.
Li_2O	None.
	99.90

Among the quartz diorite porphyry dikes near Cane Spring, shown on Plate II, are a few thin, short dikes of compact greenish-gray andesite. As their importance scarcely warrants an individual color and as they were perhaps intruded at the same time as the other dikes, they are mapped as quartz diorite porphyry.

CONTACT METAMORPHISM.

Notable contact metamorphism has been produced by the intrusion of quartz diorite porphyry in the vicinity of the London-Arizona mine, in the southern part of the Ray quadrangle, and at Christmas, just east of the quadrangle. Near the London-Arizona mine the diabase close to the porphyry has the glittering appearance that denotes the development of secondary biotite and in places has become a dark biotite schist. The alteration is the same in kind but more intense than that near Troy described above. Here and there in the Carboniferous limestones, not everywhere in actual contact with the porphyry but in all probability a consequence of its intrusion, are masses of garnet rock. About a mile southwest of the London-Arizona mine the dump of the London Range shaft, in Tornado limestone, shows considerable thulite, the pink manganese epidote, associated with some common epidote. This occurrence is perhaps

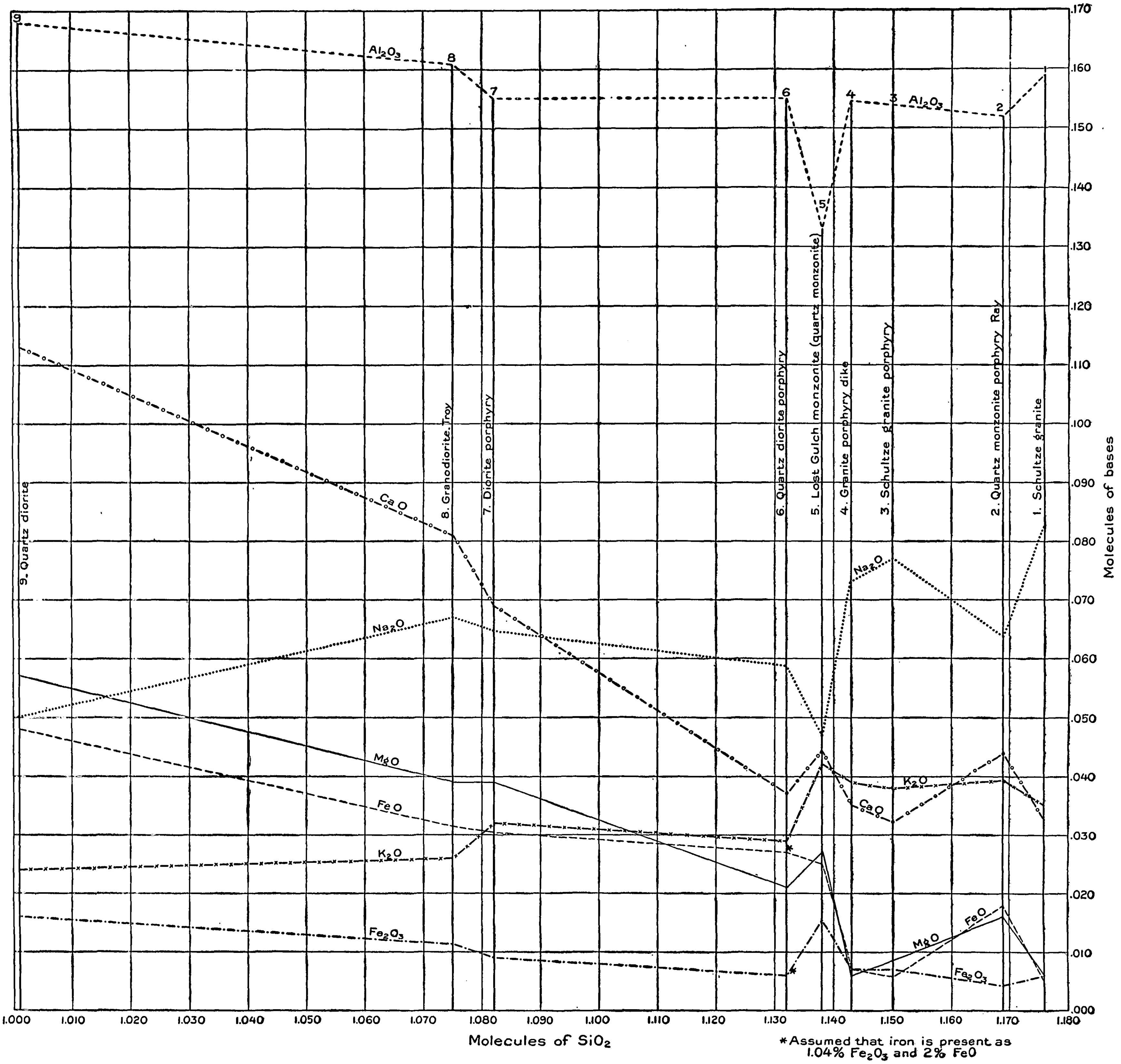


DIAGRAM SHOWING VARIATION OF MOLECULAR CONSTITUENTS IN NINE INTRUSIVE GRANITIC ROCKS AND RELATED PORPHYRIES OF THE GLOBE-RAY REGION.

also due to the intrusion of the quartz diorite porphyry, although none of that rock is visible at the surface at this place.

At Christmas the copper deposits are of contact-metamorphic origin, occurring in the Tornado limestone in close association with quartz diorite porphyry. The principal sulphides are pyrite, chalcopyrite, and sphalerite associated with garnet, magnetite, serpentine, diopside in granular and in part radial microscopic aggregates, and calcite. It is likely that other silicates than those mentioned are also present, as the mineralogy of the deposits has not been fully studied. A little bornite and chalcocite were noted, the latter clearly of supergene origin.

COMPARISON OF THE GRANITIC ROCKS.

The accompanying table of chemical analyses shows the close relationship existing between the post-Paleozoic granitic rocks and porphyries. The Lost Gulch monzonite is lower in alumina than the others and differs from them also in containing more potassa than soda. This tends to support the suggestion on pages 51-52 that the monzonite may be older than the other post-Paleozoic granitic rocks of the region.

The chemical variation in these rocks is shown diagrammatically in Plate XIX.

Chemical analyses of post-Paleozoic granitic rocks and related porphyries of the Globe-Ray region.

	1	2	3	4	5	6	7	8	9
SiO_2	70.95	70.52	69.35	68.95	68.63	68.26	65.30	64.84	60.42
Al_2O_3	16.30	15.54	15.71	15.84	13.68	15.91	15.92	16.49	17.27
Fe_2O_3	1.01	.77	1.18	1.14	2.53	3.04	1.37	1.87	2.60
FeO	.36	1.31	.43	.56	1.81		2.19	2.28	3.47
MgO	.23	.66	.36	.24	1.10	.87	1.59	1.58	2.30
CaO	1.85	2.49	1.79	1.96	2.51	2.11	3.89	4.54	6.36
Na_2O	5.16	3.96	4.78	4.56	2.94	3.65	4.01	4.18	3.14
K_2O	3.34	3.72	3.63	3.69	4.04	2.80	3.08	2.46	2.34
H_2O below 110° C	.26	.36	1.17	.86	.70	......	.34	.19	.40
H_2O above 110° C	.37	.88	.97	1.49	.87	......	.78	.98	.86
TiO_2	.23	.27	.19	.22	.69	.29	.50	.50	.83
ZrO_2	Trace.	None.	Trace.	.01	.01	......	None.	.01	None.
CO_2	......	None.	......	......	......	......	.27	Trace.	None.
P_2O_5	Trace.	.09	.08	.08	.24	......	.29	.19	.20
SO_3	Trace.	......	......	......	......	......	......	......	None.
FeS_2	......	......	......	......	.11	......	......	......	......
S	Trace.	Trace.	Trace.	None.	......	......	.20	None.	.05
Cr_2O_3	......	......	......	......	......	......	None.	......	......
MnO	Trace.	.02	Trace.	Trace.	.15	......	.05	.06	.13
BaO	.04	.03	.07	.07	.05	......	.12	.02	.03
SrO	......	None.	......	......	Trace.	......	None.	None.	.06
Li_2O	......	......	......	......	Trace.	......	None.	None.	......
	100.10	100.62	99.71	99.67	100.06	(96.93)	99.90	100.19	100.46

1. Schultze granite, 1 mile west of Schultze ranch, Globe quadrangle. E. T. Allen, analyst.
2. Granite Mountain porphyry (quartz monzonite porphyry), Granite Mountain, Ray district. R. C. Wells, analyst.
3. Granite porphyry (facies of Schultze granite), 2 miles south of Schultze ranch. E. T. Allen, analyst.
4. Granite porphyry, 4½ miles south of Schultze ranch. E. T. Allen, analyst.
5. Lost Gulch monzonite (quartz monzonite), Lost Gulch, Globe quadrangle. W. F. Hillebrand, analyst.
6. Quartz diorite porphyry dike in granodiorite, Troy, Ray quadrangle. R. C. Wells, analyst.
7. Diorite porphyry dike in granodiorite, half a mile north of Troy. W. T. Schaller, analyst.
8. Granodiorite, Troy, Ray quadrangle. R. C. Wells, analyst.
9. Quartz diorite, 2 miles northwest of Kelvin, Ray quadrangle, George Steiger, analyst.

WHITETAIL CONGLOMERATE.

In the reports on the Globe quadrangle the Whitetail formation was described as a deposit of rather coarse and in many places somewhat angular stony detritus that lay in the hollows of a former land surface and together with that surface was covered by dacitic lava. The material is generally of local origin and varies with the underlying rock. It appears to have accumulated particularly on areas of diabase, and in such situations is made up of angular or very imperfectly rounded fragments of that rock with a minor proportion of limestone fragments. The fragments are as much as a foot in diameter and are generally more or less decomposed. Typical aspects of the Whitetail formation are shown in Plate XX.

The formation is the record of the operation, prior to the dacite eruptions, of forces and processes similar to those that afterward, on a larger scale, accumulated the Gila conglomerate, which in some places is almost identical with the Whitetail. Apparently then as now areas of diabase tended to become lowlands and were strewn more abundantly than at present with stony detritus, locally reworked and partly stratified by transient streams. Detrital fans at the mouths of shallow gulches, merging with the stony litter of an arid surface, were covered by the tuff and lava of the dacitic eruptions and so preserved. In the absence of fossils a rough approximation to the age of the Whitetail formation, deduced from the general physical history of the region, is all that is possible. As it lay on the surface over which the probably early Tertiary dacitic lavas were erupted, it also is referred to the same period.

Excellent places to observe the Whitetail formation are the steep slopes of Teapot Mountain near Ray (Pl. XLIII, *A*) and near the Continental mine, in the northwestern part of the Globe quadrangle.

DACITE.

OCCURRENCE AND DISTRIBUTION.

Dacite covers large areas and is widely distributed in the Globe quadrangle but in the Ray quadrangle occurs only at the north end of the Dripping Spring Range. The mass through which Mineral Creek has cut its gorge north of Ray is merely the southern extremity of a thick and extensive flow whose surface may be seen from any of the summits north of Scott Mountain stretching in rugged desolation for many miles to the northwest. (See Pl. XXI, *A*.) Into this thick mass of lava Mineral Creek and its tributary, Devils Creek, have incised deep, narrow canyons of notably picturesque character. The main portion of this flow is faulted down against the older rocks of the Dripping Spring Range, but outlying remnants rest here and there on the higher parts of this range north of Scott Mountain, and a considerable area of dacite, partly covered by the Gila conglomerate, extends southward to the vicinity of Ray.

Originally this flow probably covered most of the Globe quadrangle and much of the Ray quadrangle, but its continuity has been greatly reduced by faulting. The maximum thickness is unknown, but existing remnants show that it must have exceeded 1,000 feet. In spite of vigorous postdacitic deformation of the region, it is clear that the flow was poured out over an irregular surface in whose ravines and valleys the Whitetail formation had previously accumulated.

The basal portion of the dacite is well exposed 2 miles northwest of Walnut Spring, where a small body of this rock caps a prominent flat-topped summit in the Dripping Spring Range and rests partly on diabase and partly on the Mescal limestone, with here and there a little of the Whitetail formation intervening. Here the lower 3 or 4 feet of the dacitic formation consists of a light pinkish-gray, rather soft rock, with small sparkling flakes of black mica and fragments of diabase and limestone. It closely resembles the typical dacite, presently to be described, but is a shade lighter in color and, as shown by the microscope, is a glassy dacite tuff. Above this is a 12 to 15 foot layer of a brittle, nearly black vitrophyre, with resinous luster, which is a persistent and characteristic feature at the base of the lava flow. This grades upward into the typical pink dacite, which maintains its lithologic character with scarcely any variation wherever it occurs in the Globe and Ray quadrangles.

In Webster Gulch, north of Miami, between the Warrior mine and the Inspiration mill, the dacite rests on a deposit of soft dacite tuff with layers of diabase fragments and brown clay. The material, owing to its softness, is poorly exposed, but there appear to be at least four or five layers of the diabase detritus, some of which are separated by pink dacite tuff. The total thickness of the tuff, diabase fragments, and clay may be 150 feet or more. The deposit appears to be a very small one, and presumably the material was washed into a local basin before and during the dacitic eruptions, being covered finally by the dacite flow. The deposit is of special interest as containing the chrysocolla ores of the Warrior and Geneva mines.

PETROGRAPHY.

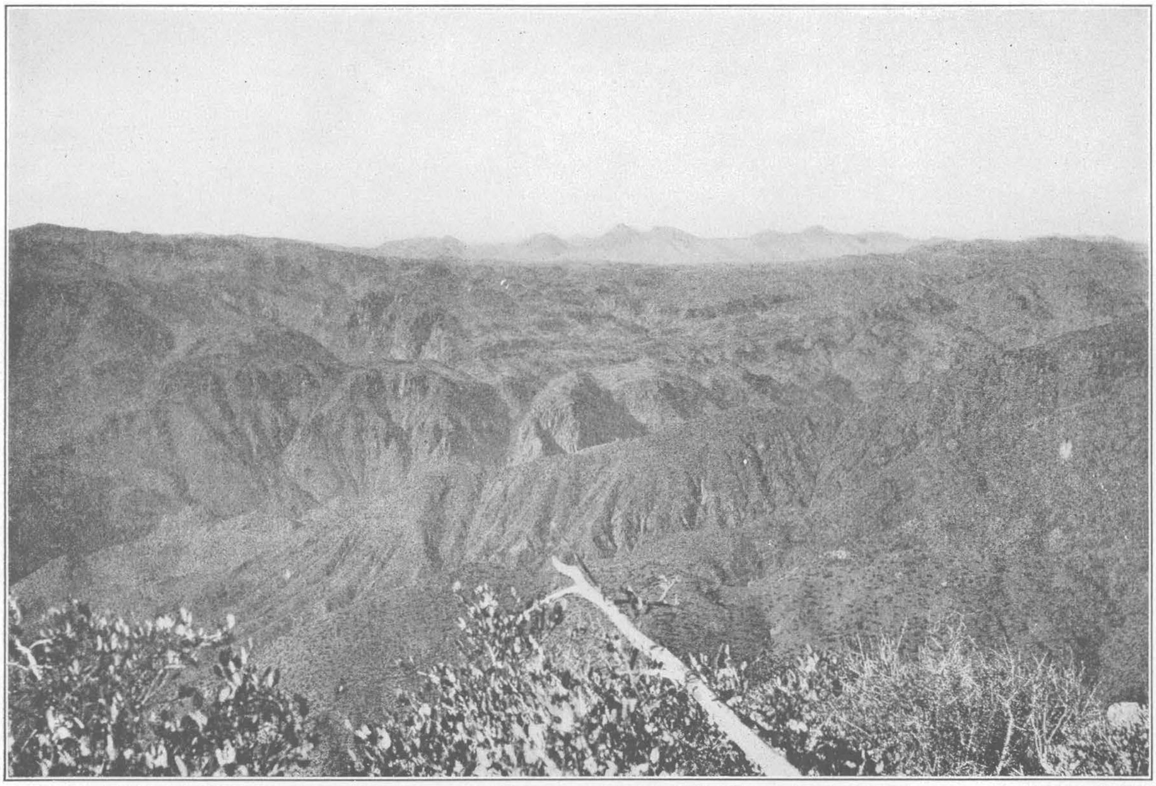
In natural exposures the dacite has a very characteristic light pinkish-gray color. It has a tendency to weather into large, boulder-like masses, forming characteristically rocky surfaces, which, as suggested by Plate XXI, *B*, are difficult of traverse. Many of these loose masses are over 6 feet in diameter, and, owing

A. UPPER PART OF 75-FOOT SECTION.

B. LOWER PART OF SAME SECTION.

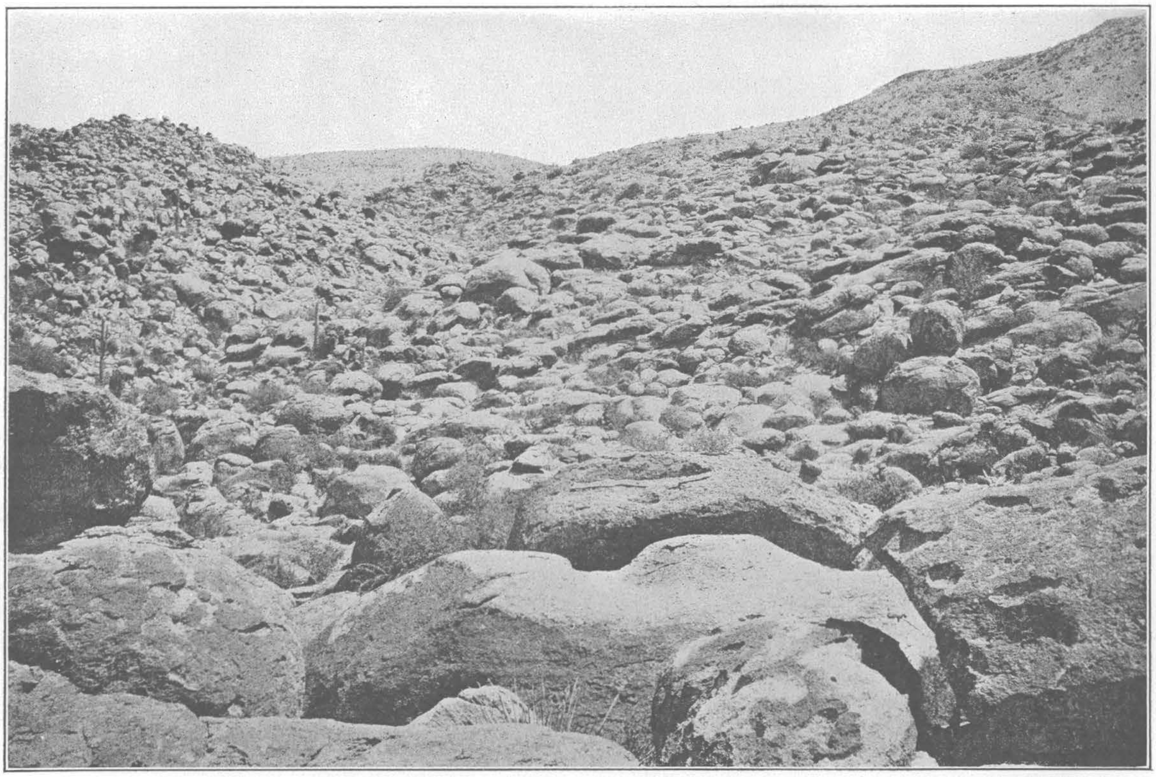
WHITETAIL CONGLOMERATE AS EXPOSED THREE-QUARTERS OF A MILE NORTHWEST OF CONTINENTAL SPRING IN THE GLOBE QUADRANGLE.

Most of the fragments are diabase but there are some of limestone.



A. VIEW NORTHWEST OVER DACITE FLOW NORTH OF RAY, SHOWING ROUGH, DESOLATE CHARACTER OF ITS SURFACE.

The spurs in the foreground are chiefly diabase with masses of disrupted Cambrian strata. The distant mountains are those extending northwest from Superior past Roosevelt, including the south end of the Mazatzal Range.



B. CHARACTERISTIC EROSION SURFACE OF DACITE JUST NORTH OF OLD DOMINION MINE, NEAR GLOBE.

to differential weathering of glassy lithoidal portions of the rock, they show curiously pitted exteriors. The origin of the boulders is traceable to a rather irregular division of the rock into rude cuboidal blocks by systems of joints, which may not be visible until brought out by initial disintegration. Such joints can well be seen in the cliffs along Mineral Creek, in the northwest corner of the Ray quadrangle, and at the Sixtysix ranch, in the southwest corner of the Globe quadrangle, where various intermediate stages may be observed between angular joint blocks and rounded boulders. As a rule, the weathering of the dacite is a very superficial process, being confined to the disintegration of exposed surfaces. Decomposition has rarely penetrated the rock for more than a fraction of an inch.

The color of the freshly fractured dacite (Pl. XVIII, *B*) is light gray, usually of a decided pinkish tinge, with small streaks or blotches of nearly white material. The rock is harsh to the touch and at first glance appears to be more porous than it actually is. It is firm and tough rather than hard and brittle, and being easily quarried and fairly durable, it makes a good building stone. Owing to the small size of the phenocrysts, few of which exceed 3 millimeters in length, the porphyritic structure is not conspicuous, and the rock has a rather uniform texture. Small included fragments of other rocks may be locally abundant, and most of these are diabase. Such inclusions are particularly numerous and well exposed in a little gorge, cut through the eruptive rock 1½ miles northeast of Government Spring, in the Globe quadrangle; but there are few masses of the dacite that do not contain some of these fragments.

Close examination of a fresh surface of the dacite shows numerous phenocrysts of feldspar, many of which have the striated cleavage faces of plagioclase, although a few are apparently orthoclase (sanidine). Sparkling hexagonal scales of biotite, rarely over a millimeter or two in diameter, are scattered through the rock, though their number varies considerably in different specimens. Phenocrysts of quartz are invariably present but are not conspicuous, and occasionaly small black phenocrysts of hornblende can be detected. All the phenocrysts are embedded in a dull-pinkish semilithoidal matrix, which gives the general tint to the rock.

Under the microscope the prevalent pinkish variety of the dacite shows vitrophyric structure. The phenocrysts of feldspar, quartz, and biotite, and a few of hornblende are inclosed in a streaky or ropy semiopaque glassy groundmass, showing the beautiful billowy flowage lines characteristic of this structure in andesitic and rhyolitic rocks.

The feldspars, which are principally plagioclase, are all more or less rounded in outline from magmatic corrosion. They are perfectly fresh and clear and range in composition from labradorite (Ab_1An_2) to andesine (Ab_5An_3). Zonal structure is common and the outer shells are less calcic than the inner.

The potassic feldspar is much less abundant than the plagioclase and is the clear, vitreous variety of orthoclase commonly known as sanidine. It has been more strongly corroded than the plagioclase and presents rounded or even embayed outlines. It shows the usual cleavages, optical orientation, index of refraction, and birefringence of orthoclase, but so far as observed is not twinned. It is generally more irregularly cracked than the plagioclase, and fragments of the broken crystals have occasionally been displaced by movement of the magma. The ratio of the andesine and labradorite to the orthoclase is probably greater than 10 to 1.

The quartz presents no features of exceptional interest. It is deeply embayed and destitute of all crystal boundaries, as is common in rocks of this type. It is perhaps a little more abundant than the orthoclase but much subordinate to the plagioclase.

The biotite is the common conspicuously pleochroic variety, with the strong absorption usual in andesitic rocks. Some of it shows magmatic alteration, which has involved not only the outer surface of the crystal but its whole mass. This altered mica has lost part of its color and pleochroism, the lamellae have frayed out at the ends and split apart, and the whole is filled with specks of opaque iron oxide. Intergrowths between the different phenocrysts are not uncommon and rarely quartz and andesine form micropegmatite. The accessory constituents are a green hornblende, occurring in small prismatic crystal fragments, apatite, titanite, zircon, and a little magnetite.

The groundmass of the dacite is glassy and, notwithstanding the thickness which the flow must have attained, nowhere exhibits more than incipient crystallization. Globulites, trichites, feldspathic microspherulites, and an indeterminate ferritic dust which renders the groundmass semiopaque and gives the pink tint to the rock are common. In some specimens the groundmass shows the minutely divided and shadowy double refraction characteristic of the devitrification of siliceous glasses into obscure aggregates of quartz and feldspar; but distinct well-formed crystals of younger growth than the evidently intratelluric phenocrysts do not occur. The rock is a vitrophyric biotite dacite and belongs with the hyalodacites of Rosenbusch.[1]

A chemical analysis of a typical specimen of the biotite dacite collected a quarter of a mile north of the Old Dominion mine, in the Globe quadrangle, is given below:

Chemical analysis of dacite.[2]

[E. T. Allen, analyst.]

SiO_2	68.75
Al_2O_3	15.48
Fe_2O_3	2.50
FeO	.44
MgO	.56
CaO	2.23
Na_2O	3.89
K_2O	3.88
H_2O below 110° C.	.79
H_2O above 110° C.	.57
TiO_2	.50
ZrO_2	.03
CO_2	None.
P_2O_5	.06
SO_3	None.
Cl	.03
F	None.
S	None.
Cr_2O	None.
NiO	None.
MnO	.02
BaO	.08
SrO	None.
	99.82

In the norm quantitative system of classification and nomenclature the dacite is toscanose.

It has been noted on page 68 that there is at the bottom of the dacite flow a more glassy facies, with megascopic flow banding. This rock ranges in color from light gray to dark gray or black. In many specimens the banding is obviously due to the alternation of streaks of glistening black glass with those of more lithoidal material. Small included rock fragments, particularly of diabase, are perhaps more numerous in this facies than in the more common pink dacite described in the preceding pages. The phenocrysts recognizable by the unaided eye are of the same kind as those of the pink rock.

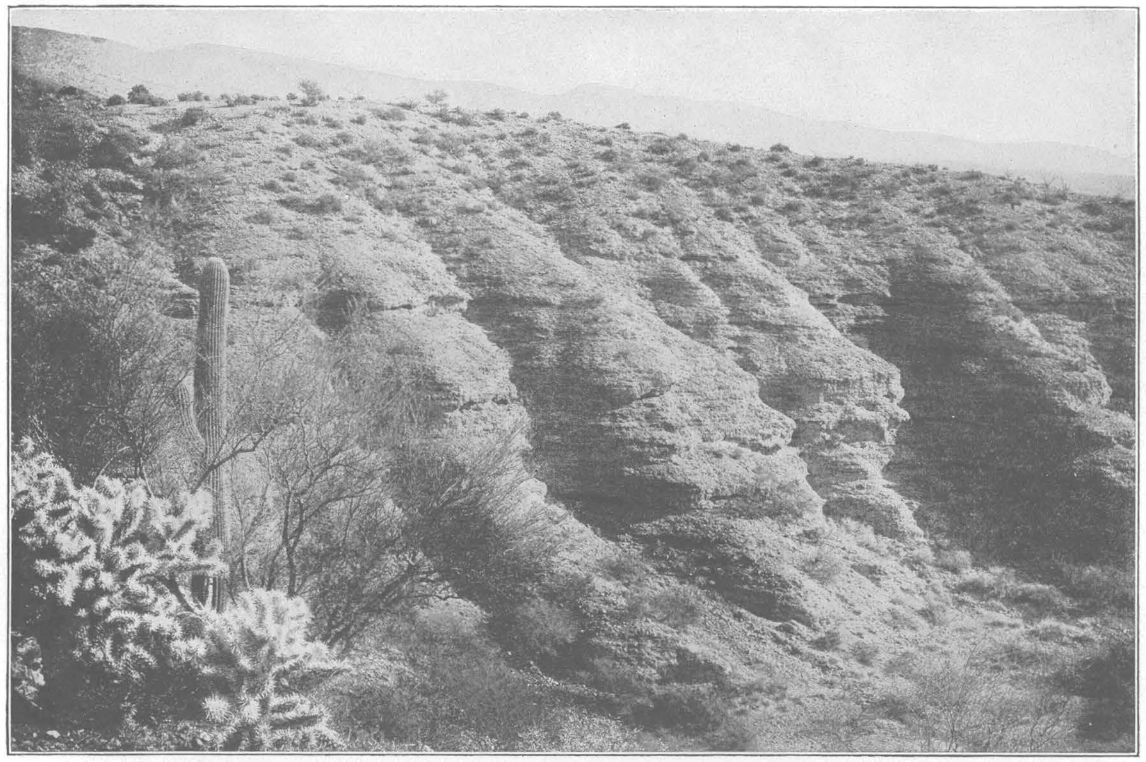
Under the microscope this glassy dacite is seen to differ from the pink facies chiefly in the groundmass, which, being less crowded with incipient crystal growths, is more transparent and is, as a rule, a pale-brown, slightly globulitic or trichitic glass. Microscopic flow structure is developed in great perfection and beauty, and the rock is typically vitrophyric. The phenocrysts are the same as in the more lithoidal dacite, but green hornblende occurs a little more abundantly in the thin sections examined and is in a few sections nearly as abundant as the biotite. The other accessory minerals are zircon, apatite, titanite, and iron oxide, as in the common lithoidal dacite.

Here and there a yet more glassy facies is associated with the dark vitrophyre just described. This is a gray brittle volcanic glass of greasy luster in which can be seen small phenocrysts of fresh feldspar, quartz, and biotite. Under the microscope the rock appears as a colorless perlitic glass containing scattered phenocrysts of plagioclase, orthoclase, quartz, and biotite and minute microlites of feldspar.

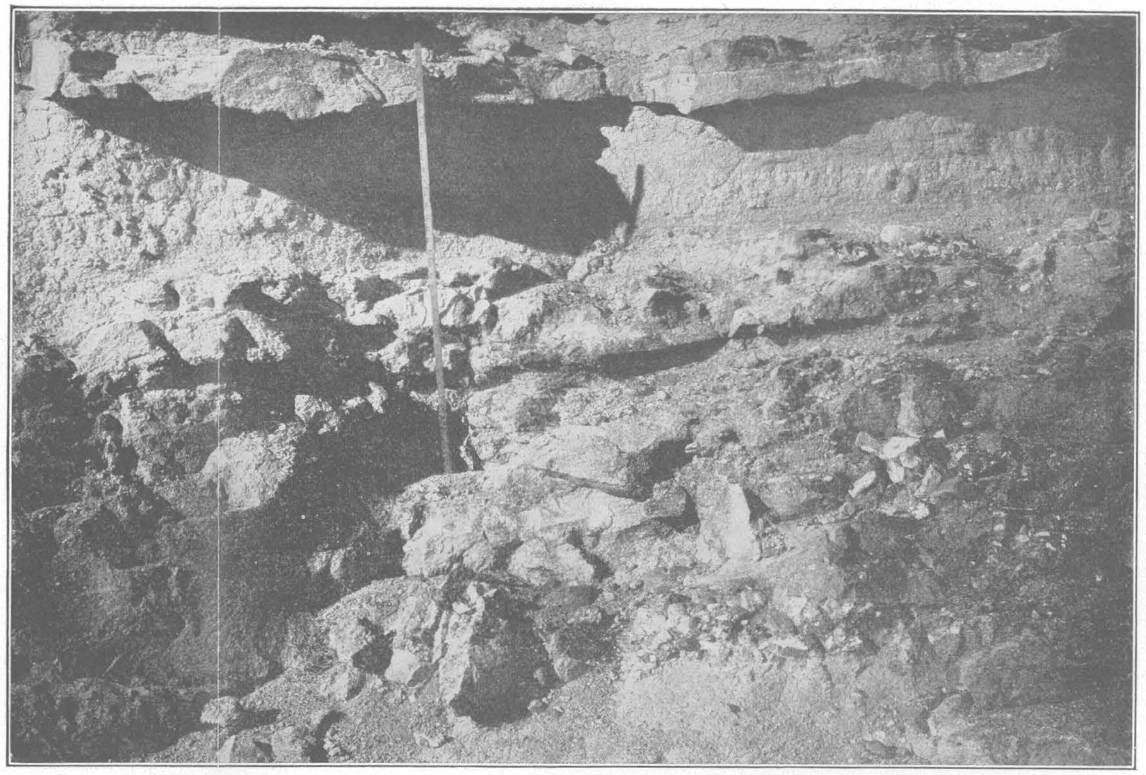
Some of the tuff that occurs locally at the base of the massive dacite is exceedingly troublesome to separate in the field from the overlying massive dacite. It is particularly difficult to separate the white or slightly pinkish tuff that immediately underlies the gray vitrophyric dacite. This is a firm rock that shows small crystals or fragments of feldspar, quartz, and biotite in an abundant, uniformly fine-grained base. It might easily be taken for a massive lithoidal rhyolite. Under the microscope fractured or corroded crystals of plagioclase, biotite, hornblende, and quartz are seen to lie thinly scattered in a dusty-gray glassy groundmass that somewhat indistinctly reveals the reentrant curves and sharp points of minute glass sherds—the characteristic structure of glassy volcanic ash. In parts of the Globe

[1] Mikroskopische Physiographie der massige Gesteine, 3d ed., pp. 344-848, 1896.

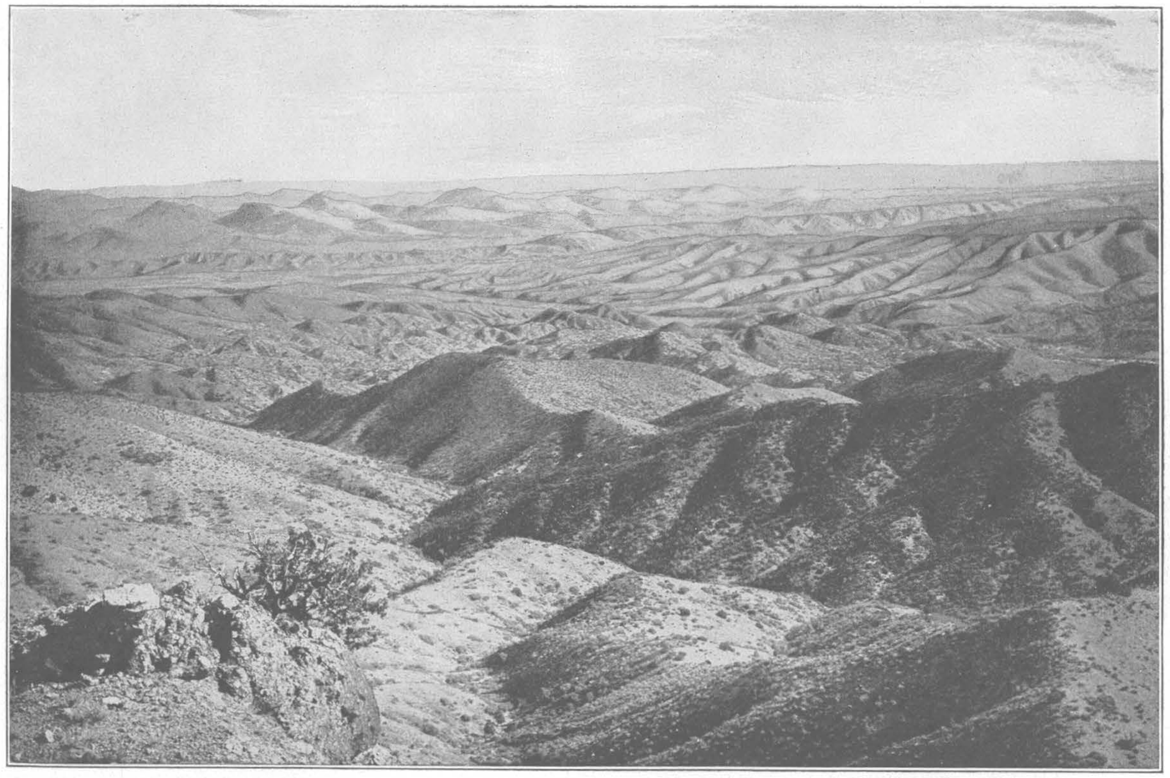
[2] U. S. Geol. Survey Prof. Paper 12, p. 92, 1903.



A. A TYPICAL NATURAL EXPOSURE OF THE GILA CONGLOMERATE SHOWING CHARACTERISTIC EROSION, 2½ MILES EAST-SOUTHEAST OF DRIPPING SPRING RANCH.



B. NEARER VIEW IN THE SAME GENERAL LOCALITY AS A, SHOWING CONSTITUTION OF A PARTLY SANDY VARIETY.



C, D. VIEW SOUTHEAST FROM THE TOP OF NEEDLE MOUNTAIN.

On the right are the granitic lower slopes of the Pinal Range, near the Schultze ranch, overlapped in part by the long, intricately dissected spurs of Gila conglomerate. The town of Miami, situated near the center of the view shown in C, was not in existence when the photograph was taken.

quadrangle this tuff has undergone some decomposition. With nicols crossed it is seen that very little true glass remains, the groundmass having been changed into a very minute aggregate of indefinite and shadowy crystal forms. Calcite, which is unknown in the massive dacite, is here abundant, not only throughout the devitrified glassy base but as an alteration product of the plagioclase. In this alteration there is none of the general clouding and breaking down of the feldspar, as is often seen in weathered rocks, but the calcite is separated by a sharp boundary from the perfectly clear and fresh plagioclase at the expense of which it is forming.

In the Globe quadrangle also some tuffs occur below that just described. These as a rule are plainly clastic rocks of light-gray or pale-yellow tints, varying in lithologic character from point to point. The microscope shows them to be glassy volcanic ashes, containing fragments of the same minerals that occur as phenocrysts in the dacite, with scattered particles of diabase or other foreign rock, inclosed in a devitrified glassy base. In most places they contain abundant calcite.

AGE.

There are no available data for fixing the exact date of the dacitic eruption. It is known to have occurred after the irruption of the granitic, monzonitic, and dioritic rocks of the region. On the other hand, it clearly preceded the deposition of the Gila conglomerate and the development of the present topography. The dacite is therefore considered as probably of Tertiary age.

GILA CONGLOMERATE.

The Gila conglomerate as it occurs in the Globe quadrangle has been fully described in publications on that area.[1] Geologically it is a deposit of exceptional interest, but in the present report, where the aim is to supply in this portion simply a geologic setting for the description of the copper deposits, the formation will be rather briefly treated. A more detailed account, with fuller discussion of the significance of the deposit, is planned for the forthcoming Ray folio.

[1] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, pp. 47-57, 1903; U. S. Geol. Survey Geol. Atlas, Globe folio (No. 111), pp. 5-6, 1904.

The Gila is essentially a fluviolacustrine deposit consisting of coarse, imperfectly rounded or angular rock detritus near the mountains but grading into gypsiferous silts in the central portions of the larger valleys.

The general character of the Gila formation as it occurs within the Globe quadrangle is that of a firm but not hard conglomerate, the material of which ranges in coarseness from boulders or angular masses 8 or 10 feet in diameter to fine sand. As a rule it is roughly stratified, but individual beds show little persistence, layers of conglomerate passing into sand or vice versa. Some of the pebbles are well rounded and probably were derived for the most part from one of the Paleozoic conglomerates, but most of them are subangular or angular, and the formation might in places be termed a sedimentary breccia. Lawson [2] has called such material fanglomerate. Although the Gila conglomerate has in places been subjected to considerable deformation and erosion, it is obviously in the main a deposit laid down in the existing valleys and extends in characteristic long dissected slopes up the flanks of the ranges from which its materials were derived. A typical slope of this kind is that on the northeast versant of the Pinal Range, south of Miami, shown in Plate XXII, *C–D*.

The Gila conglomerate is well exposed underground on the 420-foot and deeper levels of the Miami mine near the No. 4 shaft. Here it consists almost exclusively of fragments of Schultze granite and Pinal schist with varying proportional of sandy matrix. The fragments, which reach 6 feet in diameter, are subangular, and the material as a whole is poorly assorted, large boulders in many places lying next to layers of cross-bedded silt. The bedding, except in the sand layers, is indistinct, although the large schist fragments are generally slabby and lie roughly parallel.

In the Ray quadrangle the Gila conglomerate is well developed and plays a more conspicuous part in the landscape than in the Globe quadrangle. Dissected slopes of the conglomerate in Dripping Spring Valley are shown in Plate IV, and nearer views of the material in Plate XXII, *A* and *B*. In the middle part of this

[2] Lawson, A. C., Fanglomerate, a detrital rock at Battle Mountain, Nev. (abstract): Geol. Soc. America Bull., vol. 23, p. 74, 1912; also, The petrographic designation of alluvial-fan formations: California Univ. Dept. Geology Bull., vol. 7, pp. 325-334, 1913.

valley coarse material is in places overlain by brown silts and sandy clays, in part pebble bearing and containing at least one bed of impure diatomaceous earth. These silty beds grade both downward and laterally into the usual coarse angular detritus. They evidently record the former existence of a lake in which the finer materials brought down by torrential streams from the neighboring mountain sides settled quietly to the bottom. Evidence of contemporaneous stream channeling is clearly shown in some exposures of the conglomerate, as may be seen in Plate XXIII. It is not always easy to distinguish such contemporaneous stream cutting from later channeling and filling accomplished by streams during the general dissection of the conglomerate.

South of Ray, along Mineral Creek, the Gila conglomerate is harder than in most other parts of the Ray quadrangle and has weathered into steep bluffs and picturesque rounded towers of which Big Dome (Pl. XXIV, *B*) is a good example. The character of this material is shown in Plates XXIII, *B*, and XXV. Overlying the dacite north of Ray is a coarse, irregularly bedded rubble of dacite, quartzite, and limestone fragments, above which lies about 200 feet of well-stratified tuffaceous beds composed mainly of glassy dacite detritus. This material was presumably washed from the upper part of the dacite flow beneath it. All the conglomerate in this part of the Ray quadrangle contains abundant dacite fragments, and in places, as near Government Spring or Mineral Creek, in the southwest corner of the Globe quadrangle, layers of glassy tuffaceous detritus are interbedded with the coarse conglomerate. The tuffaceous beds, considered by themselves, might be taken as indicative of a continuance of dacitic eruptions during the accumulation of the Gila conglomerate, but it is more accordant with the history of deformation in the region to conclude that those eruptions had ceased and that the particles of glassy dacite were eroded from the solidified lava and swept by streams into depressions where they accumulated, probably in part in short-lived lakes.

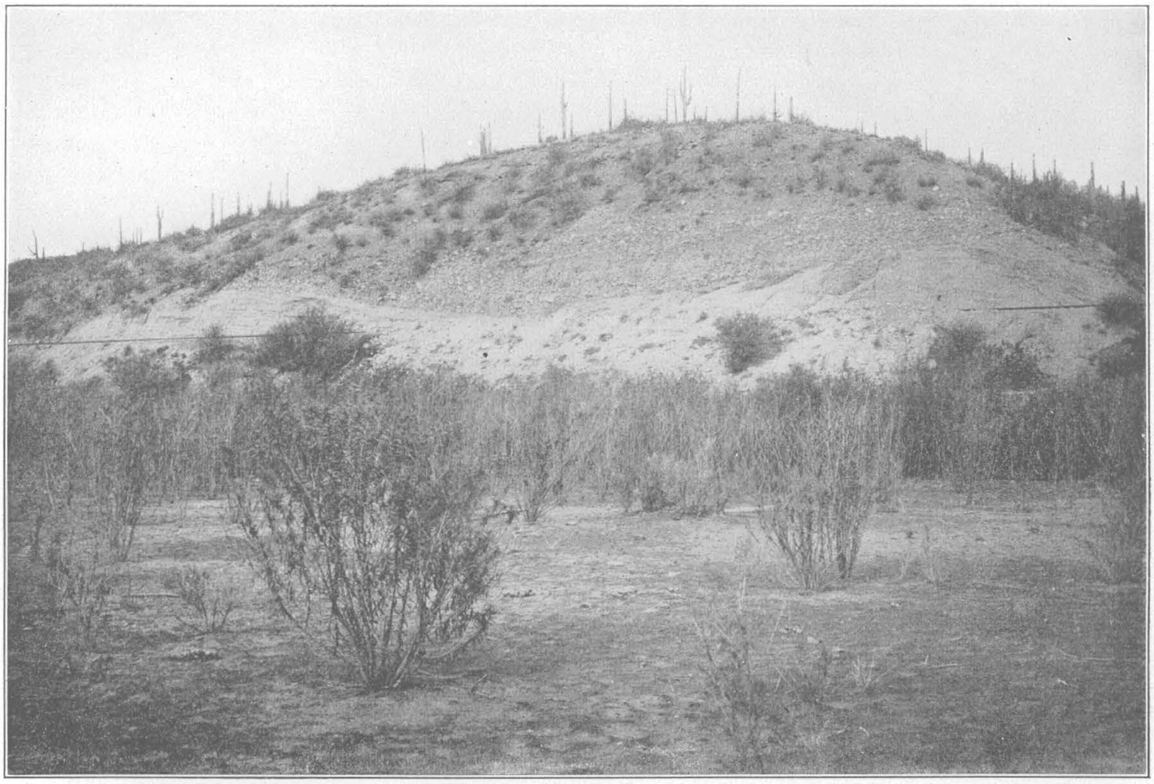
Some of the coarsest material noted in the Gila conglomerate is on the east fork of Mineral Creek, near the northern border of the Ray quadrangle. Here one partly rounded mass of granitic rock from the Pinal Range measured about 7 by 10 by 25 feet and was estimated to weigh 300 tons. As a rule, the higher the neighboring mountains and the more massive and resistant their rocks the larger the fragments in the Gila conglomerate.

In the southwestern part of the Ray quadrangle, southwest of Gila River, the Gila formation shows a greater thickness of distinctly bedded strata than in any other locality studied. The general dip is to the east-northeast at about 30°, but along the east side of the older rocks of the Tortilla Range the dip is in places fully 75°.

The beds are of varied composition. Probably the most abundant material is a brownish-gray conglomerate in rather thin beds in which the coarse constituents are angular fragments of andesite, andesitic porphyries, and limestone. Many of these fragments are 2 feet or more in diameter, and some of the masses were observed to lie partly in one bed and partly in another, as if they had been thrown independently into the accumulating material. The matrix of these blocks and imperfectly rounded boulders is a poorly washed brown-gray sand in which grains of minute size are mingled with larger particles and fragments of all sizes up to the blocks mentioned. The material of the sand is partly granitic and partly andesitic. The granitic material probably came from the west or south, and the andesitic material from the east or southeast.

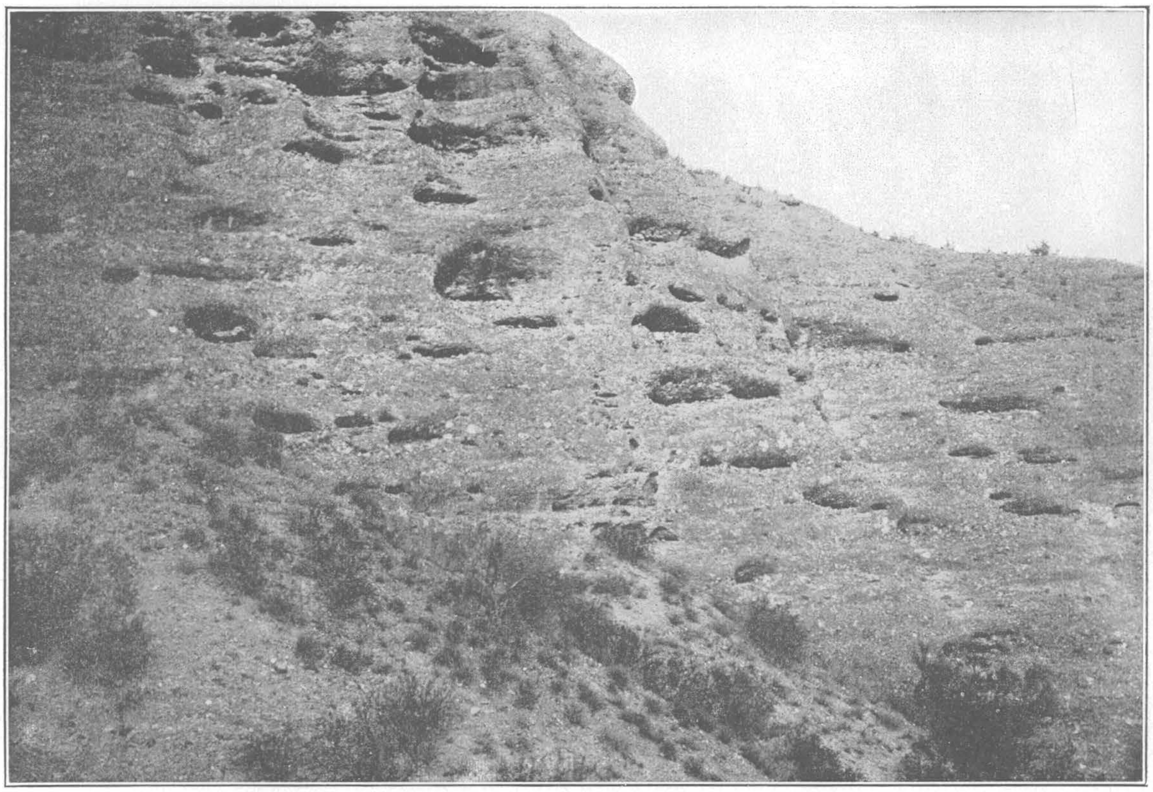
The variety of the conglomerate above described is not very different, so far as material is concerned, from that east of Gila River in the vicinity of Hayden. The conglomerate there also contains much andesitic material but is not so well bedded as that between Branaman station and Hackberry Spring.

Associated with the prevailing variety of sedimentary material between Branaman and Hackberry Spring were observed one bed, about 1 foot thick, of fine-grained creamy-white sandstone, and, a little higher in the series, another thin bed of light-gray tuff. The sandstone consists chiefly of sharply angular particles of quartz with a few minute flakes of brown biotite. The tuff under the microscope shows fragments of pyroxene, feldspars of various kinds, biotite, and bits of andesite or basalt, in a groundmass of partly devitrified glass sherds.



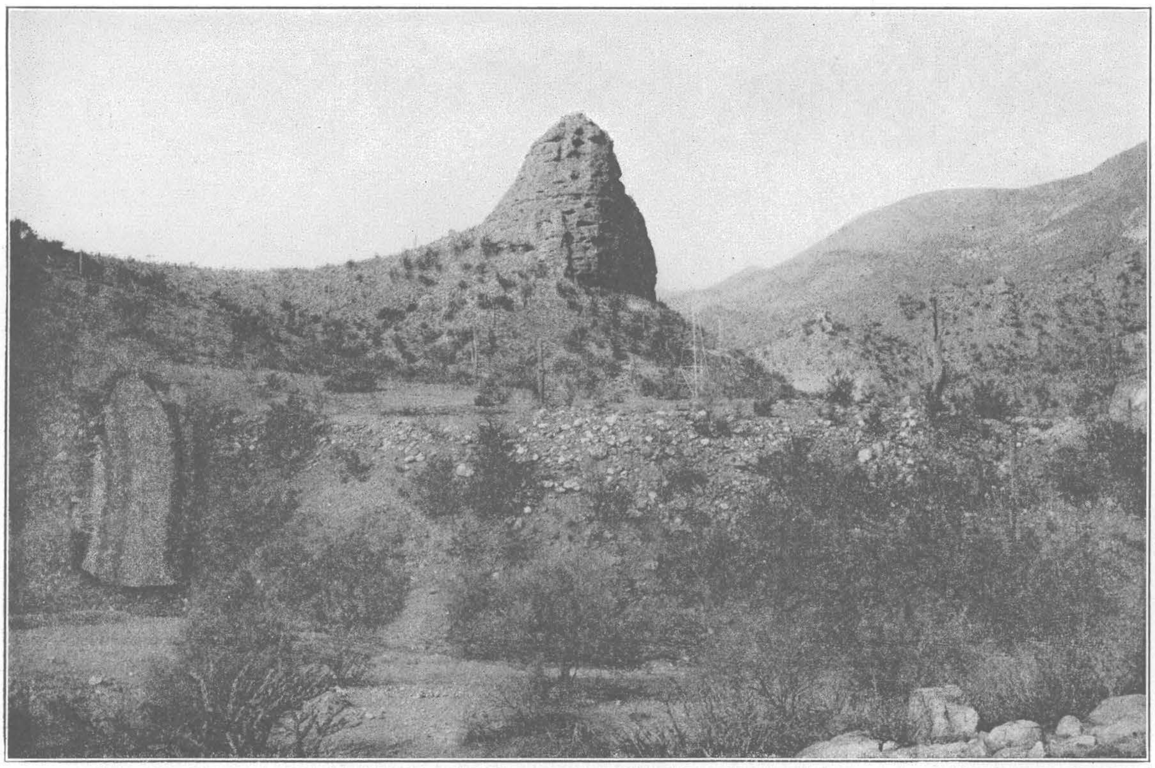
A. STREAM CHANNEL SCOURED IN SANDY FACIES OF GILA CONGLOMERATE AND FILLED WITH COARSER MATERIAL.

Between Erman and Branaman stations on the Arizona Eastern Railroad, Ray quadrangle.



B. CAVERNOUS WEATHERING IN HARD GILA CONGLOMERATE ON MINERAL CREEK, 3 MILES SOUTH OF RAY.

A. VIEW NORTH UP MINERAL CREEK ABOUT 3 MILES BELOW RAY, SHOWING BLUFFS AND DOMES OF GILA CONGLOMERATE.



B. NEARER VIEW OF BIG DOME, SEEN IN THE DISTANCE IN *A.*

A pinnacle of hard Gila conglomerate whose top is 447 feet above the stream at its base.

Near Hackberry Spring (see Pl. II) the Gila formation consists of well-bedded coarse sandstone, composed almost entirely of partly rounded granitic crumbs derived from the coarse pre-Cambrian granite of the Tortilla Range. Along the upper, north-south portion of Hackberry Wash the Gila is prevailingly reddish and sandy and occurs in beds for the most part about a foot thick. These beds consist largely of andesitic detritus and contain some fragments of andesite as much as 2 feet across. A view of these beds as exposed on the east side of Hackberry Wash is shown in Plate XXVI, *A*. Stratigraphically under them and lapping up against the Paleozoic rocks to the west (Pl. XXVI, *B*) is fully 100 feet of soft, crumbling brownish-gray sandstone and sandy shale. There is much faulting in this vicinity, and the silty material is probably faulted against the older rocks and is not the real base of the Gila formation. Where the basal part of the formation is exposed, as farther north along the east side of the Tortilla Range, it consists of coarse fragments of obviously local derivation. The brown sand and shale is made up principally of mineral particles derived from the granite of the range.

In the extreme southwest corner of the Ray quadrangle is a synclinal basin of Gila conglomerate surrounded for the most part by hills of pre-Cambrian granite. This basin is drained by the intermittent Ripsey Wash, near the mouth of which, about 3 miles west of Kelvin, the Gila formation may be seen resting on the granite. Here the formation consists of light pinkish-gray tuffaceous-looking beds carrying fragments of granite in a matrix composed largely of volcanic material, apparently dacitic. The beds vary much in thickness, ranging from shaly seams to strata measuring over 6 feet. Other facies appear farther south. Much of the material is a coarse breccia, the beds of which are thick and rather vaguely laminated. Blocks of granite 3 feet in greatest length are embedded in coarse granitic sand or in a matrix of granitic and dacitic débris. In places beds of soft sandstone or fine silt separate the coarser layers.

The beds southwest of Gila River are in part so different from the Gila conglomerate in other parts of the quadrangle and are as a whole so much better stratified that my inclination at first was to regard them as a distinctly older formation, probably having an unconformable relation to the Gila. No evidence of unconformity, however, could be detected, and the well-bedded material appears to grade upward and laterally into Gila conglomerate of the common variety. Evidently the basin in which deposition took place in the southwestern part of the Ray quadrangle was exceptionally deep, and rapidly accumulating coarse fluviatile material graded at times into finer sediments laid down in comparatively still water.

The deformation of these beds is considered under "Structure" (pp. 75–80).

The accumulation of the Gila conglomerate is clearly indicative of intensely active erosion consequent upon the period of vigorous deformation that outlined the present mountains and valleys of the region. As a result of the block faulting and earth movements that followed the eruption of the dacite, the mountain ranges were much higher than at present and the larger or structural valleys much deeper. Consequently the stream grades were steep and the erosive and transporting powers of the running water were far greater than they are now in the same region. Possibly the greater height of the mountains was accompanied by greater precipitation than at present, but the general character of the deposit points to a decided preponderance of mechanical disintegration over rock decay and to an arid rather than a humid climate.

The same indication is afforded by the occurrence of gypsum associated with the silty facies of the Gila formation on Salt River north of the area here specially considered. To one familiar with the intensive work occasionally accomplished in a few hours by the fierce rush of local storm water along one of the present streamways there appears to be little necessity to require any great increase in precipitation to account for the deposition of the Gila conglomerate under the conditions of waste supply and grade then prevailing. Some increase there may have been, but not enough to make the conditions of plant growth, rock disintegration, erosion, transportation, and deposition very different in kind from those of to-day.

The thickness of the Gila formation varies greatly from place to place, and probably no measurement gives the true maximum. Between Hackberry Spring and Gila River near

Branaman station a simple computation, based on the average dip of 30° to 35° and the width of outcrop, gives a thickness of 7,500 to 8,500 feet, say, 8,000 feet. This is on the supposition that the beds near the base of the section continue northeastward under the beds exposed near the river and that there has been no duplication by faulting or folding. It is quite possible that some of the lower beds are of slight areal extent, but any considerable duplication could hardly have escaped notice. The foregoing estimate does not take account of the 3½-mile belt of Gila conglomerate between Branaman station and the Dripping Spring Range to the northeast. Near the river there is certainly several hundred feet of this conglomerate that is stratigraphically higher than the beds southwest of the river. The total thickness of these upper deposits and the extent to which they are underlain by the more regularly bedded material exposed southwest of them could be determined only by boring.

In 1910 some borings were made near Hayden with a view to obtaining a water supply for the reduction works then building. Drill hole No. 1 started at an elevation of 1,950 feet above sea level on the flood plain of the Gila, went through 80 feet of sand and gravel and then through 770 feet of Gila conglomerate, in which it was abandoned. Drill hole No. 2, which was started at an elevation of 2,097 feet in the gulch near the power house, penetrated 920 feet into the conglomerate and was abandoned in that formation. No. 4 shaft of the Miami mine is 710 feet deep, all in Gila conglomerate.

In 1915 a churn-drill hole 20 inches in diameter was begun by the Miami Copper Co. about 1,600 feet east-southeast of No. 4 shaft. It was intended to drill through the conglomerate in order to explore the underlying schist, which was estimated to lie at a depth of about 2,300 feet. The hole attained a depth of 2,050 feet, all in conglomerate, and then had to be abandoned, in October, 1916. The conglomerate apparently is of the same general character from top to bottom of the hole. Probably the drill would have penetrated dacite before reaching the schist.

About a mile southeast of the A shaft of the Old Dominion mine a drill hole in 1915 went through 1,000 feet of Gila conglomerate, which was ascertained at this place to be underlain by quartz diorite (Madera diorite), possibly overthrust material. (See p. 77.)

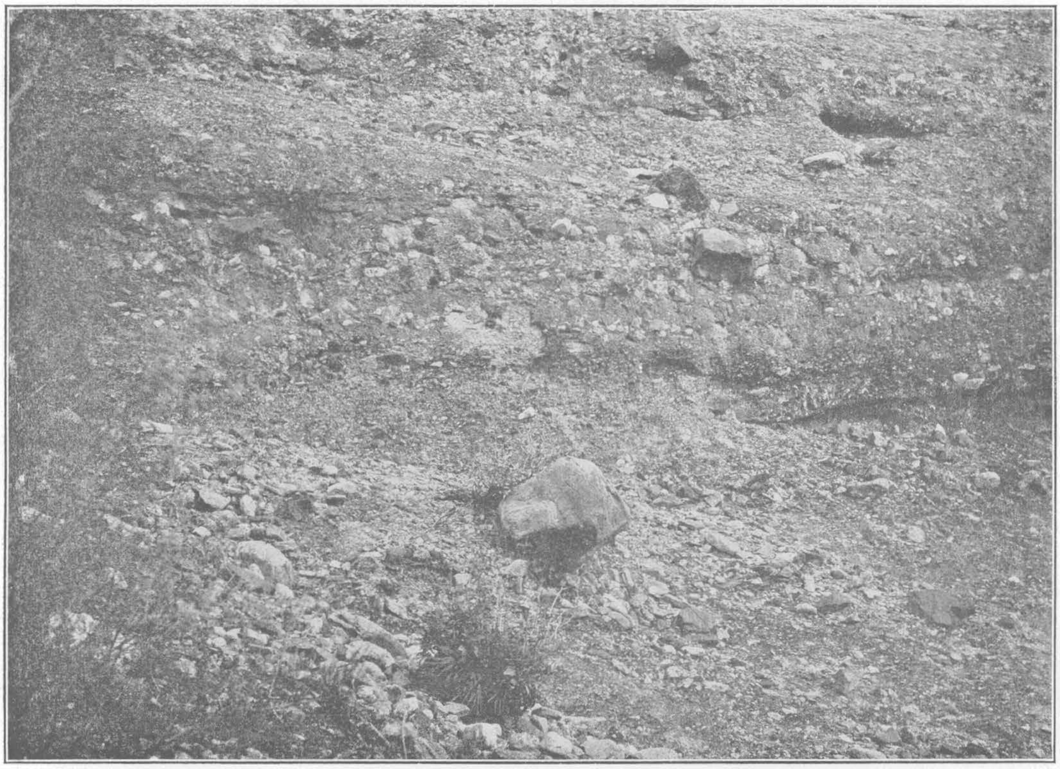
No identifiable fossil remains were found in the Gila conglomerate of the Globe-Ray area in the course of the investigations upon which this report is based. A few small crumbling particles of bone, however, noted near the head of Dripping Spring Valley, show that the deposit is not wholly devoid of animal remains. The formation has generally been regarded as probably of early Quaternary age. The present investigation has brought out no evidence requiring a revision of this supposition, unless the great thickness and deformation of the beds southwest of Gila River are considered as incompatible with assignment to the youngest of the geologic periods. In 1906 Dr. T. Shields Collins, of Globe, forwarded to the Survey a fossil bone said to have come from the Gila conglomerate near that town. J. W. Gidley, of the National Museum, to whom it was referred for determination, reported that it is the distal half of the right humerus of an extinct species of horse, probably *Equus complicatus*, and is indicative of Pleistocene age.

BASALT.

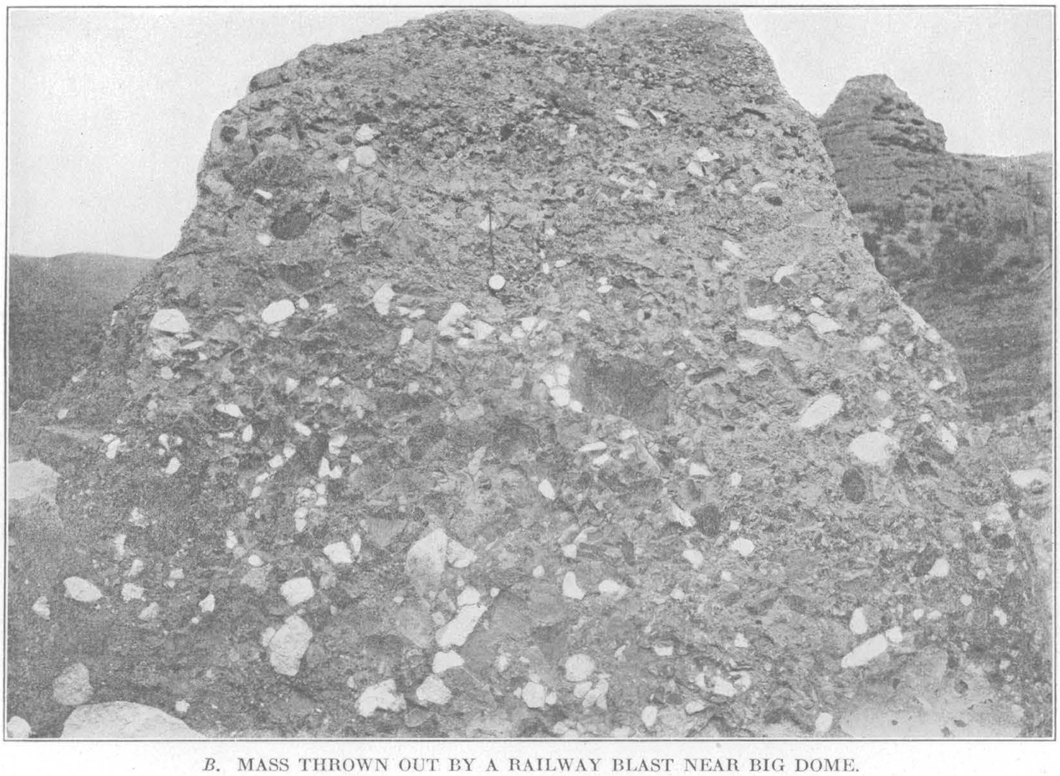
During the deposition of the Gila conglomerate there were minor outpourings of basalt. The largest body of this rock, a flow from 50 to 150 feet thick, in an area of conglomerate about 5 miles west of Miami, near the western border of the Globe quadrangle, has been fully described in the Globe folio.

RECENT DEPOSITS.

Detrital accumulations younger than the Gila formation and probably referable to the later part of Quaternary time include certain sheets of unconsolidated or only partly consolidated rock waste that have been considerably dissected by the present intermittent streams and now form sloping terraces or low flat-topped ridges. These are particularly well developed in the neighborhood of Ray and are well shown on the geologic map of Ray and vicinity (Pl. XLV). Some rather small remnants of these terraces are shown in Plate XXVII, *A*. More extensive ones may be seen north of Sharkey Gulch, west of Mineral Creek. The material forming the tops of these terraces has been derived from the adjacent hill slopes and merges with the

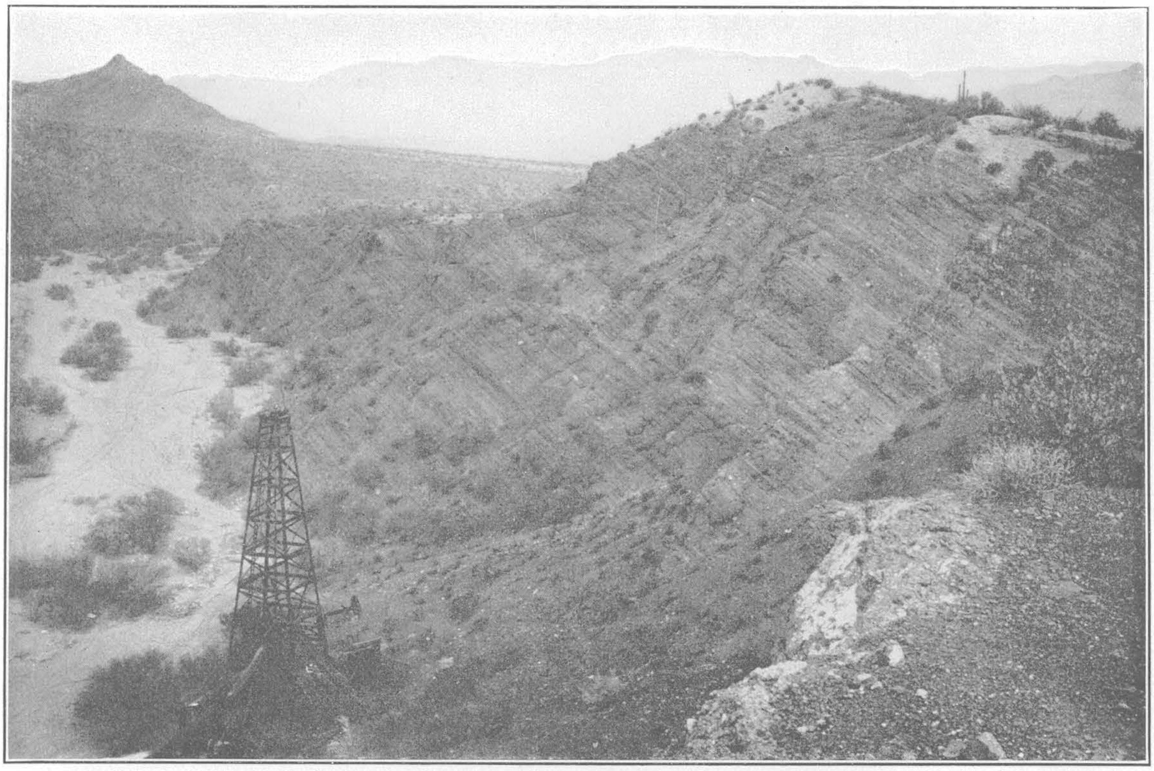


A. NATURAL EXPOSURE OF THE GILA CONGLOMERATE FORMING BIG DOME.



B. MASS THROWN OUT BY A RAILWAY BLAST NEAR BIG DOME.

Boulders or fragments are quartzite, granite, quartz diorite, limestone, dacite, and diabase.



A. UNUSUALLY WELL STRATIFIED AND STEEPLY TILTED MATERIAL PROVISIONALLY INCLUDED WITH THE GILA CONGLOMERATE.

Exposure is near Hackberry Spring, in the southwestern part of the Ray quadrangle. The direction of view is nearly north. The derrick records an attempt to find oil under these beds.

B. MOUTH OF GORGE BELOW HACKBERRY SPRING, LOOKING SOUTHWEST.

The camera was placed on the bluff shown in *A*. The gorge is cut in steeply upturned Paleozoic beds and diabase; the entrance is in Tornado limestone. At the right, just across the gravelly stream bed, and probably faulted down against the limestone, is some of the fine silty material described on page 73 as underlying the beds shown in *A*. It is this silt that appears to have been regarded as possibly oil bearing.

ordinary stony detritus of those slopes. It represents a series of low-angle confluent alluvial fans formed during a halt in the dissection of the Gila conglomerate. Terraces along Mineral Creek south of Ray (see Pl. XXVII, *B*), on one of which the village of Kelvin is situated, and similar benches and mesas in the Gila conglomerate areas of the Gila and Dripping Spring valleys mark the same and perhaps other steps in the development of the present topography. As these terraces originally had wide ranges of slope and altitude, their close correlation by reference to sea level is impossible.

Lower and younger than the terraces are the flood-plain deposits of the Gila and its principal tributaries. Along the river there are considerable areas of excellent agricultural land, but the tenure of this is uncertain, menace from flood being always imminent. Inundations such as have deposited the silt are no respecters of human occupancy and may destroy in a few hours the labor of years. Near Hayden large areas of ranch land have been utilized by the Ray Consolidated Copper Co. as a dumping ground for mill tailings.

In connection with recent deposits mention may be made of local conglomerates cemented by copper silicate and carbonates that occur along some of the streamways where they pass through areas of copper-bearing rocks. These occur at various elevations up to 50 feet or perhaps more above the present arroyo bottoms. They are stream gravels cemented by the action of cupriferous water that seeps slowly from the adjacent rock, and the process has probably continued up to the present time. These copper-bearing conglomerates may be seen in Copper Canyon, and with the vivid stains on the cliffs probably suggested the name of that ravine.

STRUCTURE.

GENERAL FEATURES.

Some mountains, such as the Appalachians, stand in relief because the neighboring valleys, with which they are in contrast, have been carved by erosion below a surface once broadly coincident with the present ridge crests. Others, such as those in southwestern Idaho and southeastern Oregon, which Russell[1] has described, owe their prominence to direct uplift relative to the valley floors, and their forms have been modified only very slightly by running water. Still others, like Mount Shasta in California, are mountains of volcanic accumulation, piled above an older surface. In actuality few if any mountains belong exclusively to one of the three ideal types. Most exhibit some erosional modification, and as regards many of them it is difficult or impossible to decide whether deformation or erosion has had the larger share in their development.

As shown in the general description of its topography, the Ray-Miami region is characterized by ranges trending nearly northwest, separated by detritus-laden valleys. This larger differentiation of the surface into ridges and troughs or mountains and valleys is a direct result of earth movements. The ranges are essentially tectonic features. Erosion, however, has profoundly modified their primitive form, and all those details that attract the eye and are retained by the mind as pictures of the highland landscape are the work chiefly of streams, for the most part intermittent in their activity. So far as concerns the main valleys erosion has been merely incidental to the extensive accumulation of rock waste washed from the neighboring mountain slopes or has been limited to the dissection of the material thus laid down. The depressions as a whole represent actual deformation of the lithosphere, not a mere carving of its surface.

In a final analysis deformation of rocks under stress takes place by fracture or flowage, or by some combination of the two processes. In a broader structural sense and without present consideration of that kind of flowage which is associated with the development of schistosity or with general recrystallization, rocks may be deformed by folding or by faulting. In most regions both of these kinds of major deformation are exemplified and the character of the resultant structure depends upon the relative share of each. In the Ray-Miami region folding has played practically no part in the development of post-Cambrian structure. Faults, on the other hand, are extraordinarily numerous, and the characteristic structural unit is the tilted fault block. Such folding as has been observed in this region is apparent chiefly in the limestones and nowhere indicates strong compression, the resulting dips rarely exceeding 25°. It is exemplified gen-

[1] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: U. S. Geol. Survey Bull. 217, pp. 13-17, 1903.

erally by a slight sagging or arching of the strata in some fault block. Where the Gila flows across the Tornado limestone in the southeast corner of the Ray quadrangle the beds form a gently arching anticline with northwesterly axis, exposed for a width of 1¼ miles along the river. The dip is nearly horizontal on the southwest flank, where the limestone passes beneath the Gila conglomerate, and about 30° on the northeast flank, where cut by the river section. Many gentle minor folds are associated with the main anticline.

Although faulting has been the dominant mode of deformation in the region, the mountains, as will presently be shown, are not merely uptilted blocks of the simple Great Basin range type, nor is the evidence for their tectonic origin of the obvious ocular sort that is immediately convincing. Before it is considered the character of the faults in general will be briefly described and the structure of each range will be sketched in outline.

FAULTS.

Nomenclature of faults.—As there has been wide diversity in the use of terms used in descriptions of faulting, clearness can be attained only by an initial explanation of the nomenclature to be followed in this report. All terms relating to faulting will be here used as recommended or defined by the committee on the nomenclature of faults of the Geological Society of America.[1] The application of some of the more important of these terms is illustrated in figure 3.

Evidence of faulting.—In many regions the presence of faults is inferred as the most reasonable way of explaining certain observed structural relations. In the Ray–Miami region the evidence as a rule is of a more direct character. The very topography of the Dripping Spring Range, for example, as stated on page 28, is indicative of intricate faulting. A distant view of the range suggests neither the simplicity of a single homoclinal block[2] nor the linear elements of form that we have learned to associate with mountains of folded strata. A view from any high point over parts of this range or over much of the Globe quadrangle is equally suggestive of dislocation. The Globe report[3] contains the following paragraph:

> If one will stand upon the top of Webster Mountain and look northward or eastward over the confusedly hilly country spread out before him, he will be struck with the apparently chaotic distribution of the various rocks, as indicated by their respective and characteristic tints in the landscape. Here and there patches of limestone gleam white through the thin screen of scanty vegetation, while areas of quartzite are indicated by a reddish color, and masses of diabase by a dull olive tint. The beds show no trace of folding, and the eye seeks in vain for any persistent or regular structure that may account for this rocky patchwork. * * * In traversing this faulted region one steps with bewildering frequency from quartzite to limestone, granite, or diabase, the line of separation being often clearly defined by a fault breccia, forming a bold outcrop that may be followed over the country for miles. Probably few equal areas of the earth's surface have been so thoroughly dislocated by an irregular network of normal faults and at the same time exhibit so clearly the details of the fracturing.

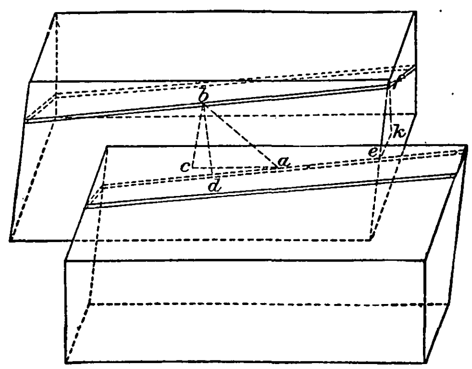


FIGURE 3.—Diagram illustrating terms used in describing faults. The upper and lower surfaces of the block are horizontal; the end faces are vertical and at right angles to the fault strike. *a*, *b*, *c*, and *d* lie in the fault plane; *e*, *f*, and *k* in the end face. Let the point originally adjacent to *a* move to *b*; then *ab*=slip or net slip; *cb*=dip slip; *ac*=strike slip; *bd*=perpendicular slip; *ad*=trace slip; *fk*=throw; *ek*=heave.

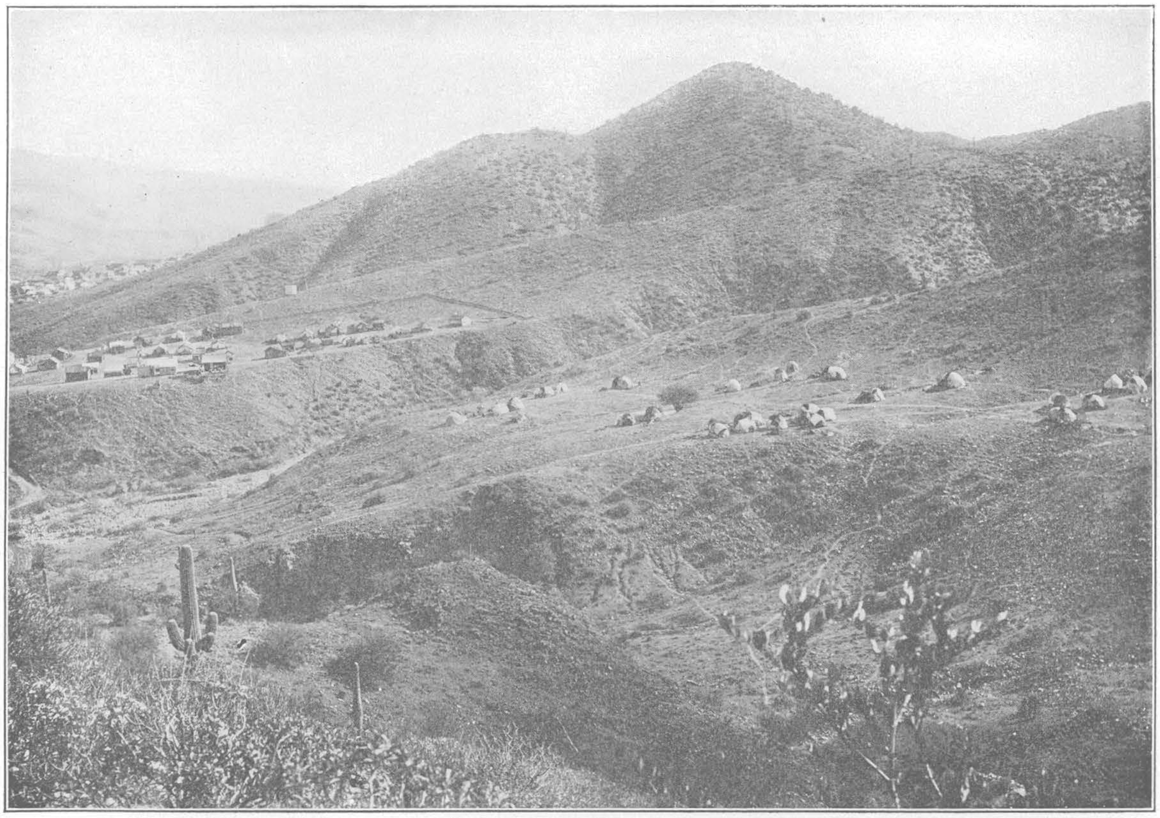
When the foregoing was written the Dripping Spring Range in the Ray quadrangle had not been geologically mapped and studied. It displays perhaps still better than any equally large area in the Globe quadrangle the fine-textured fault mosaic characteristic of the region.

Indurated, boldly outcropping fault breccias mark the courses of many faults, particularly those that traverse quartzite or have quartzite in one wall. This brittle but weather-resisting rock is the great breccia maker. Even those faults that, at the surface, pass through other rocks than quartzite, may have quartzitic

[1] Geol. Soc. America Bull., vol. 24, pp. 163–186, 1913.

[2] A homocline is a block of bedded rocks all dipping in the same direction. See Daly, R. A., A geological reconnaissance between Golden and Kamloops, B. C., along the Canadian Pacific Railway: Canada Geol. Survey Mem. 68, p. 53, 1915.

[3] U. S. Geol. Survey Prof. Paper 12, pp. 97–98, 1903.



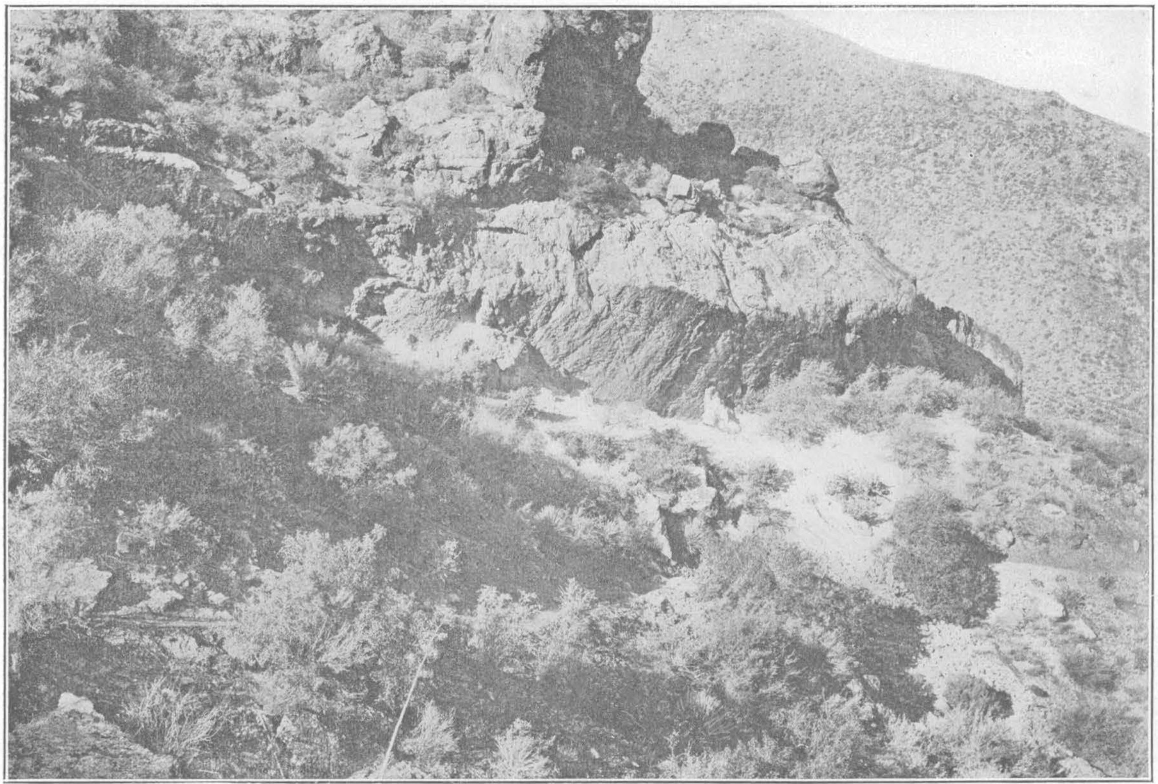
A. REMNANTS OF AN ALLUVIAL TERRACE ON THE SOUTH SIDE OF COPPER CANYON, NEAR RAY.

The town in the distance is Sonora, the Mexican settlement of the district. Barcelona, the Spanish settlement, and Vitoria, a temporary Apache camp, are shown on the terrace.

B. VIEW SOUTH, DOWN MINERAL CREEK, FROM A POINT ABOUT 3 MILES SOUTH OF RAY.

Shows dissected cut terrace in Gila conglomerate west of the creek. The sharp peak on the right sky line is in the Tortilla Range. Nearly under it, on a terrace between Mineral Creek and the Gila, is the village of Kelvin, once the headquarters of the Ray Copper Mines, Ltd. but now a place of small importance. The railroad built by the present company appears on the east bank of the creek.

QUATERNARY TERRACES.



A. FAULT IN DRIPPING SPRING RANGE, 2 MILES SOUTHEAST OF DRIPPING SPRING RANCH.

The fault plane dips west, away from the observer. The rock on the hanging-wall side is Troy quartzite; on the footwall side, diabase. The diabase has crumbled away, leaving the quartzite as an overhanging scarp on which may be seen the striations produced by movement along the fault.

B. FAULT ON WEST SIDE OF MINERAL CREEK, HALF A MILE SOUTH OF RAY.

The observer is looking south, nearly along the fault. The rock of the footwall, just above the old wagon wheels, is Dripping Spring quartzite. The rock of the hanging wall, on which bushes are growing, is Pinal schist. The schist rests on the younger quartzite, and the fault is of the reverse type.

breccias, the fragments having been derived from some place along the break where the fissure passes through or beside that rock. A number of illustrations of fault breccias were published in the Globe report. Additional views of fault outcrops in the Ray quadrangle are given in Plate XXVIII.

Distribution.—The faults are not evenly distributed over the region here described. They are particularly numerous in the northern part of the Globe quadrangle and in the Dripping Spring Range but are comparatively rare or at least inconspicuous in the main mass of the Pinal Range and in the Mescal Range. These differences will be more fully brought out in describing the structure of each range.

Directions of faulting.—The geologist after mapping the faults in a region studies their directions and tries to determine whether they can be classified into groups, each group characterized by a certain trend or strike. By this means he hopes to get some clue to the relative

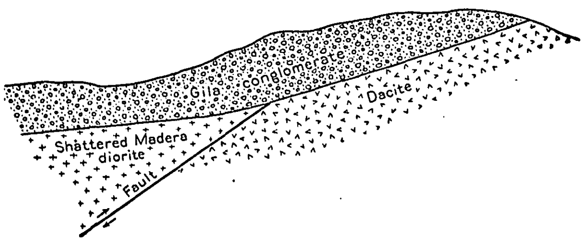


FIGURE 4.—Diagram illustrating thrust of Madera diorite (pre-Cambrian) over dacite (Tertiary) near the Old Dominion mine.

ages of the faults and to the character of the stresses that produced them. Without regard to any possible major fault that may be concealed by the Gila conglomerate, there apparently is no significant preponderance of faults having one direction of trend over those running in other directions. Here and there in the Ray-Miami region some of the principal faults are nearly parallel, but the direction of parallelism at one locality differs from that in another. For example, in the vicinity of Tornado and Tam o' Shanter peaks, in the Dripping Spring Range, the more persistent faults strike about N. 12° W., but at the north end of the same range the locally prominent fissures strike nearly N. 35° E.

Apparently no general and significant grouping of the faults in the Ray-Miami region on the basis of common trends is possible. It follows that if the faults are of distinctly different ages, discrimination must be based on other criteria than that of difference in strike.

Dip.—Of the many faults that have been mapped in the course of the detailed geologic work on the Globe and Ray quadrangles, comparatively few are so exposed as to permit a measurement of the dip of the fault fissure. As a rule the dips are high, mostly over 45°, and probably averaging about 70°.

Kind of movement.—The result of the movement has generally been what is termed a normal fault. To what extent the slipping has been up or down the dip (dip slip) or horizontal (strike slip) is rarely determinable.

In a few places the displacement is of the reverse or overthrust type. One such fault near the Old Dominion mine, near Globe, has been described in another paper.[1] Here a mass of shattered Madera diorite (pre-Cambrian) has been thrust from the southwest over dacite (Tertiary) up a plane of 37°. Only the thin edge of the upthrust block is now in part exposed, the greater part of the mass being buried under the Gila conglomerate, which was deposited after the faulting. The general relations are shown diagrammatically in section in figure 4.

Another reverse fault is recognizable on the west bank of Mineral Creek, about a mile below the town of Ray. The relations here are shown in Plate XXVIII, *B*; the Pinal schist on the right or west has been thrust up over the smooth footwall of Dripping Spring quartzite on the left or east. The dip of this footwall is about 45° W. The throw must be at least 150 feet, for the Pioneer shale has been cut out.

In Elder Gulch, 3 miles northeast of Kelvin, the Tornado limestone rests on pre-Cambrian granite, and the contact dips west at 15° or less. The limestone is disturbed and fissured. Although the younger rock here rests upon the older, it does not appear probable that normal slipping could take place on so low a slope, and the dislocation is supposedly due to thrusting. On the northwest the fault ends against an intrusive mass of quartz diorite, and about a third of a mile away on the southeast it ends against another fault that is apparently of normal type, with downthrow to the east.

Running north from the east side of Tam o' Shanter Peak in the Dripping Spring Range is the outcrop of a fault that appears to record

[1] Ransome, F. L., Geology at Globe, Ariz.: Min. and Sci. Press, Feb. 12, 1910, p. 257.

a thrust of the rocks west of it toward the north and east. The dip of the fault ranges along the strike from 20° to 45°. North of the peak the effect of the fault has been to cause the Troy quartzite to override the Dripping Spring quartzite, the diabase, and perhaps also the Mescal limestone, which does not appear at the surface. The front of the overthrust mass as seen from Dripping Spring Valley forms a rough scarplike outcrop, shown near at hand in Plate XXIX, *A*. A notable feature of this scarp is the unusual quantity of quartzite débris, much of it in huge blocks, that litters the slope in front of it. Evidently this material is residual and has been left by the erosional retreat of the edge of a flat-lying overthrust mass. The material is too abundant to have been derived from the upthrown side of a steep fault scarp. Close inspection of the cliff shows that the Troy quartzite is greatly shattered and jointed (Pl. XXIX, *B*), and at a few places along the base of the cliff are exposed overhanging irregular billowy surfaces of movement. The mass appears to be roughly spoon-shaped and to have been thrust forward to the northeast in the direction of its tip.

The overthrust faults have been described in some detail, not because they are important structural features, but rather because they are exceptional and are of interest in their connection with deformation so preponderantly of another type.

The part played by thrust faulting in any region is likely to be obscure, for unless the thrust plane crops out distinctly the existence of the fault may entirely escape notice. Even if the presence of a fault is known, its structural importance can not always be estimated.

Minor thrust faults are to be expected in a region of normal faulting, for as the blocks wedge together local thrusts are exerted and part of one block may be shoved over another. There is apparently no way of determining whether obscure thrust faults, such as that near the Old Dominion mine (p. 77) which disappears westward under the Gila conglomerate, and the one in the Live Oak ground (pp. 116–119), belong to this group of minor or secondary dislocations.

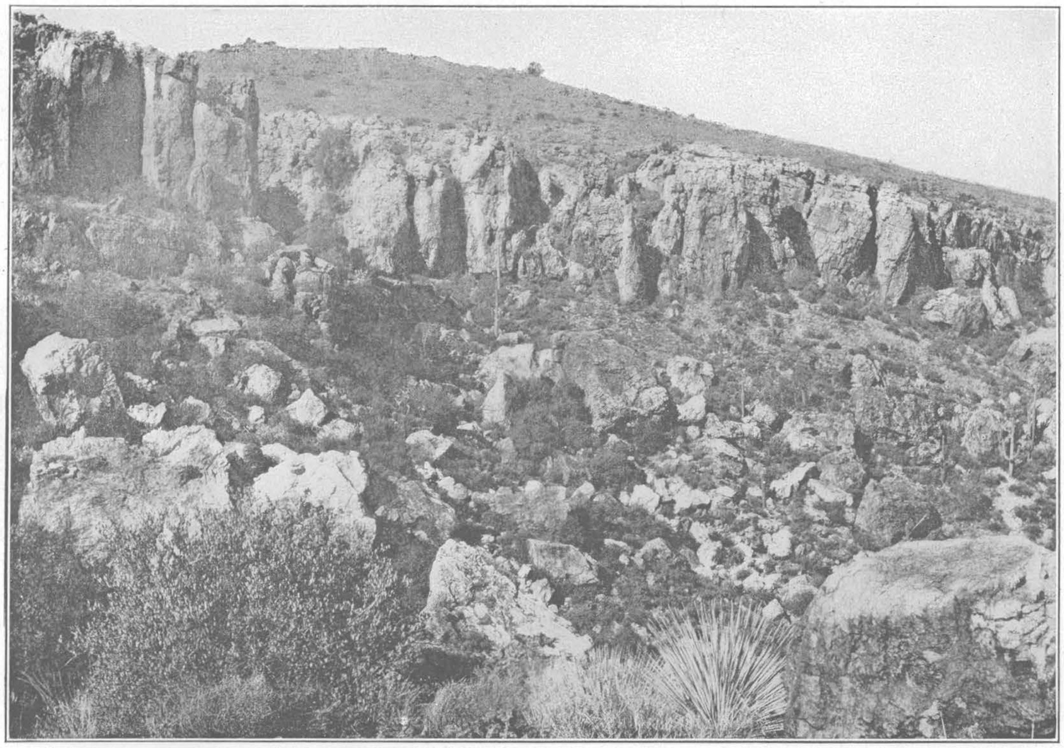
Such of the faults as are of special interest in connection with the ore deposits are described in the sections on the geology of the Ray and Miami districts.

Amount of displacement.—The throws of the individual faults, exclusive of faults concealed by the Gila conglomerate, consideration of which is for the present postponed, are not as a rule very great. Probably few of them exceed 1,000 feet. Along the west slope of the Dripping Spring Range one of the most persistent faults has been traced from Hackberry Gulch,[1] 2 miles southwest of Troy, nearly to Rustler Gulch, north-northeast of Ray, a distance of over 5 miles. Half a mile south of Rustler Gulch this fault brings Troy quartzite on the east against Pinal schist on the west, indicating a throw of 875 feet. In Susie D. Gulch, southeast of Ray, the same fault brings into juxtaposition the lower part of the Tornado limestone and the Mescal limestone, indicating a throw of 725 feet or more.

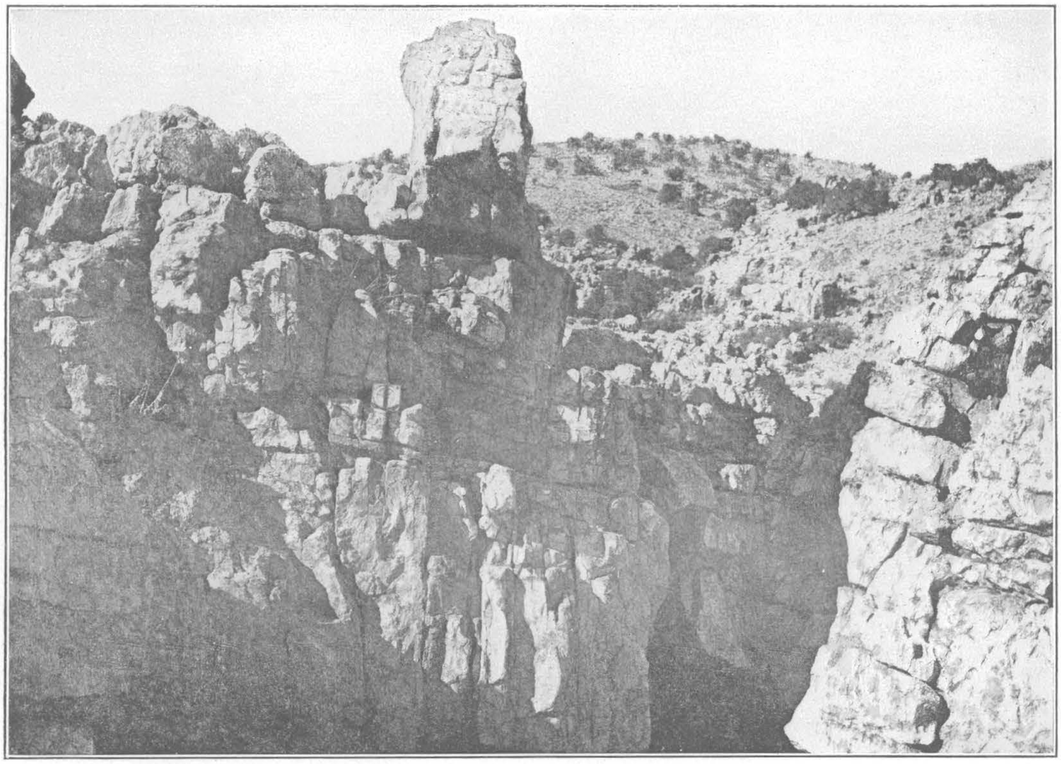
The same strata are brought together half a mile west of Troy Mountain by a nearly north-south fault that crosses the Dripping Spring Range. A mile north of Troy a nearly east-west fault brings the Tornado limestone against the Dripping Spring quartzite, a throw of at least 975 feet, and in the same locality another fault brings the Devonian limestone against the Cambrian Pioneer shale, a throw of 1,100 feet or more. One mile southwest of the London-Arizona mine a north-northwesterly fault has dropped the Tornado limestone against the basal portion of the Troy quartzite, a throw of 725 feet or more. A mile and a quarter north of the same mine the Tornado limestone in contact with the Mescal limestone shows a throw of at least 725 feet. The examples given probably show more than the average displacement of those faults in the region that are not concealed beneath the Gila conglomerate.

Relative ages.—The faults clearly are not all of one age. Many of them, so far as can be determined, do not displace the Gila conglomerate. This appears to be generally true of the faults in the Dripping Spring Range. On the other hand, certain fault fissures north of Ray do cut the conglomerate, and some faults in the Tortilla Range southwest of Gila River also appear to displace it. Many faults dis-

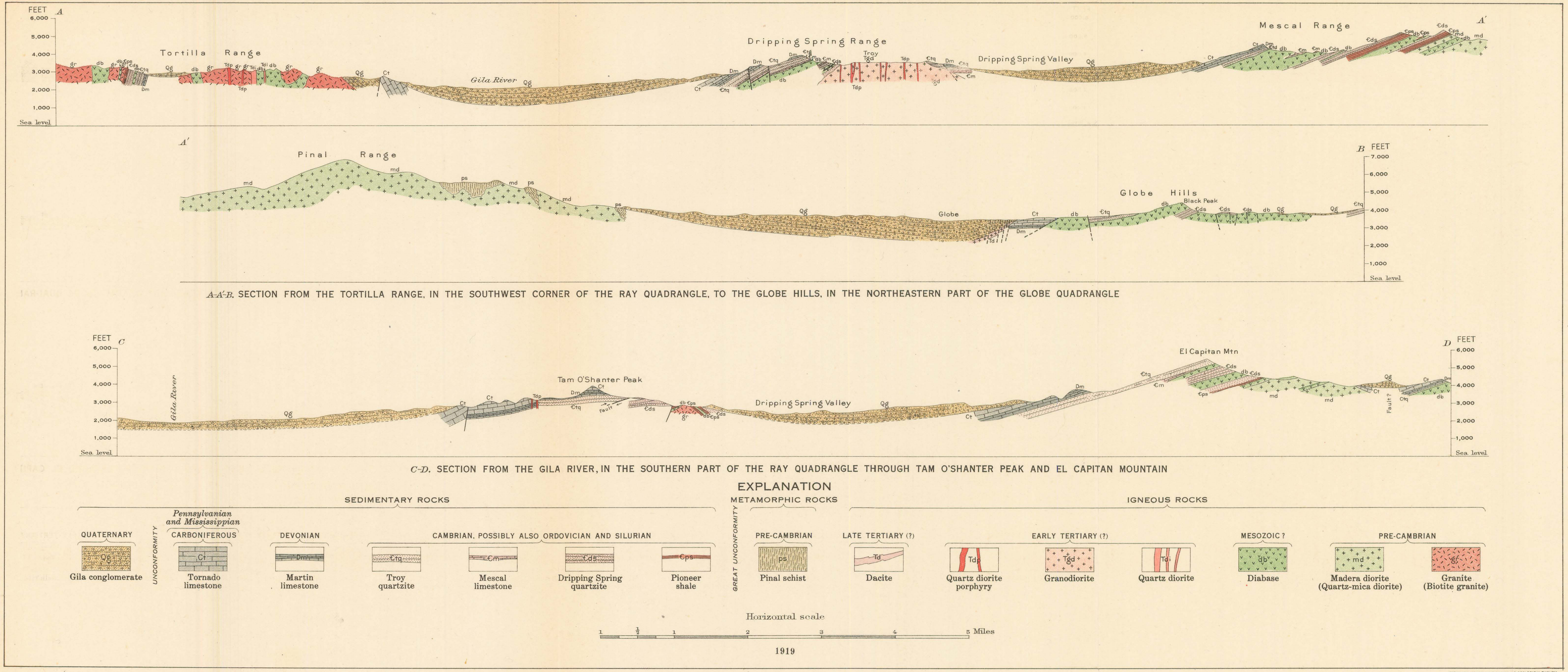
[1] Not the same as Hackberry Wash or Hackberry Spring, south of Kelvin.



A. EDGE OF BLOCK OF TROY QUARTZITE OVERTHRUST ON DIABASE AND DRIPPING SPRING QUARTZITE, 2 MILES NORTH OF TAM O' SHANTER PEAK, RAY QUADRANGLE. LOOKING NORTHWEST.



B. NEARER VIEW IN SAME LOCALITY AS *A*, SHOWING JOINTING IN OVERTHRUST QUARTZITE.



GEOLOGIC SECTIONS IN THE RAY AND GLOBE QUADRANGLES, ARIZONA

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

locate the dacite, and from the extent of this displacement it appears probable that a large part of the faulting in the region is postdacitic. In a few places, however, fault fissures along which, in the older rocks, there has been considerable movement apparently pass under dacite without any disturbance of that rock. Such instances, however, are not numerous.

Faulting and igneous intrusion.—To what extent faulting actually preceded the intrusion of diabase in Mesozoic time and prepared the way for the great shifting of blocks of strata in the liquid magma is unknown. The character of some of the contacts of the diabase with the other rocks suggests, however, that the invasion by the magma was facilitated to some extent by previous faulting. Be that as it may, it is certain that at the time of the intrusion the beds, particularly those beneath the Troy quartzite, were broken in rather extraordinary fashion into irregular blocks, and that these, after more or less movement in the magma, became fixed as huge inclusions in the solidified diabase, as may be well seen in the Mescal Range, in the northeast corner of the Ray quadrangle.

At a number of places dikes of diorite porphyry have been injected along fault fissures. This is most clearly shown southwest of Troy, where the dikes in part follow fault fissures and in part fissures of no apparent displacement.

Expression in topography.—None of the faults, so far as known, finds superficial expression as a simple unmodified fault scarp. Minor scarps such as are shown in Plate XXIX, exist here and there, but these are due to the erosion of the softer rock on one side of the fissure. The rock which has undergone the greater erosion may or may not be on the downthrown side.

That the steeper faces of some of the ranges may be erosionally modified and in part complex fault scarps is probable. The extent to which this may be true will be discussed later.

Over minor drainage lines the faults appear to have exercised no direct control, and the ravines do not as a rule coincide with lines of fissuring. Yet the faulting, by bringing into juxtaposition rocks of diverse behavior under erosion, has in an indirect and irregular way conditioned much of the topographic detail. The minute and unsystematic character of the fault dissection is reflected by a correspondingly irregular and intricate topography. The diabase and the granitic rocks are on the whole more readily eroded than the sedimentary rocks, and had the faulting been of such a character as to bring to the surface long belts of these rocks, the drainage would undoubtedly have shown some tendency to conform to their distribution. The existing fault pattern, however, is too patchy, too lacking in linear elements, and too much like a gigantic terrazzo pavement to influence appreciably or persistently the direction of stream erosion. Beyond the fact that a majority of the fault outcrops cross prominent ridges in swales or saddles, topography alone gives little clew to the course of a fault.

Cause of the faulting.—Whatever the causes that led to the extraordinary faulting of the Globe-Ray region, they were probably not local and are not likely to be clearly understood until our knowledge of the geology of Arizona is much more comprehensive and accurate than at present. The outstanding fact is the contrast between the broad, monotonous structural features of the Arizona Plateau and the jumble of jostled fault blocks in the country here described along its southwest border. The faulting is unquestionably connected with the forces and movements that differentiated the Colorado Plateaus province from the basin and range province,[1] and the question of its origin is a broad regional problem. Faulting of the kind described appears to be the result of collapse—of a widespread inability of the deeper rocks of the earth's crust to support their load. As a whole, however, the mountain region of Arizona does not appear to have subsided generally with respect to the plateau. Had it done so its ranges might be expected to contain a large proportion of rocks younger than those exposed in the plateau scarp, and conditions would resemble somewhat those near El Paso, Tex., where, from the precipitous Franklin Mountains, composed of Paleozoic and pre-Cambrian rocks, the eye may range for hundreds of miles into Mexico, where the only rocks visible are Mesozoic or younger. On the contrary, the rocks making up the ranges of the Arizona region, exclusive of Mesozoic and Tertiary igneous rocks, are to a large extent

[1] Preliminary map of the physiographic divisions of the United States: Assoc. Am. Geographers Annals, vol. 6, pl. 1, 1917.

older than those exposed in the bounding cliffs of the plateau. North of Payson and about 75 miles north-northwest of Miami, for example, the plateau surface is the Coconino sandstone (see Pl. XIII, p. 50) and has an elevation, near the brink, of about 8,000 feet. The Pinal Range attains nearly as great an elevation, but its crest is composed of pre-Cambrian rocks. In the Pinal Range, therefore, the pre-Cambrian rocks appear to have been elevated with respect to the same rocks in the plateau. Of course, 75 miles is a long distance, even in Arizona, and it might not be safe to base a conclusion on this one comparison. The inference is in accord, however, with what has been observed elsewhere and at places much nearer the plateau edge, as in the Mazatzal Range and in the Sierra Ancha. In fact, the general impression gained from fairly extensive reconnaissance trips in this part of Arizona is that the pre-Cambrian rocks in the range region stand on the whole rather higher than in the plateau and in places are much higher. If this impression is correct, then it follows that the structural collapse of the range region must have been preceded by an uplift in which the fundamental crystalline rocks were raised above the general level of the corresponding rocks under the plateau.

Notwithstanding the irregular character of the diabase intrusion, the prevalence of the sill form and the general parallelism of intrusive diabase sheets in pre-Cambrian granite with those in the overlying Paleozoic sedimentary rocks are approaches to regularity that would hardly be expected if the rocks at the time of intrusion were greatly faulted and if the sedimentary beds had their present dip. Along the northeast base of the Mescal Range, for example, there is a fairly regular sheet of diabase in pre-Cambrian granite. This sheet dips southwest at about 20°, or approximately at the same angle as the dip of the stratified rocks on El Capitan. (See Pl. II, p. 26.) If these beds were nearly horizontal when the diabase magma was injected, conditions of equal load might have caused the diabase in the granite to follow in places an approximately horizontal plane of intrusion. If, on the other hand, the beds were then inclined 20° it is difficult to see what conditions could have induced the diabase to cut the structureless granite at so nearly the same angle. There appears to be a suggestion here that at the time the diabase was intruded the beds of the Ray-Miami region were nearly horizontal and the region itself was structurally a part of what is now the plateau.

Presumably the extensive faulting that followed the eruption of the dacite in Tertiary time was coincident with part of the structural separation between the plateau and range regions. Whether it initiated this differentiation or merely accentuated a distinction that had already appeared is not known.

THE MOUNTAIN RANGES.

Apache Mountains.—About 4 miles northeast of the area shown on Plate II are the Apache Mountains. These have the usual northwesterly trend of the ranges of the region, and their line is continued northwest of Salt River by the Sierra Ancha. Both ranges are structurally homoclines, with dip to the northeast, and are composed chiefly of Cambrian rocks with intrusive sheets of diabase and diorite porphyry. Between the Apache Mountains and Globe are the relatively low Globe Hills, which are shown in part on Plate II. These consist of Paleozoic and pre-Cambrian rocks ranging from coarse Archean granite at the base to the Tornado limestone at the top. The sedimentary rocks have been invaded by a huge irregular sill of diabase, and all the rocks, including some overlying dacite, have been displaced by numerous faults.

Pinal Range.—The Pinal Range, southwest of the Globe Hills and separated from them by the area of Gila conglomerate traversed by Pinal Creek, is divisible into three portions that, superficially at least, present different tectonic features. The high middle portion of the range and some of the lower ground to the northwest consist of the Pinal schist intricately intruded by the Madera diorite (quartz mica diorite) and other granitic rocks. The quartz diorite in some localities is crowded with inclusions of schist, and the schist in places is cut by countless small offshoots from the main intrusive mass. This pre-Cambrian complex, within the area over which it is now exposed, together with the younger intrusive masses of Schultze granite, Willow Spring granite, and Lost Gulch monzonite, appears to have behaved substantially as a unit in the post-Cambrian movements to which the region has been subjected.

North of this division is a part of the range that, as rather inadequately shown on the small scale of Plate II, is elaborately dissected by faults, so that rocks of very different ages from pre-Cambrian granite to Tertiary dacite are brought into juxtaposition in different blocks. The result is a fine-textured fault mosaic such as is very characteristic of the region and is especially well illustrated in the Dripping Spring Range, presently to be described.

Overlapping the middle massive section of the Pinal Range on the southwest and extending southeastward toward Gila River is the third division, sometimes distinguished by a separate name—the Mescal Range. This, as may readily be seen from the cross sections of Plate XXX and from Plate III, is a homocline with dip of 20° to 25° southwesterly. The rocks involved range from pre-Cambrian granitic rocks exposed along the northeast base of the mountains to the Tornado limestone lapping up on their southwest slope. Into these rocks, especially into the quartzites, shale, and limestone of the Apache group, has been intruded in intricate fashion a branching sheet of diabase, within which are included many isolated blocks of the invaded strata.

El Capitan, the culminating summit of the Mescal Range in the Ray quadrangle, presents to the northeast a bold scarplike face (Pls. III and XXX), in which the edges of the southwestward-dipping beds are exposed. Part of the lowland which this peak overlooks to the north is occupied by some of the same rocks of which the main ridge of the Mescal Range is composed, and, like the beds in that ridge, these also dip to the southwest. On the northwest they are faulted down against the schist and Madera diorite of the main Pinal mass. (See Pls. II and XXX.) In all probability another fault, concealed by the Gila conglomerate, bounds them on the southwest and accounts for their present position with reference to the strata of El Capitan.

The second and third divisions of the Pinal Range may be considered broadly as a single structural unit, a homoclinal block.

Dripping Spring Range.—Southwest of the Pinal and Mescal ranges and separated from them by Dripping Spring or Disappointment Valley is the Dripping Spring Range. This range, the structure of which is necessarily generalized on the small scale of Plate II, is a remarkable example of a fault mosaic. The fault fissures intersect in all directions and form an intricate network. Although in some parts of the range it is possible to recognize the predominance of faults trending in some one general direction, the fault net as a whole does not appear to be susceptible of analysis into groups of fissures classified on the basis of direction or age.

In consequence of the generally excellent exposures and the readiness with which, as a rule, the different formations may be recognized by one familiar with their lithology, the major faults are not difficult to detect and can generally be traced for considerable distances, usually to the point where the dislocating fissure passes into rocks of one kind, meets another fault, or disappears beneath the Gila conglomerate.

The detailed geologic map of the Ray quadrangle, not yet published, shows certain broad structural features more clearly than the smaller-scale generalized map of Plate II. The part of the range lying east of the nearly north-south zone of faulting that passes just east of Tam o' Shanter Peak shows a general progression from younger rocks in the south to older rocks in the north. In other words, if the irregularities due to minor faulting be disregarded, this part of the range is a homoclinal block with general dip to the south. A similar progression and structure is shown by the section of the range lying between the Tam o' Shanter Peak fault zone and the zone extending northward past Steamboat Mountain to the Dripping Spring ranch. At the south end of this shattered block is the Cretaceous andesite overlapping the Carboniferous limestone; at the north end is the Cambrian Pioneer shale.

Between the fault zone last mentioned and the strong north-south fault that passes half a mile west of Troy Mountain is the section of the range that contains the intrusive granodiorite mass of Troy. This section shows some tendency toward the same southward-dipping homoclinal structure, but the irregularity of the minor faulting and doubtless also the structural effects of the granodiorite intrusion almost completely mask this suggestion of uniformity.

From Hackberry Gulch, 2 miles southwest of Troy, two conspicuous faults diverge northward. One is the fault already referred to as passing half a mile west of Troy Mountain. The other runs northwestward, passing about three-quarters of a mile east of Ray. Between these faults and stretching beyond their known extent to the north is a section of the range that shows the same stratigraphic descent from the Tornado limestone at its southern tip to the Pinal schist and Pioneer shale on the north. North of Scott Mountain, however, the intrusion of diabase and the numerous minor faults have introduced much structural irregularity.

West of the block just described is a comparatively small section of the range in the vicinity of Ray which has been uplifted relatively to the block east of it some 800 to 900 feet.

About 4 miles north of Ray a north-northeast fault drops the dacite on the northwest against the older rocks on the southeast.

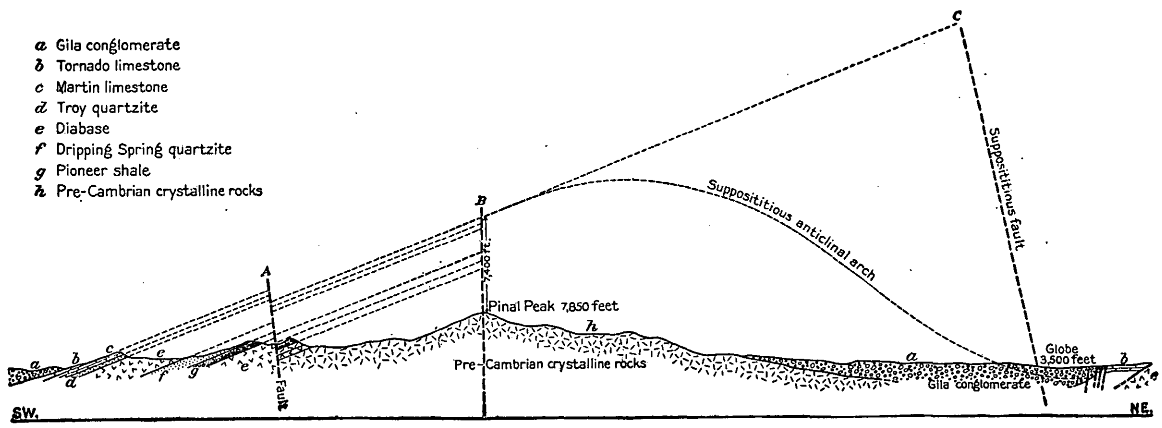


FIGURE 5.—Diagram illustrating structure of the Pinal Range. Horizontal and vertical scales the same.

If a simple homoclinal range, tilted, like the Mescal Range, to the southwest, were cut into sections by north-south faults, each section being displaced so as to be from 500 to 1,000 feet lower than its neighbor to the southeast, and if, further, each section were cut by numerous minor faults into a correspondingly numerous set of small blocks which underwent considerable jostling and movement before they came to rest, the resulting structure would be approximately that of the Dripping Spring Range. Whether the movements took place in the order just given is not known and perhaps can never be ascertained.

Tortilla Range.—That part of the Tortilla Range within the Ray quadrangle presents a rather striking difference in structure from the ranges just described. It is in the main a ridge of pre-Cambrian granite cut by various intrusive rocks. At its north end near Ray, where it coalesces with the Dripping Spring Range, it is composed largely of Pinal schist. In the southern part of the Ray quadrangle the granite is flanked on the east by the same Paleozoic beds that are found in the Dripping Spring and Mescal ranges, but in the Tortilla Range these beds have dips of 80° to 90° and consequently appear on the geologic map as inconspicuous narrow bands. These steeply upturned beds are considerably faulted, and at least a part of the faulting appears to have taken place after the deposition of the Gila conglomerate. The conglomerate itself is sharply upturned along the mountain flank, with dips as high as 60°.

EVIDENCE THAT THE VALLEYS ARE TECTONIC.

As appears in the section across the Pinal Range in Plate XXX, the strata on the southwest side of the main pre-Cambrian mass dip regularly to the southwest at 20° to 25°. When these strata are projected upward, as indicated in the accompanying diagram (fig. 5), at the same general dip, with allowance for a fault or intrusion displacement at A, it will be seen that the base of the Pioneer shale, if extended to B, would be about 3,400 feet above the summit of Pinal Peak and the base of the Tornado limestone would be about 7,400 feet above the same summit. In terms of elevation above sea level the base of the Cambrian would stand at 11,250 feet, where the Pinal Range is now. About 10 miles north-northeast of Pinal Peak and just northeast of the town of Globe, in the Globe Hills, these same Paleozoic rocks appear at altitudes of less than 5,000 feet. Without question these beds were once continuous with those that lap up on the southwest flank of the Pinal Range.

Two hypotheses readily suggest themselves in explanation of the present relation of the beds on the opposite sides of the range. It may be supposed that they swept over the crystalline rocks in a great arch, as indicated in figure 5; or it may be supposed that they continued upward, past the present crest of the range, at approximately the same dip of 20° to 25°, and that on the northeast they were cut off and dropped by a profound fault, a supposition also illustrated diagrammatically in figure 5. In either case, if the full movement indicated, either of folding or of faulting, took place at one time, before erosion could make much impression on the uplift, a range of enormous height must have resulted. In all probability, however, the range never had any such altitude as the diagram shows, but was worn down by erosion during a long period of slow uplift.

There is nothing inherently improbable in the explanation of the present relations by former folding, but this hypothesis has to be considered with reference to other tectonic features of the region. Wherever the structure is exposed to view one of the most notable of such features, as has already been shown, is the practical absence of folding and the extraordinary abundance of faults. On all sides of the main Pinal mass of crystalline rocks faults abound and folds are absent. If the part of the Pinal Range shown in section in Plate XXX is an eroded anticline, then it is a remarkable exception to the general structure of the region. It might be urged that the intricate faulting so characteristic of the Globe and Ray quadrangles is the result of the collapse of just such folds as the one here suggested. If so, the uncovered crystalline rocks of the Pinal Range should show a multitude of intersecting fault fissures, whereas in fact they appear to be unusually free from them.

The second hypothesis, that the present structural relation between the beds on opposite sides of the Pinal Range is the result of faulting, appears to be more in accord with what is known of the general structure, not only of the Globe-Ray region but of a more extensive area of which the two quadrangles mentioned are merely a part. It may well be doubted, however, whether the displacement was effected by a single great fault such as is indicated in the diagram of figure 5. In all probability an area of complex faulting underlies the Gila conglomerate of the valley adjacent to Globe, and the great total displacement, a throw of over 5 miles, was accomplished by slipping along many fractures distributed over a considerable period of time during which erosion actively attacked the mass on the upthrow side of the fault zone.

Similar reasoning to that just employed applies also to the relation between the beds in the Mescal Range and the continuations of these same beds in the Dripping Spring Range. The southwest versant of the Mescal Range is virtually a dip slope, the Tornado limestone disappearing under the Gila conglomerate with a dip of about 20°. If Dripping Spring Valley were a synclinal trough, the Dripping Spring Range should be an anticlinal ridge. The range does not have that character, but as has been shown on page 81, is a much faulted homocline in which the rocks, if they were not so thoroughly faulted, would have a similar attitude to those in the Mescal homocline.

The part of the Tortilla Range within the Ray quadrangle is composed chiefly of pre-Cambrian granite, and there is little to indicate the structural relation of this mass to the adjacent valleys. The nearly vertical attitude of the Paleozoic beds in the southwest corner of the quadrangle, the known presence of considerable faults in the same locality, and the steep upturning of the Gila conglomerate along the eastern flanks of the ridges, are all suggestive of faulting rather than folding as the kind of deformation that brought the range into existence.

In order to establish the truth of the statement that the mountain ranges and principal valleys are tectonic features it is necessary, of course, to prove not only that the mountains owe their structural features mainly to faulting but that the general effect of dislocation has been the elevation of the mountain tracts relatively to the valley tracts. This to some extent has been shown to be probably true for the Pinal Range. There remains for consideration, however, the question, How far can the valleys be accounted for by erosion on the supposition that they are not due to deformation? In other words, Can the tectonic hypothesis be established by the elimination of its only alternative?

If after the region was affected by the last general deformation the land in the areas now corresponding to the valleys were as high as or higher than the land in the areas now corresponding to the mountains and if the valleys had been cut out by erosion, then obviously the valleys should show an intimate and characteristic relation either to the present drainage plan or to some older drainage plan. It is not enough that they should be occupied by streams or by intermittent watercourses. That would follow, no mater what the origin of the valleys. But, with all due regard for differences in the resistance of various rocks to erosion, the valleys, if they were the work of running water, should be roughly proportional in size to the occupying streams and should show the adjustment of shape, width, and depth to the different sections of the stream that is characteristic of a fluvial valley. To pursue this branch of inquiry thoroughly would require the study of a much larger area than that now under consideration, but observation, so far as it has gone, shows that the streams or arroyos are not in close adjustment to the valleys. The Gila, for example, as shown on page 28, breaks across the ranges from one valley to another. Its present course must have been determined when the valleys not only were in existence but were more deeply filled with detritus than they are now. The valley in which the town of Globe lies appears much too large to be the work of Pinal Creek and its tributaries, and has not the shape that might be expected were it of erosional origin. Dripping Spring Valley also appears too large for the intermittent streams by which it is drained.

The valleys are now occupied by the Gila conglomerate and must therefore have been formed before the conglomerate was deposited. This conclusion, on the supposition that the valleys are erosional features, would require a period of intense denudation in pre-Gila time, during which not only were the valleys excavated, but the neighboring mountains were correspondingly worn down. Moreover, the detritus resulting from all this erosion must have been swept completely out of the region, for clearly the excavation of the valleys and the accumulation within them of a vast deposit of gravelly and silty detritus could not go on simultaneously. This removal could have been affected only by a drainage system entirely different from that now existing and under climatic conditions totally unlike those that now prevail. The erosional hypothesis is confronted, moreover, with the difficulty of explaining why, after all this erosion, the process of valley filling should have been begun and so energetically prosecuted and how detritus, so abundant and in part so coarse, could have been supplied from mountains worn down almost to their present heights.

On the other hand, if the valleys are essentially structural features their subsequent history is readily interpreted. Whether the faulting that differentiated mountains from valleys was sudden or took place by successive small slips, the result must have been a pronounced steepening of stream grade, an abundant supply of débris from the uplifted fault blocks, and consequently a rapid accumulation of detritus in the valleys. These valleys, being tectonic, would have no regular gradient from head to outlet, but would in all probability be closed basins in which the sediment-laden storm waters from the mountains would evaporate, or, possibly, in some places, form a lake having an outlet over some low pass in the valley rim. Under such circumstances the Gila formation may have accumulated under climatic conditions very little different from those of to-day.

GEOLOGIC HISTORY.[1]

Long before Cambrian time the Globe-Ray region was part of a sea bottom upon which were accumulating fine grits and silts, probably derived from granitic rocks. The source of these sediments is unknown, and no trace of the ancient rocky floor upon which they were

[1] In the preparation of this section the Globe report (U. S. Geol. Survey Prof. Paper 12) has been freely drawn upon, much of the material being reproduced verbatim. It is believed that the reader will prefer to have the geologic narrative as complete as possible in this place and that there is no gain in attempting to rephrase those portions of the older report in which no changes are demanded by later observations.

laid down is now visible. In the course of time sedimentation ceased, and the beds were folded and compressed by forces acting in a generally northwest-southeast direction; were intruded by great masses of quartz mica diorite (the Madera diorite); and underwent crystalline metamorphism into the Pinal schist. Later intrusions of granitic rocks followed, and at the end of this period of plutonic eruptive activity the region had risen above the sea and become mountainous. A new physiographic cycle was thus initiated, but it was probably well under way before the constructive processes that have just been outlined were concluded. Before the rocks attained their final elevation erosion was vigorously at work, and upon becoming ascendant it began the actual reduction of the mountainous topography, which it carried successively through the various intermediate stages of the geographic cycle to the final one of the nearly featureless worn-down plain of old age—a peneplain.

So much, in brief, of pre-Cambrian history is decipherable from the character, structure, and texture of the older rocks. The cycle was run, and the beginning of Cambrian time was marked by subsidence and a fresh advance of the sea over what had so long been dry land. The sea as it swept over the land found it littered in part with fragments of quartz weathered out from veins in the schists and granitic rocks, and with smaller particles of feldspar and quartz derived from the disintegration of the granitic masses. The existence of particles of feldspar that have remained fairly fresh to the present time appears to afford some indication that the Cambrian climate was not conducive to soil formation or to abundant vegetation. These materials were slightly reworked by the waves into the Scanlan conglomerate, the remnants of which are now usually found resting upon the weathered and reddened surface of the Madera diorite and the granites, here and there separated from the sound rock by several feet of pre-Cambrian granitic saprolite (disintegrated rock in place). The Scanlan conglomerate, or its equivalent, covered the Pinal schist as well as the plutonic rocks. It appears that the region was submerged too rapidly to permit any considerable rounding of the pebbles by wave action or much transportation of material by littoral currents—processes both of which are favored by stability of shore line. The lack of such evidence of long-continued shore action shows that the floor upon which the Cambrian sediments were deposited was in the main due to subaerial erosion and not to marine planation.

Either there were valleys in the old peneplain as much as 200 feet in depth or the region subsided unevenly to an equal extent, for in the Apache Mountains, northeast of Globe, the interval between the pre-Cambrian peneplain and the base of the Pioneer shale elsewhere occupied by 1 to 6 feet of Scanlan conglomerate, is filled by some 200 feet of hard and varyingly arkose quartzite.

The Pioneer shale, overlying the Scanlan conglomerate and the lower quartzites of the Apache Mountains, records the accumulation of sandy silt in shallow water. The material of these sediments was in part feldspathic and probably derived from an adjacent land mass, composed largely of granitoid rocks similar to those occurring in the Pinal Mountains. Although there is no direct proof that the rocks of these mountains themselves were reduced to the general level of the peneplain and covered by the Cambrian sediments, yet it seems most probable that they were and that their present elevation and the stripping of their Paleozoic cover are due to later movements and to erosion. It is not likely that there existed any such sharp and local exception to the general unevenness of what must have been at one time an extensive peneplain.

The deposition of the Pioneer shale was followed by that of the Barnes conglomerate. The origin of this conglomerate, which, with its well-rounded pebbles, mostly quartzite, contrasts so strikingly with the reddish sandy shale beneath it, is a puzzling problem. Without any apparent unconformity, the fine silt deposited in quiet waters was succeeded by coarse material that must have been laid down under very different conditions of erosion and deposition. Such coarse material implies the action of strong currents and perhaps of waves, and it is difficult to understand how in these circumstances the underlying silt could have escaped considerable erosion. The pebbles of the conglomerate appear to have come in part from pre-Cambrian quartzites now exposed in the Sierra Ancha and Mazatzal Range, to the north of the region here described. The matrix, however, shows abundant feldspathic detritus, such as might have been supplied by a near-by unsubmerged area of the same pre-Cambrian granitic rocks as are now exposed in the Globe-Ray region. On the whole, the evidence, though far from conclusive, suggests that the Barnes conglomerate is a delta deposit, the work of streams rather than of waves.

Succeeding the deposition of the Barnes conglomerate came the accumulation of quartzose sands now represented by the Dripping Spring quartzite. The thin, somewhat shaly beds near the top of this formation show fossil worm casts or filled borings, ripple marks, and sun cracks. The quartzite was thus, at least in part, laid down in shallow water, and the sandy mud was at times exposed to the air and sun. It also is tentatively regarded as a delta deposit.

The thin-bedded impure dolomitic Mescal limestone, which overlies the Dripping Spring quartzite, marks a decided change in sedimentation. No fossils have been found in this limestone, but it probably is marine and was laid down in shallow water.

The next event in Cambrian time was the eruption of a flow of basalt. Although this flow has nowhere been observed to be much over 100 feet thick, it once covered an area of at least 500 square miles. Whether it spread over a sea bottom or was erupted on land is not known, but the extent and regularity of the flow, taken in connection with its relation to the beds below it, show that the surface covered by it had undergone little if any erosion.

After the eruption of the basalt, which has a vesicular upper surface, began the accumulation of the sandy and pebbly sediments now consolidated as the Troy quartzite. The abundant layers of pebbles and the conspicuous cross-bedding of this quartzite are suggestive of a return, during its deposition, to deltaic conditions. The upper beds, however, show lithologic gradation into the Martin limestone, which is considered to be Devonian and is unquestionably marine, as shown by its fossils.

Up to the beginning of the deposition of the Martin limestone the Paleozoic era had been marked by the preponderance of siliceous sediments indicative on the whole of shallow water or alternating land and water. From that point on marine conditions, with apparently increasing depth of water, prevailed.

The geologic record of the region studied is silent as regards Ordovician and Silurian time. No strata of these ages have been recognized, nor, on the other hand, has any unconformity been certainly detected between the supposed Cambrian and the known Devonian, to account for their apparent absence.

Walcott[1] long ago called attention to the existence of an unconformity between the Cambrian and Devonian beds in the Grand Canyon and recently L. F. Noble,[2] as a result of detailed stratigraphic studies not yet published, has obtained proof that there is also an unconformity between the Devonian Temple Butte limestone and the overlying Carboniferous (Mississippian) Redwall limestone. It is possible that in spite of the apparently unbroken sequence of beds from the base of the Cambrian to the Devonian there may be an undetected unconformity in the Globe-Ray region. Another possibility is suggested by the fact that approximately the lower half of the Martin limestone and all of the supposed Cambrian are unfossiliferous. Consequently some part of these unfossiliferous beds may prove to be Ordovician or Silurian. In the absence of any paleontologic evidence it has seemed better to adopt the provisional classification employed in this report than to make an arbitrary assignment of certain portions of the stratigraphic series to the two geologic periods that apparently lack representation.

On the assumption that the beginning of deposition of the Martin limestone marked the beginning of Devonian time, the lower beds, consisting in part of calcareous grits, show a passage from shallow water in which terrigenous sediments could accumulate to deeper water in which limestone was deposited.

From Devonian time well into the upper Carboniferous (Pennsylvanian) the region was covered by a sea abounding in animal life and depositing abundant limestone. No unconformity has been found in the Tornado limestone, which carries Mississippian and Pennsylvanian fossils. From time to time during the accumulation of the limestone there were slight incursions of land-derived sediment, and on parts of the sea floor layers of siliceous conglomerates were intercalated in the limestone series. The mass of these layers is unimportant, but they are significant in showing that this part of the Carboniferous sea was probably

[1] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado, Ariz.: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

[2] Personal communication.

neither very deep nor far distant from a land mass.

The Pennsylvanian limestone is the latest Paleozoic deposit of which the region preserves any record. If marine conditions continued into the Permian the deposits of that period must have been wholly removed before the strata were broken up and invaded by diabase. Had Permian beds been involved in that structural revolution, some remnants of them would probably have been preserved in the resulting intricate lithologic mosaic.

There are no available means of determining whether or not the region became land and was eroded before the diabase intrusion. We know only that the intrusion with its associated faulting occurred after the accumulation of the Tornado limestone and has left unmistakable record of its structural importance. The region was presumably elevated above sea level at the end of the Carboniferous and subjected to erosion. It was extensively dissected, probably in Mesozoic time, by numerous faults, which appear to have been normal in character, to be usually of moderate throw, and to have had generally northwest and northeast trends. There is ground for supposing that the crystalline massif of the Pinal Mountains escaped much of the intensity of this faulting, as it did that of a later period. The dislocations were followed or accompanied by the intrusion of an enormous quantity of molten diabase magma into the rocks of the region, particularly into those most cut by the faults. If present exposures can be taken as generally indicative of the original proportions, it appears that the intrusive rock fully equaled if it did not considerably exceed in volume the stratified rocks. As the latter were not fused at any point now exposed to observation, it is concluded that room for this great addition of material was effected by mechanical displacement. The dominant form taken by the diabase was that of the intrusive sheet or sill, and had the region been free from faults these sills would probably have been fairly regular, resembling those occurring in the less faulted portions of the general region such, for example, as are well exposed in the cañon of Salt River just below its junction with Tonto Creek or in the Sierra Ancha. As it was, however, the diabase not only forced its way between the beds as sills of varying thickness but found in the faulted rocks the most favorable opportunity for expansion. It occupied the fault fissures and shoved the detached masses of ruptured strata bodily aside, separating them so that they became in many places mere inclusions in a great mass of eruptive rock. All the observed phenomena connected with the faulting and intrusion, as well as the more general geologic considerations outlined in preceding pages, indicate that these events took place comparatively near the surface. The contact metamorphism effected by the diabase is generally slight, and aphanitic facies of the intrusive rock are common near original contacts. The manner in which the blocks of strata were displaced indicates that they were under no great load, and the large increase of volume resulting from the intrusion of the diabase must have produced considerable actual elevation of the surface over the Globe-Ray region. It would seem that when deformation and intrusion were so actively in progress at so slight a depth at least some of the magma must have found its way to the surface and been erupted as basalt. Any such manifestation of volcanic activity as may have existed has, however, since been removed by erosion.

After the diabase intrusion the region, having probably gained in elevation, was eroded. As pointed out on page 57, it is not yet determined whether the andesitic volcanic outbursts which have left their products in the southeastern part of the Ray quadrangle and in the region south of Gila River preceded or followed the intrusion of the diabase. The andesitic rocks are associated with coal-bearing late Cretaceous or early Tertiary beds and are believed to be younger than the diabase. This part of the geologic history is still obscure, and much more light will probably be thrown on it when detailed studies are made of the region south and east of that covered by the Globe and Ray quadrangles. It is not unlikely that during late Mesozoic and early Tertiary time the region here described underwent many unrecorded vicissitudes and may have been covered by volcanic rocks and sediments that were afterward stripped away. To this obscure time, following the andesitic eruption, apparently belongs the irruption of the quartz diorite, the Schultze granite, the granodiorite at Troy, the quartz monzonite porphyry of the Ray district, and the related granitic monzonite and dioritic porphyries of the region. The intrusion of these rocks was probably accompanied and followed by faulting and was the immediate cause of ore deposition.

With the cessation of igneous intrusion, at a time which can not be definitely fixed from present information but which is provisionally considered as coinciding with the earlier or middle part of the Tertiary, the region, characterized by a diversified topography, was apparently dry land and undergoing erosion. Although the surface was probably less rugged, the general conditions as regards climate and erosional activity appear to have been not greatly different from those of the present day. As shown by the accumulation of the Whitetail formation, coarse, rather angular detritus was washed down the slopes and deposited in the more open valleys and gulches. It was during this period of erosion and waste accumulation that most of the enrichment of the Ray and Miami copper deposits is believed to have taken place.

Over this uneven surface, with its hollows partly filled with the Whitetail formation, was poured, probably in early or middle Tertiary time, an extensive flow of dacite. The greater part of the region here described appears to have been covered by this lava, which issued from a vent or vents as yet undiscovered. As the Whitetail formation in places shows rude stratification and the massive dacite in some localities is underlain by beds of dacite tuff, it is probable that the region contained transient bodies of water, probably in consequence of the disturbance of the drainage by faulting before and during the volcanic activity.

Following closely after the dacite eruption, and possibly as a consequence of it, came the great faulting to which are chiefly due the present structure and less directly the topography of the region. The character of this faulting has been described on pages 76–80. By it much of the country, especially the Dripping Spring Range, was shattered to an extent very imperfectly represented by the great number of small fault blocks outlined on the small-scale geologic map of Plate II or on Plate XLV.

In the absence of any satisfactory evidence for connecting with the recognized geologic epochs the events which took place in this district after the Carboniferous period, the postdacitic faulting is rather arbitrarily considered as ending the Tertiary. The provisional nature of this and other post-Carboniferous correlations in this region should not be forgotten. They may be considerably modified when the present geologic work is supplemented and extended by the study of a broader area. The divisions recognized appear to be distinct chapters in the local physical history. They may not, however, be inserted at the correct places in the larger volume of the geologic story of the earth.

The Quaternary was begun by a vigorous erosion of the complex lithologic mosaic resulting from the superposition of the postdacitic shattering upon an earlier structure that was already complex. Great quantities of coarse, rocky detritus were washed down the slopes and deposited as the Gila formation in valleys partly, at least, of structural origin. It has already been shown that the larger conglomerate-filled valleys probably owe their original depression to faulting.

The character of the Gila formation indicates that the climatic conditions of the early Quaternary were not very unlike those of to-day. Prevailing aridity and dominance of mechanical disintegration over rock decay were prominent features, and the precipitation apparently occurred in violent downpours of short duration.

There has been at least one eruption of basalt during the Quaternary period, as shown by the flow intercalated in the Gila formation south of Gold Gulch, in the northwestern part of the Globe quadrangle, and by smaller masses in the western part of the same quadrangle. The basalt apparently issued from more than one small vent, and its present distribution is not entirely understood.

The early Quaternary erosion that supplied the materials for the Gila formation undoubtedly effected pronounced changes in the topography, but it usually is difficult or impossible to distinguish between such changes and those brought about in late Quaternary time.

More or less faulting has continued throughout the Quaternary, and these later dislocations have had a recognizable effect upon the structure, as shown by the shapes and distribution of the areas of Gila conglomerate.

In late Quaternary time erosion has been active over the whole region, reducing the mountains and dissecting the Gila conglomerate. In some parts of the region, as near Hutton Peak and Needle Mountain, this later degradation appears to have been exceptionally active and has left fragments of the Gila formation, originally a valley deposit, upon the summits of ridges and peaks. Within many areas of conglomerate, however, the present intermittent streams have merely effected an intricate dissection and sculpturing, without exposing the base of the formation save near its margins. This trenching was locally accompanied by the cutting of stream terraces, best seen in the Ray district and on Bloody Tanks Wash in the Globe quadrangle.

CHAPTER IV.—MINES AND MINING.

PURPOSE OF CHAPTER.

Although at first thought it might be supposed that the discussion of the geologic details of the two districts described should, in accordance with logical order, immediately follow the account of the general geology of the region, it will soon be apparent that an understanding of local geologic relations requires some knowledge of the mine workings. This supplies such justification as may be necessary for the present arrangement.

It is not to be expected that a geologic report should particularly concern itself with the financial and technical problems that are being solved in the mining of disseminated copper ores. Nevertheless, descriptions of the deposits themselves are likely to be more readily comprehended if introduced by a concise account of property boundaries, company organization, underground workings, and general mining methods. The present chapter is intended to give the reader such a preliminary survey of the local industry from its practical side as may enable him to realize the industrial importance of the deposits, to understand the general mode of their exploitation, and to follow readily subsequent descriptions in which there will of necessity be reference to the various companies by name and to their respective mining operations. Details of mining or milling technique and of mechanical equipment will be omitted or will receive but brief mention.

MIAMI DISTRICT.

MINING COMPANIES AND CLAIM GROUPS.

The ore bodies of the Miami district, so far as they are at present known, are confined to a rather irregular east-west ridge that separates Webster Gulch on the north from Liveoak Gulch on the south. This may conveniently be referred to as Inspiration Ridge, from the mine of that name. The average breadth of the ridge is about 1 mile, and its height above the bottoms of the gulches mentioned ranges from 400 to 600 feet. The ore bodies lie on an arc, concave to the south, of a horizontal circle of about 1½-mile radius. This curve in general coincides with the crest line of the ridge, but at its west end it sweeps southward toward Liveoak Gulch. The total length of the known ore belt, or bow, as it may be suggestively called, is 2 miles, and its greatest breadth, near the middle of the curve, is about 1,500 feet.

The situations of the principal claim groups with reference to each other and to the ore bow may be seen from figure 6, or in greater detail from Plate XXXI.

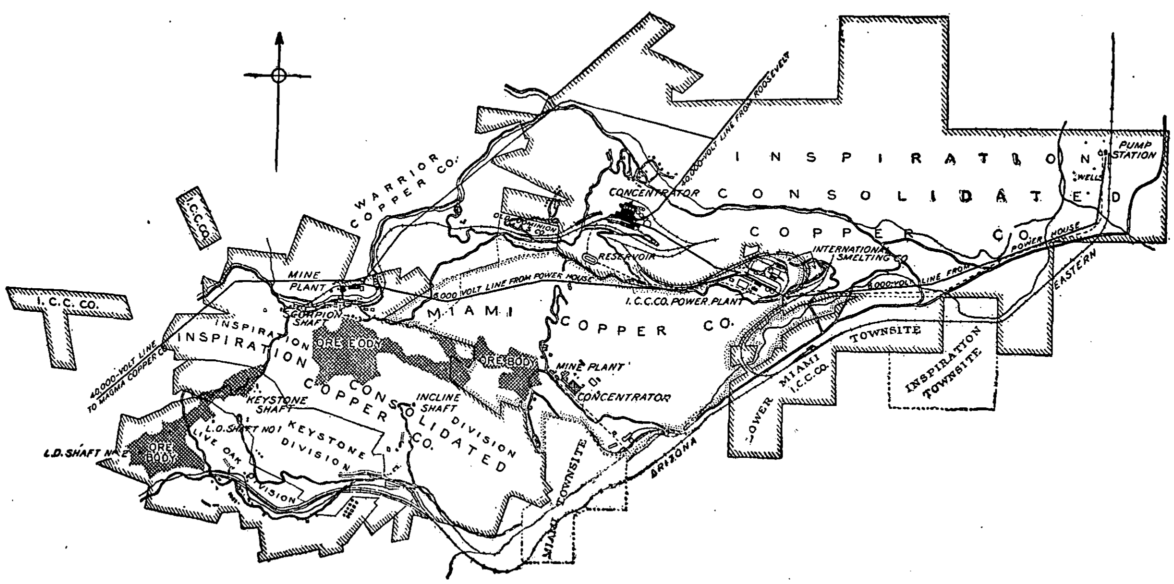
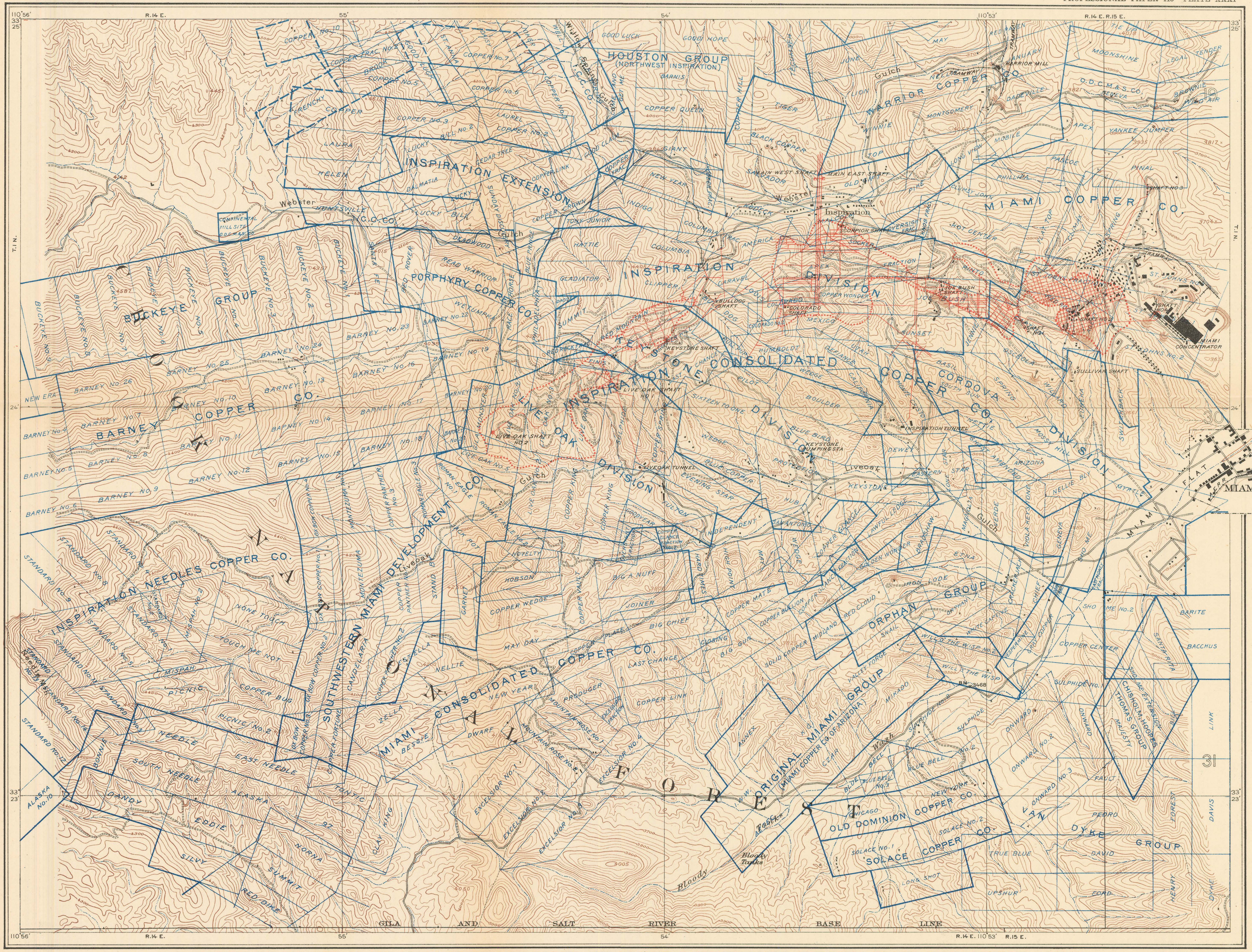


FIGURE 6.—General plan of land ownership, ore bodies, and reduction works in the Miami district. Reduced from a map prepared by the Inspiration Consolidated Copper Co. in 1916. Scale approximately 4,300 feet to the inch.



EXPLANATION

Claim

Claim group

Underground workings

Outline of ore bodies

MAP SHOWING TOPOGRAPHY, CLAIMS, CLAIM GROUPS, ORE BODIES, AND PRINCIPAL UNDERGROUND WORKINGS IN THE MIAMI DISTRICT, ARIZONA

R. B. Marshall, Chief Geographer.
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Surveyed in 1910.

Scale $\frac{1}{12000}$

Contour interval 25 feet.
Datum is mean sea level.

APPROXIMATE MEAN DECLINATION 1910.

Claim boundaries, underground workings, and outlines of ore bodies compiled in 1917 by F. L. Ransome from maps of the Inspiration Consolidated Copper Co. and the Miami Copper Co.

At the eastern tip of the bow is the ground of the Miami Copper Co.,[1] much of which lies east of the area shown in Plate XXXI.

This company, organized under the laws of Delaware, is capitalized at $4,000,000, with 800,000 shares at $5 par value. It is controlled by the General Development Co., or, as it is commonly expressed, by the "Lewisohn interests." The Miami Copper Co. owns over 1,000 acres, of which from 200 to 300 acres is held as known or prospective mining ground, the remainder being ranch land for water supply and land for storage of tailings. The total expenditure in preparation for mining and milling has been given as $4,157,000.[2] At the end of 1918 the company had produced 312,003,720 pounds of refined copper and had paid dividends amounting to $19,595,043.75—an achievement that speaks for itself.

Directly west of the Miami ground is the Inspiration group of the Inspiration Consolidated Copper Co. The Inspiration Copper Co., organized in 1908 under the laws of Maine, was capitalized at $10,000,000 with shares of $10 par value. The company owned the original Inspiration group, covering about 546 acres, with a ranch on Pinal Creek. Late in 1911 this company, after having acquired the Cordova group, which lies south of the Miami group, was consolidated with the Live Oak Copper Co., and soon afterward bought additional ground in Webster Gulch for railway and milling purposes. The Inspiration Consolidated Copper Co., also a Maine corporation, is capitalized at $30,000,000 with 1,500,000 shares of the par value $20. As given in the company's annual report for 1916, the distribution of these shares was as follows:

	Shares.
Issued and outstanding	1,181,967
Unissued	318,033
	1,500,000

West of the Inspiration group on the ore bow is the Keystone group, 243 acres, formerly owned by the New Keystone Copper Co., organized under the laws of Delaware with an authorized capital of $3,000,000 in shares of $5 par value. Early in 1915 the New Keystone property was purchased by the Inspiration Consolidated Copper Co. for $795,940, payable in shares of Inspiration stock at $20 a share.

Finally, at the west tip of the ore bow, as at present determined, is the Live Oak group of about 200 acres, which, as previously mentioned, is also now the property of the Inspiration Consolidated Copper Co.

Both the Keystone and Live Oak groups produced considerable chrysocolla ore from veins in granite porphyry before the importance of the disseminated ore was realized.

The Inspiration Consolidated Copper Co.'s lands were classified by the company in its 1916 report as follows:

	Acres.
Mining lands	1,870
Lands for mill site, tailings disposal, water-supply, etc.	2,346
	4,216

At the end of 1918 the Inspiration Co. had produced 319,946,970 pounds of copper and had paid dividends amounting to $27,955,014.50.

West of the Live Oak group lies the Barney group, 450 acres, owned by the Barney Copper Co., organized under the laws of Arizona with an authorized capital of $5,000,000 in shares at $5 par value. Considerable prospecting has been done on this group, but the drill holes have not yet shown the presence of ore in commercial quantities. Similar statements might be made with reference to the Montezuma group, southwest of the Live Oak group, which has been prospected by the Southwestern Miami Development Co.; to the Schultze group, still farther southwest, explored by the South Live Oak Development Co.; and to the Needles group, which partly incloses the west end of the Barney group. North of the Miami and Inspiration groups are the large holdings of the Warrior Copper Co.,[3] originally embracing 1,158 acres, in two main groups, of which a part only of the southern (Black Warrior) group is shown in figure 6 and Plate XXXI. This ground has produced large quantities of ore,

[1] For details of organization, property, equipment, and methods of mining, see annual reports of the Miami Copper Co.; also the following papers:

Stevens, H. J., Copper Handbook, 1910–11, pp. 1158–1162, 1911.

Channing, J. P., The Miami mill: Min. and Met. Soc. America Bull., vol. 4, pp. 86–88, 1911.

Tolman, C. J., jr., The Miami-Inspiration ore zones: Min. and Sci. Press, Nov. 13, 1909, pp. 646–658.

Bowen, H. P., Data on Miami churn drilling: Eng. and Min. Jour., vol. 97, pp. 902–903, 1914; Engineering notes and methods at Miami: Idem, vol. 100, pp. 15–17, 1915.

Scott, D. B., Stoping methods of Miami Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 137–153, 1917.

Deane, E. G., The block method of top slicing of the Miami Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 240–244, 1917.

[2] Eng. and Min. Jour., vol. 95, p. 1102, 1913

[3] See Stevens, H. J., Copper Handbook, 1910–11, pp. 1799–1801, 1911, for details.

chiefly chrysocolla, from the Montgomery and Dadeville claims, but disseminated sulphide ore has not been found in workable quantity, although it should be added that the ground has not been thoroughly explored.

A considerable part of the land in the northeastern part of the Black Warrior group, near the mouth of Webster Gulch, was purchased by the Inspiration Consolidated Copper Co. for its concentrator site. The same company acquired also the Little Miami group, north of the Miami group.

Sampling is a far more important matter in connection with low-grade disseminated ores than in ore of higher tenor with more definite limits. In all the mines in the Miami district the sampling is kept close up to the working faces. All drifts, crosscuts, and raises within the general ore zone are sampled at intervals of 5 feet, and the assay results are entered on detailed assay maps. A portion of such an assay map, showing the transition from ore to slightly enriched sulphides, is reproduced as figure 7.

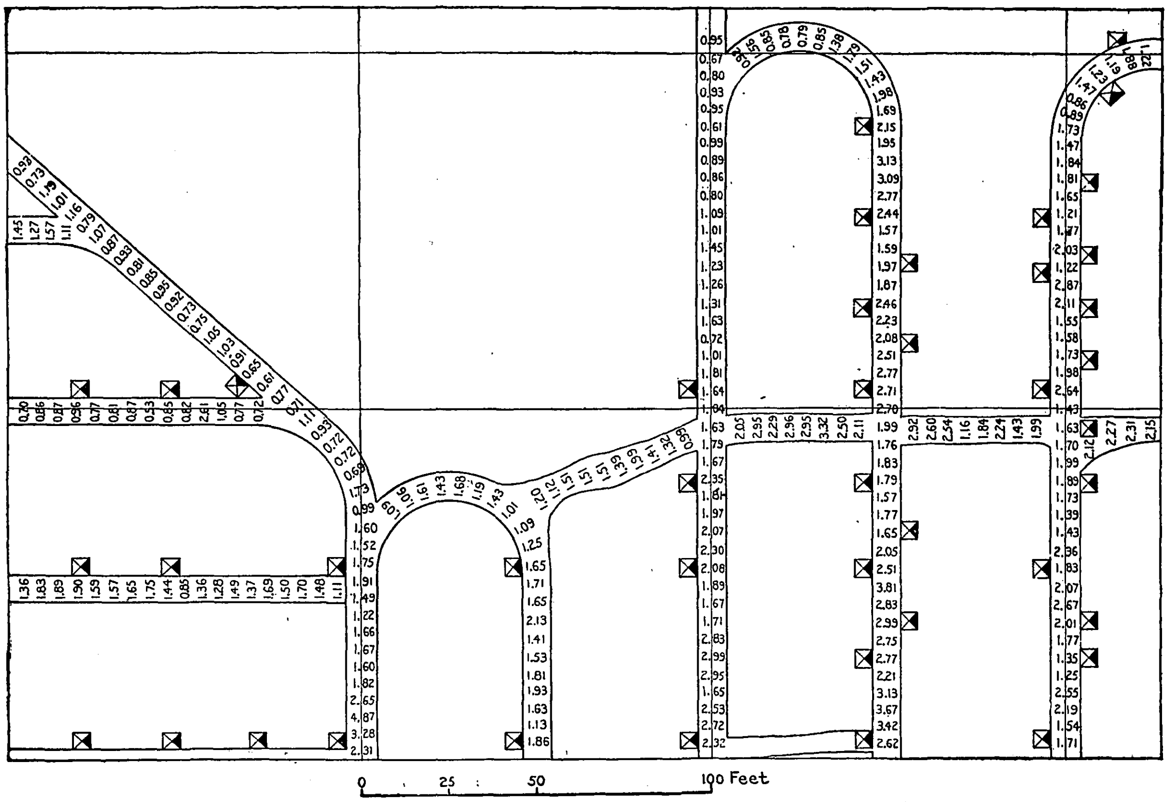


FIGURE 7.—Portion of an assay level map of one of the mines in the Miami district, showing method of recording assays.

UNDERGROUND DEVELOPMENT.

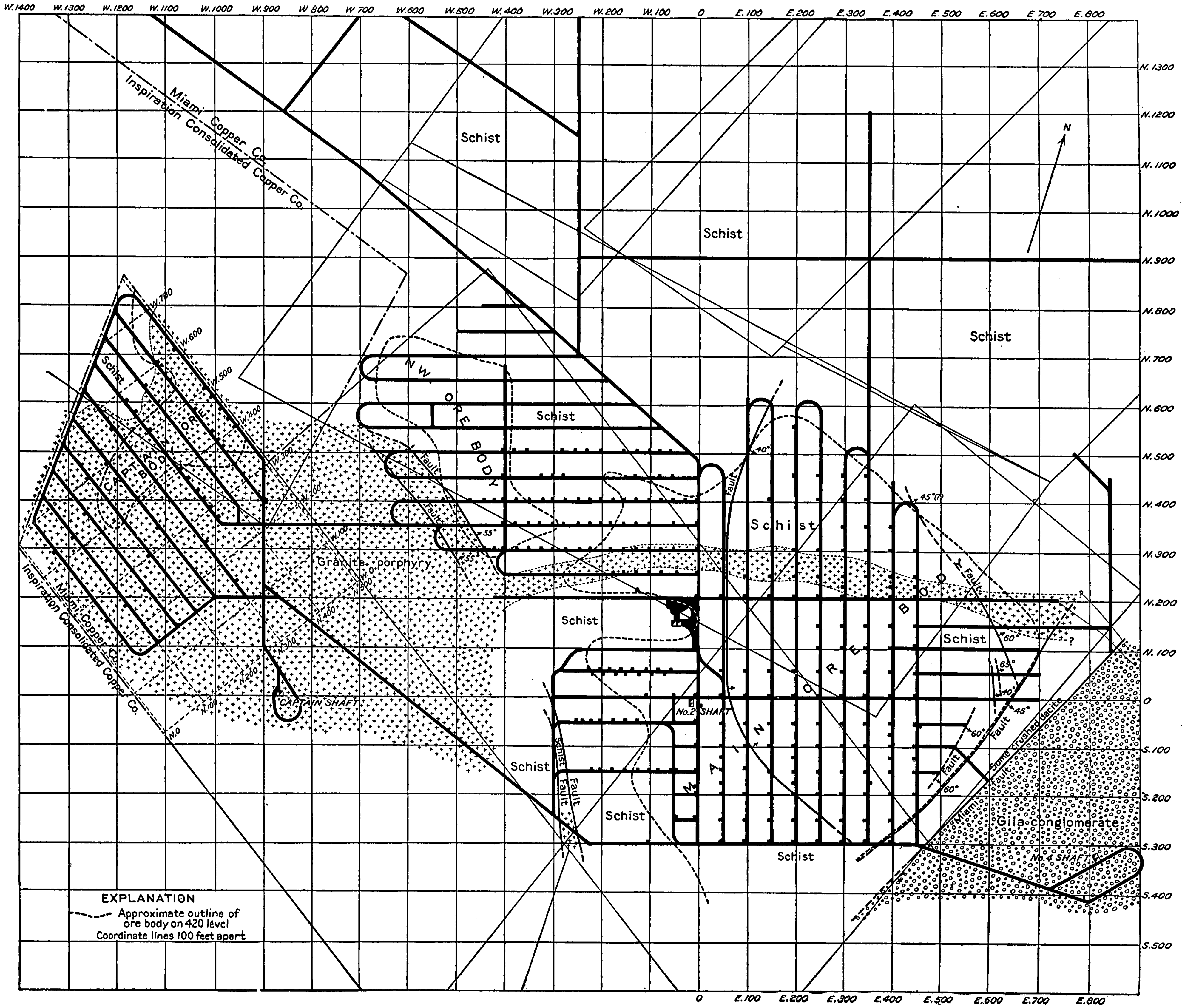
GENERAL CHARACTER.

Work underground in the Miami district proceeds with such rapidity that any detailed description of mine workings becomes obsolete before it can be published. Partly on this account and partly for the reason that in mining for disseminated ore the levels are laid out as vertically superposed rectangular lattices which, as displayed on a map, have less geologic significance than levels driven along a lode, the descriptions that follow, both of the mines at Miami and of those at Ray, will be of a brief and general character.

MIAMI MINE.

The Miami ore body was discovered and its general extent determined by the ordinary mining methods of sinking, drifting, and crosscutting. Afterward, however, this work was supplemented and the range of exploration extended by the use of churn drills.

There are four shafts. The No. 1 shaft, situated on the Captain claim, proved to be about 450 feet southwest of the main ore body. It was extended in 1913 to the 420-foot level and is used for men and supplies. Shaft No. 2, 720 feet deep, is on the Red Rock claim, 850 feet northeast of the No. 1 shaft. It penetrated



GEOLOGIC PLAN OF THE 420 LEVEL OF THE MIAMI MINE.

the ore body centrally and was the principal working shaft throughout the period of preliminary mine development, but was lost in 1913 through the caving of the ground. Shaft No. 3, in the northeast corner of the Red Spring claim, is about 2,200 feet northeast of the No. 2 shaft and is approximately 1,500 feet away from the main ore body. It is not in use except as a downcast for ventilation. No. 4, the largest shaft, is on the St. Johns No. 1 claim, in the Gila conglomerate, and is about 450 feet east of the ore as at present blocked out. This is the main working shaft, through which all ore is hoisted in balanced 7½-ton Kimberley skips. It is 12 by 16 feet in the clear and 710 feet deep. It has two skip compartments, one 5 by 11 foot cage compartment, and one pipe and ladderway compartment. There are two geared hoisting engines, operated by steam, one for raising ore and the other for moving men and supplies. The hoisting capacity is 500 tons of ore an hour.[1]

The mine has 12 levels, designated with respect to the depth of each below the collar of the No. 2 shaft as follows:

Levels of the Miami mine.

Designation and depth below collar of No. 2 shaft.	Distance to shaft station next above.	Approximate elevation above sea level, with collar of No. 2 shaft taken as 3,730 feet.
	Feet.	*Feet.*
220-foot	220	3, 510
245-foot	25	3, 485
270-foot	25	3, 460
295-foot	25	3, 435
320-foot	25	3, 410
345-foot	25	3, 385
370-foot	25	3, 360
395-foot	25	3, 335
420-foot[a]	25	3, 310
470-foot	50	3, 260
570-foot[a]	100	3, 160
720-foot[a]	150	3, 010

[a] Haulage levels, 150 feet apart.

Of these levels the 370-foot is known also as the "first mining level" for the main ore body—that is, the level above which stoping is to be confined until the upper part of the mine has been worked out. For the Captain ore body, the 245 is the "first mining level." The levels above the 370 are referred to as "sub-mining levels." The 420-foot level (Pl. XXXII) is a tramming level, through which all the ore from the levels above is hauled to the shaft in trains drawn by electric locomotives. In the northwestern and southeastern portions of the mine the 395-foot level is a sublevel, from which is controlled the drawing of ore from the stopes into the loading pockets that deliver to the tramming level. The 570 and 720 levels will in turn become haulage levels for the deeper stages of stoping. The ore is hauled to the shaft in trains of 30 to 40 3½-ton cars drawn by 6-ton electric locomotives. The tracks are 2-foot gage, laid with 45-pound rails. The total length of the drifts run to the end of 1916 was about 38 miles. The mine is ventilated by means of two fans, each with a capacity of 60,000 cubic feet.

The arbitrarily assumed "north" of the Miami system of mine coordinates and drifts is 18° 1′ west of true north. In the northwestern and southwestern parts of the mine the principal tramming drifts run parallel with the stopes, whereas in the Captain ground, as in the Ray mines, they are at right angles to them. The general plan of the levels is that of a rectangular lattice with intervals of 50 feet. In other words, on each level the ore is blocked out in 50-foot squares. Raises at the drift intersections connect each level with those above and below.

West of the main Miami ore body, in the northwestern part of the Captain claim, is what is known as the Captain ore body. This is really the extension eastward into Miami ground of the Inspiration ore body. Although on Plate XXXI a connection is indicated between the Captain ore body and the main Miami ore body, the slender neck of connecting material is partly oxidized and may be rather doubtfully classed as ore. For all practical purposes the two ore bodies in the Miami mine are distinct, drifts from one to the other going through barren ground.

The Captain levels are at 80, 107, 135, 190, 245, 270, 345, 370, 395, and 420 feet below the collar of No. 2 shaft. The Captain workings are laid out on a separate coordinate system, of which the "north" is 33° 58′ east of true north. In other words, the north and south

[1] For technical details of shaft, hoisting equipment, mill and power plant, see Stevens, H. J., Copper Handbook, 1911-12, pp. 1159-1162, and the company's annual reports.

drifts in the Captain workings make an angle of nearly 51° with the north and south drifts of the main Miami workings. This difference and the fact that in the Miami mine "north" may mean true north, magnetic north, N. 18° W., or N. 33° 58′ E. ("Captain north") are rather confusing to anyone not thoroughly familiar with the mine maps and with local usage.

The upper surface of the Miami main ore body was not flat but, as may be seen from figure 8, swelled upward into three rounded hill-like protuberances, two of which were considerably larger and higher than the other. The levels above the 345-foot were laid out for the purpose of stoping these hillocks so as to allow the overburden to cave down to an approximately horizontal surface over the main body of the ore. Consequently these upper levels were not of great extent and did not long remain open. They coincided roughly with the areas inclosed by the corresponding contours of figure 8. The 420-foot and 570-foot levels connect with the No. 4 shaft, and the 470-foot level with the No. 3 shaft. The 420-foot level also connects with the No. 1 shaft.

The Miami Co. in 1916 had on its mine pay roll about 640 men—590 underground and 50 on the surface. It was producing in September of that year 5,455 tons of ore daily. About 200 men are employed in the mill.

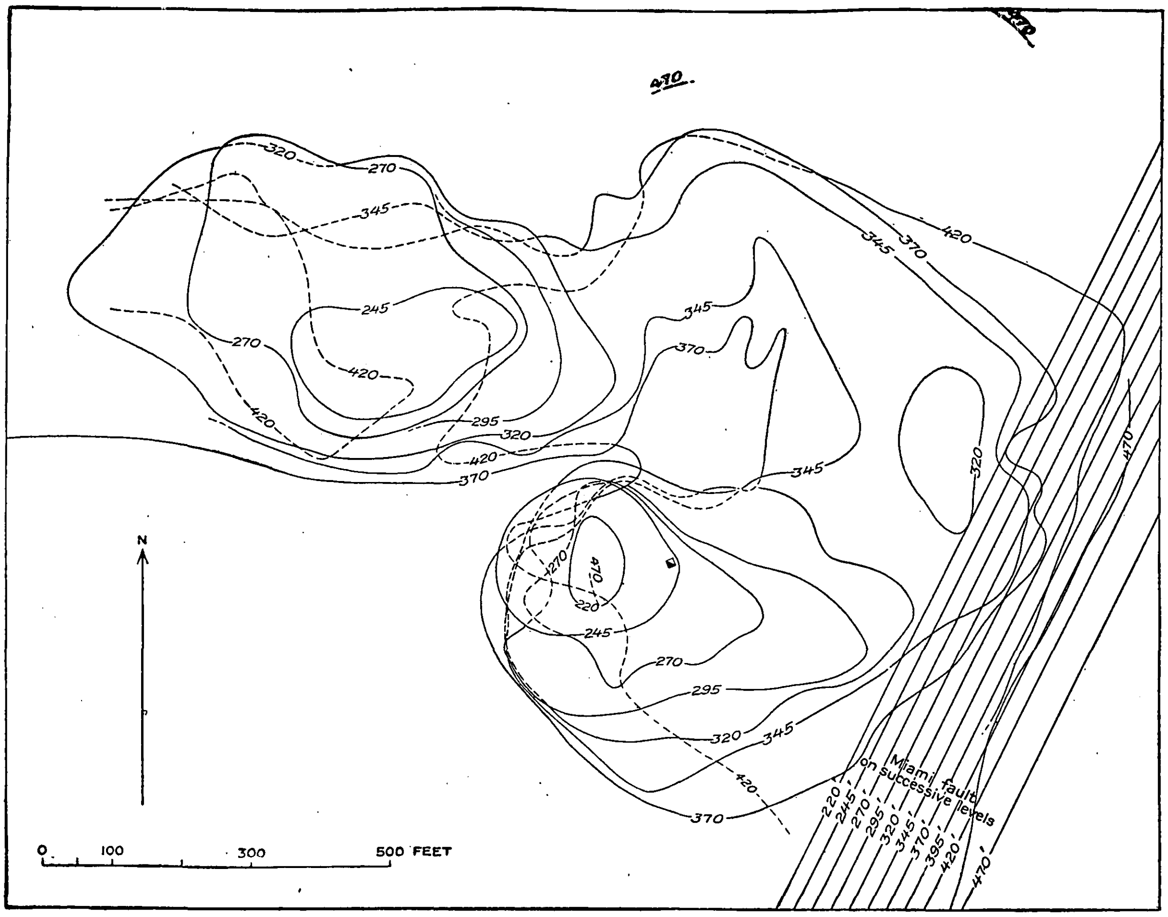
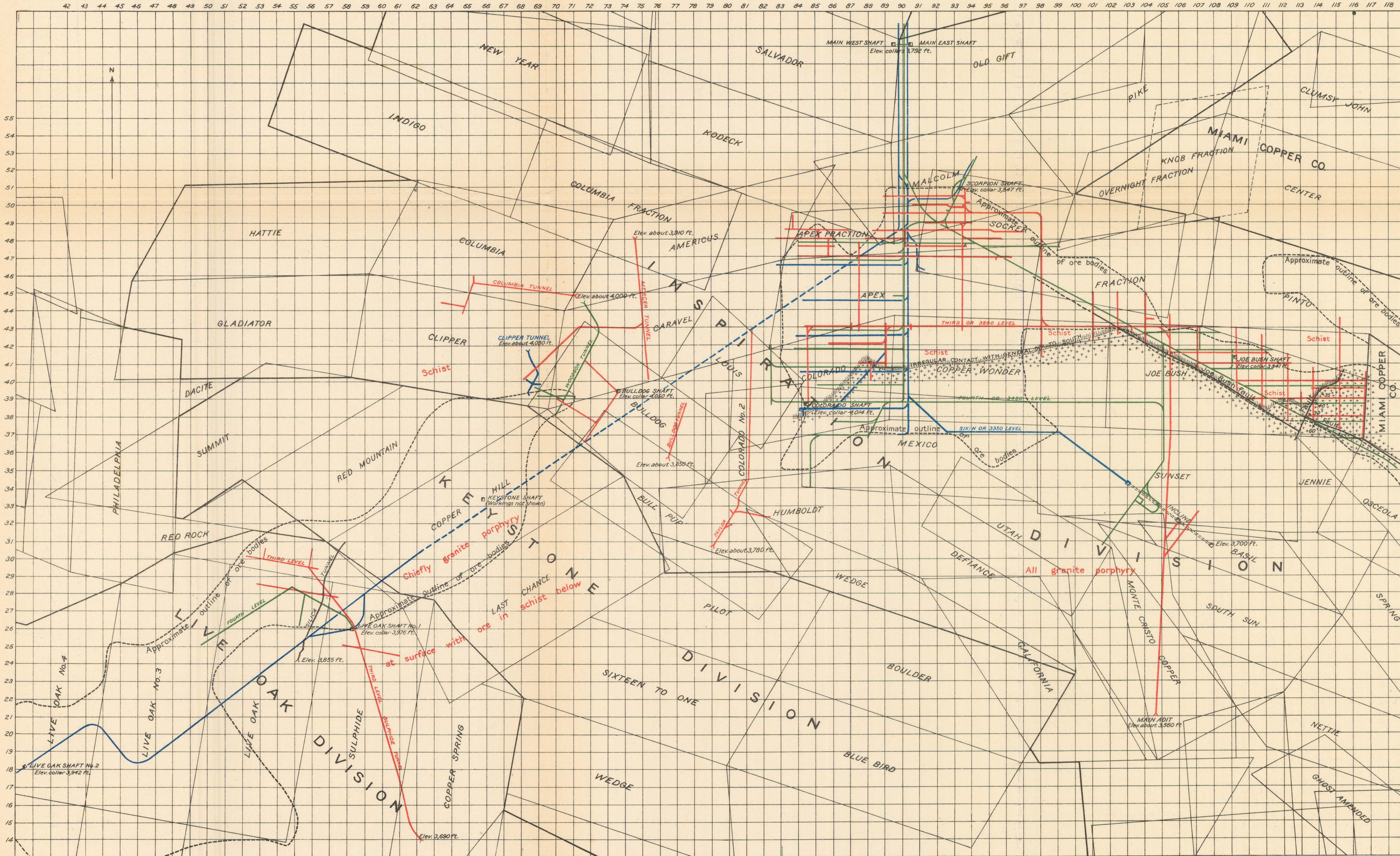


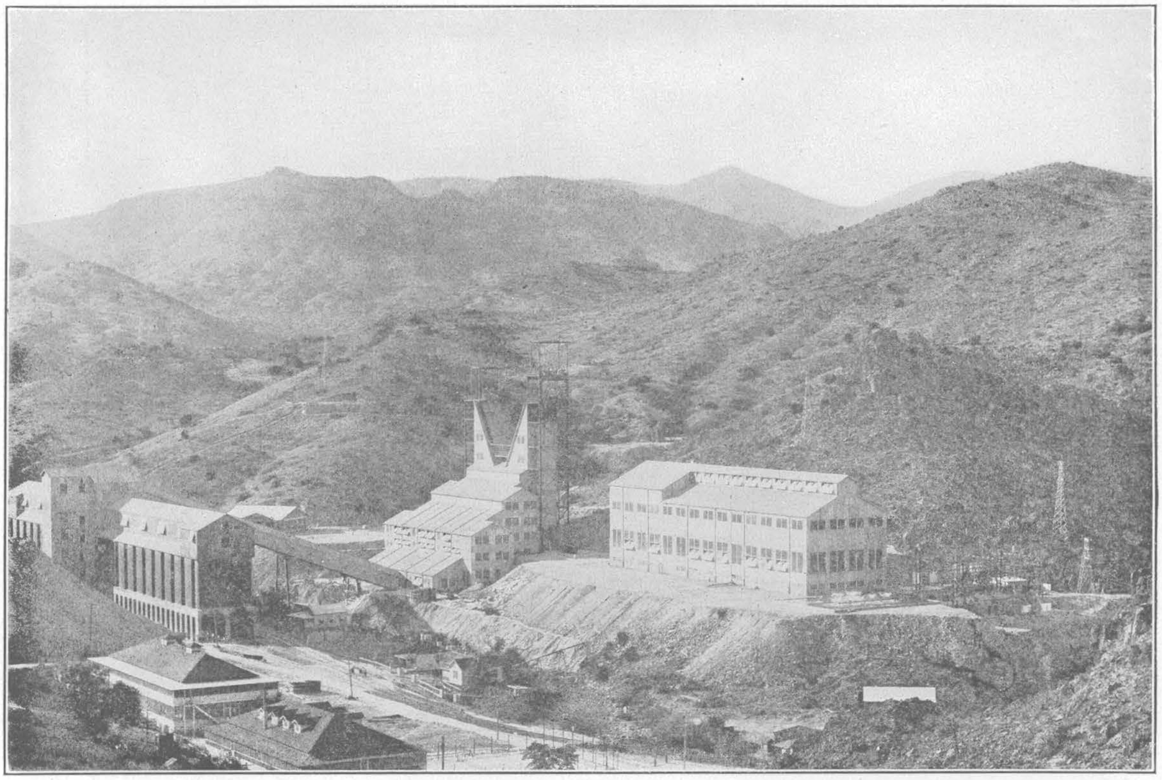
FIGURE 8.—Diagram showing by contours on each mine level the approximate shape of the Miami ore body. Figures affixed to contour lines show depth in feet below the collar of the No. 2 shaft. Dotted contours indicate overhang—that is, they are drawn on the underside of the ore body.

INSPIRATION MINE.

The workings of the Inspiration mine (Pl. XXXI) extend westward under Inspiration Ridge for 3,300 feet from the Miami ground and open southward through a 2,000-foot adit into Liveoak Gulch. Horizontally they ramify over a much greater area than those of the Miami mine, but the ore as yet is less thoroughly blocked out.

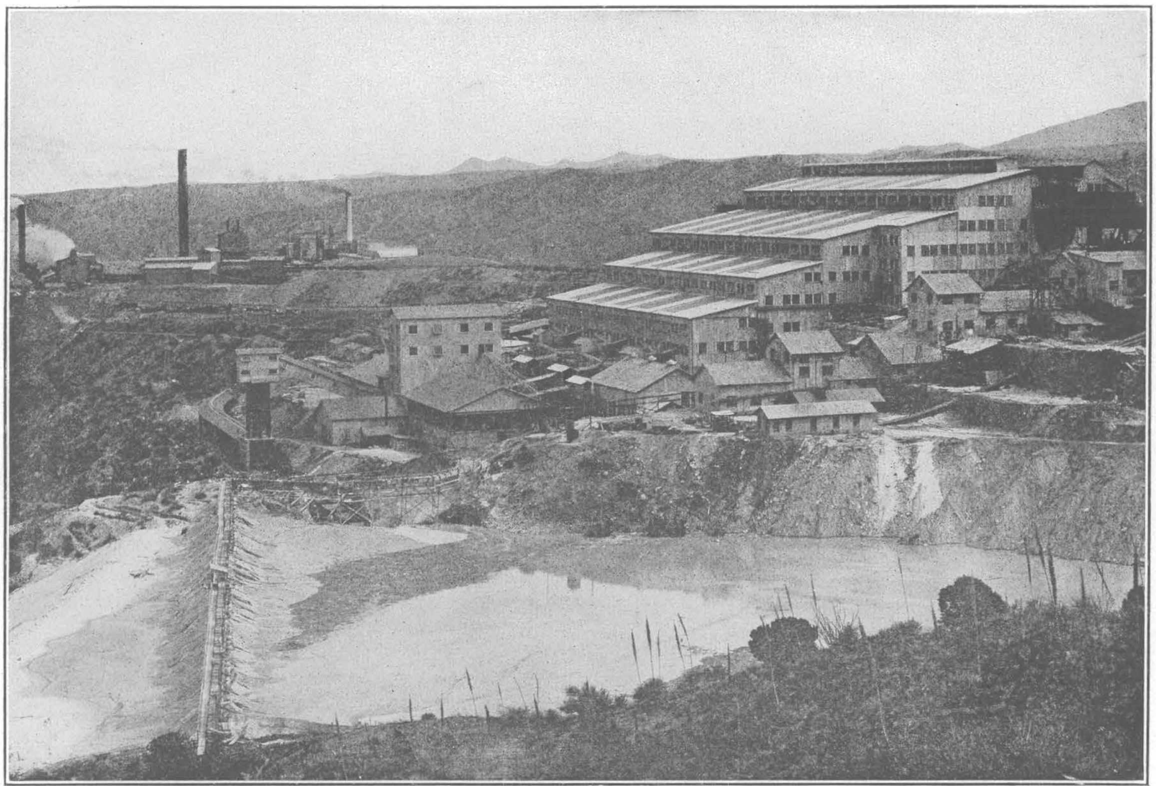


GENERAL PLAN OF THE INSPIRATION CONSOLIDATED COPPER CO.'S UNDERGROUND WORKINGS
SHOWING PRINCIPAL HAULAGE LEVELS AND OUTLYING PROSPECTING WORK
Coordinate reference lines are 100 feet apart



A. HOIST AND COMPRESSOR HOUSE AND COARSE-CRUSHING PLANT AT THE MAIN SHAFTS.

Looking northwest. Photograph from the Inspiration Consolidated Copper Co.



B. CONCENTRATOR.

On the left is the International smelter. The even slope of the Gila conglomerate is well shown in the background, and in the distance appears the Pinaleno Range, west of Solomonsville. A small part of the Pinal Range is seen on the right. The view is nearly south. Photograph from the Inspiration Consolidated Copper Co.

SURFACE EQUIPMENT OF THE INSPIRATION CONSOLIDATED COPPER CO.

Before beginning of stoping, in July, 1915, the lengths of the various kinds of underground openings were as follows:

	Miles.
Shafts	1.2
Haulage ways	7.7
Ordinary drifts	21.1
Main raises	21.2
Finger raises	2.5
	53.7

During 1916 fully 28 miles of underground openings were driven and 31 miles of earlier work were destroyed by caving operations.

Most of the underground exploratory work was accomplished through the Scorpion shaft, 545 feet deep, on the north side of the ridge, and the Joe Bush shaft, 500 feet deep, on the south side. The Colorado shaft, 635 feet deep, also connects with the main workings on the south side of the ridge. The positions of these shafts may be seen from Plates XXXI and XXXIII.

In 1912 work was begun on two large vertical shafts known as the Main West and Main East shafts. They are situated 104 feet apart in Webster Gulch, well north of the ore body, and are 585 feet deep. These shafts, lined with concrete, were finished in 1915. Each has three compartments. Two in each shaft are occupied by 12½-ton skips, operated by automatic electric hoists. The third compartment in one shaft contains a double-deck passenger elevator, counterbalanced by a weight running in the third compartment of the other shaft.

The surface equipment at these shafts (Pl. XXXIV, *A*), including the mine compressor and hoist house, coarse crushing plant, and ore bins, is in keeping with the scale and thoroughness of this company's operations throughout.[1] At the time of last visit, in September, 1916, about 18,000 tons of ore was hoisted in 16 working hours each day.

An inclined shaft on the south side of Inspiration Ridge, about halfway between the Joe Bush shaft and the portal of the main adit, also connects with the principal levels.

[1] For details of equipment see the following:
Burch, H. K., and Whiting, M. A., Automatic operation of mine hoists as exemplified by the new electric hoists for the Inspiration Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 10-23, 1917.
New man-hoist at Inspiration: Eng. and Min. Jour., vol. 101, pp. 476-477, 1916.
Company's annual report for 1913.
Burch, H. K., Mine and mill plant of the Inspiration Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 707-740, 1917.

The Inspiration mine levels are as follows:

Levels of the Inspiration mine.

Designation.	Distance to shaft station or level next above.	Elevation above sea level.
	Feet.	*Feet.*
Sublevel 6	....	....
Sublevel 5½	....	3,685
Sublevel 5	35	3,650
Sublevel 4½	35	3,515
Sublevel 4 or third level[a]	35	3,580
Sublevel 3½	35	3,545
Sublevel 3	35	3,510
Sublevel 2½ or fourth haulage level	30	3,480
Sublevel 2 (old Joe Bush 400 level)	40	3,440
Sublevel 1½	30	3,410
Sublevel 1	30	3,380
Sixth haulage level	30	3,350

[a] Also referred to as the Tunnel level.

These designations, it must be confessed, are not readily grasped and used by the visitor, although fortunately the rectangular system of coordinates and drifts in the Inspiration mine has a true north-south and east-west orientation. The most extensive level is the third or Tunnel level. This connects all shafts with the tunnel portal in Liveoak Gulch.

West of the main workings are the Bulldog shaft, 300 feet deep, and six exploratory tunnels. All work in these had been abandoned in 1912. Their relative positions and their relation to the topography may be seen from Plates XXXI and XXXIII. The Woodson tunnel is of interest as being the place where the disseminated ore of the Miami district was first mined on a profitable scale and as having thus given the clew to the mining possibilities that are now in process of realization.

The ground of the Inspiration group, in addition to the mining development mentioned, has been extensively and in part thoroughly explored by churn drilling, so that the outlines of the main ore body are fairly well known.

To connect the main shafts in Webster Gulch with its concentrator, 1½ miles away, with the International smelter, and with the Miami branch of the Arizona Eastern Railroad, the Inspiration Co. has built about 4½ miles of standard-gage railway.

KEYSTONE MINE.

The old Keystone workings on a vein of chrysocolla, as they were in 1902, were briefly described in the Globe report.[1] These were considerably extended during subsequent years but are now abandoned and were not examined in 1912.

The new shaft, about 600 feet northeast of the old tunnels, is 330 feet deep. Levels 150 and 250 feet below the collar block out the ore, for the most part in rectangles 100 by 200 feet. The orientation of the rectangular level system is 20° 40′ west of true north.

LIVE OAK MINE.

Like the Keystone, the Live Oak mine formerly produced much chrysocolla from a vein in granite porphyry. The old tunnels and stopes are all above the modern workings.

The Silica tunnel of the Live Oak workings follows a vein of chrysocolla in granite porphyry. This was stoped to the surface. An inclined shaft was sunk on this vein, but the first level, 32 feet vertically below the collar, proved to be below the main ore body. A second level, 70 feet below the collar, was as disappointing as the first. The third level, about 95 feet below the second, is the sulphide tunnel, which has its portal in Liveoak Gulch and connects with the No. 1 vertical shaft, 496 feet deep in August, 1912, at a depth of 273 feet. The vein originally worked does not appear on this level, although a crosscut of 350 feet was run to find it. Later work has been devoted to opening up a body of disseminated ore northwest of the shaft, both on this level and on the fourth level, 117 feet below the sulphide tunnel. In April, 1912, this level was being extended southwest to connect with the No. 2 shaft, then just completed, but work on the connecting drift was afterward stopped. This shaft, about 2,000 feet southwest of the No. 1 shaft, is 1,181 feet deep. It has levels opened at 800 and 900 feet. The drifts from this shaft run northwest and northeast. At the date of writing (July, 1917) the fourth level of the Inspiration workings has apparently not yet been extended to a connection with the Live Oak workings, through the Keystone ground.

In addition to the underground work the Live Oak ground has been carefully explored by drilling on a rectangular coordinate net oriented 10° east of north.

[1] U. S. Geol. Survey Prof. Paper 12, pp. 160-161, 1903.

WARRIOR MINE.

Although the Warrior mine is not one of those on the known belt of disseminated ore, it is so close to them as to deserve brief description here. The principal workings are on the Dadeville, Montgomery, and Winnie claims, and the levels, although rather irregular, trend as a whole nearly east and west, for a distance of about 2,500 feet. The most extensive level is a tunnel, at an altitude of about 3,790 feet, with one portal on the Nellie claim, near the bottom of Webster Gulch, and another on the Dadeville claim, in a small side ravine about 1,000 feet to the east-southeast. There are shorter levels at distances of about 40 and 80 feet above the main level and at 50 and 130 feet below it. In general the workings become lower from east to west, as they follow a flat-lying strip of ore, 160 feet in greatest width, which dips in that direction at an angle of about 12°.

DRILLING.

Churn drilling has played a very important part in the development of the Miami district, notwithstanding the fact that the Miami ore body was discovered and was extensively explored by other methods.

Some of the earlier holes were irregularly placed, but the general plan on the ground now owned by the Inspiration Consolidated Copper Co. has been to test the ore zone and define its limits by holes placed 200 feet at the intersections of a regular system of rectangular coordinates. Drifts subsequently run follow these same lines and intersect the drill holes. On outlying properties, where the presence of ore in commercial quantity has not been demonstrated, scout holes are put down with less attention to regular spacing and alinement.

On the Live Oak ground, where the ore in general is deeper than elsewhere in the ascertained zone, there were in February, 1914, 105 drill holes, ranging from 237 to 1,113 feet in depth. Farther east, on the Inspiration and Miami groups, the holes are generally not so deep. The deepest hole in the district is that drilled by the Miami Co. southeast of its No. 4 shaft. This hole was abandoned in the Gila conglomerate at 2,050 feet. A hole started from the bottom of the 300-foot Barney shaft reached a depth of 1,448 feet below the surface. On the Montezuma group No. 1 hole, of the

Southwestern Miami Development Co., is 1,285 feet deep and No. 2 hole 1,240 feet deep. Probably before this report is printed still deeper holes will have been bored in the outlying parts of the district.

The drilling has been accomplished for the most part with portable rigs of the Star type, although some Keystone rigs were used. The initial diameters of the holes range from 10 to 22 inches. The total cost per foot of hole, including road building, varies widely with circumstances, but the average for holes less than 600 feet deep was between $2 and $3.[1] Some of the deep Live Oak holes and of course the deep Miami hole were much more expensive.

The passage of the hole from the oxidized capping into ore or unoxidized rock is recognizable by a distinct change in the color of the sludge from reddish to gray. Although the

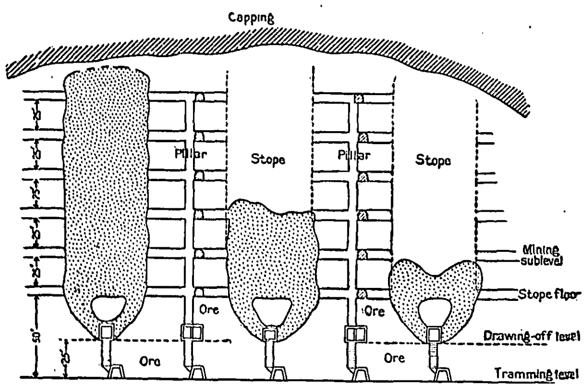


FIGURE 9.—General cross section through stopes and pillars in the Miami mine, showing method of stoping. (After D. B. Scott.)

logs of some of the earlier holes are not wholly trustworthy, the records of rocks passed through in most of the borings have been carefully kept by the engineers in charge and are reliable. With a little experience the sludges derived from the Gila conglomerate, dacite, schist, and porphyry are, as a rule, readily distinguishable. Except where the rock is obviously barren the sludge is dried, sampled, and assayed for every 5-foot vertical interval. So far as could be ascertained there is no large or constant discrepancy between the results obtained by drilling and those obtained by subsequent drifting, although on ore containing about 2 per cent of copper many of the drill samples assayed about 0.2 per cent less than drift samples.

[1] Weber, W. G., Methods and costs of operating well-drilling machines in prospecting for copper: Engineering—Contracting, vol. 33, pp. 401-402, 1910 (condensed from a paper in Wisconsin Engineer, April, 1910).

STOPING.

The general plan of stoping as originally worked out for the Miami mine by Mr. N. O. Lawton, its first superintendent, has been described by C. F. Tolman, jr.[2] That plan, however, has been modified as work proceeded. The Captain ore body and the southwest and northwest parts of the main ore body are worked by a so-called "shrinkage-stope" method which has been described in detail by D. B. Scott, the company's mine efficiency engineer.[3] In brief the system comprises a main tramming level, a drawing-off level 25 feet above it, and sublevels, for use in stoping, at intervals of 25 feet above the drawing-off level. In the Miami mine the first tramming level is the 420. The main tramming drifts are 50 feet apart longitudinally, and originally a stope 50 feet wide was carried over every other drift, leaving pillars 50 feet wide between. (See fig. 9.) Recently, however, in the Captain ore body, the rooms and pillars have been made narrower. Stoping begins 50 feet above the tramming level, and as the miners work upward only so much of the broken ore is drawn off as will leave working space between it and the top of the stope. As a rule, about 39 per cent of the broken ore must be drawn to provide working space and to make room for the increased volume of the broken material. After the completion of the stopes the intervening longitudinal pillars are broken up, the miners working from the top down and retreating through the drift and crosscuts in the solid portion of the pillar. Systematic drawing of ore usually begins when the mining in any section of the workings lacks about 30 per cent of completion. When the ore is all drawn and the overburden has caved down to the stope floor, the process is repeated from a lower tramming level.

In the eastern part of the mine the upper part of the ore body was mined by the square-set method. The expected collapse of the sets after the removal of the ore formed a thick mat of timber under which stoping has proceeded by top slicing and caving. A modified form of top slicing as developed at Miami has been described by Deane.[4]

[2] Min. and Sci. Press, Nov. 13, 1909, pp. 657-658.

[3] Stoping methods of Miami Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 137-153, 1917.

[4] Deane, E. G., The block method of top slicing of the Miami Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 240-244, 1917.

In 1912 mining by the modified "shrinkage-stope" method was costing about 76 cents a ton, including a fixed development charge of 31 cents a ton. Some of the ore mined by square setting was probably costing from $1.65 to $1.75 a ton. The total average mining cost in 1915 was $1.0158 a ton, the cost by different methods not being given. According to Deane, the cost by the block method of top slicing as used in 1916 was 88 cents a ton. In 1916 the Miami Co. was mining daily about 4,000 tons by shrinkage stoping and 2,000 tons by top slicing.

MILLING.

The first large modern mill to operate on disseminated ores in the district is that of the Miami Copper Co. (Pl. XXXVI). It is situated close to the No. 4 shaft and is a well-designed, very substantial building of concrete, steel, and iron, with an average capacity in 1916 of 5,074 tons a day. The details of its original equipment have been given by J. Parke Channing.[1] Recently, however, an annex for the treatment of ore by flotation has been added.

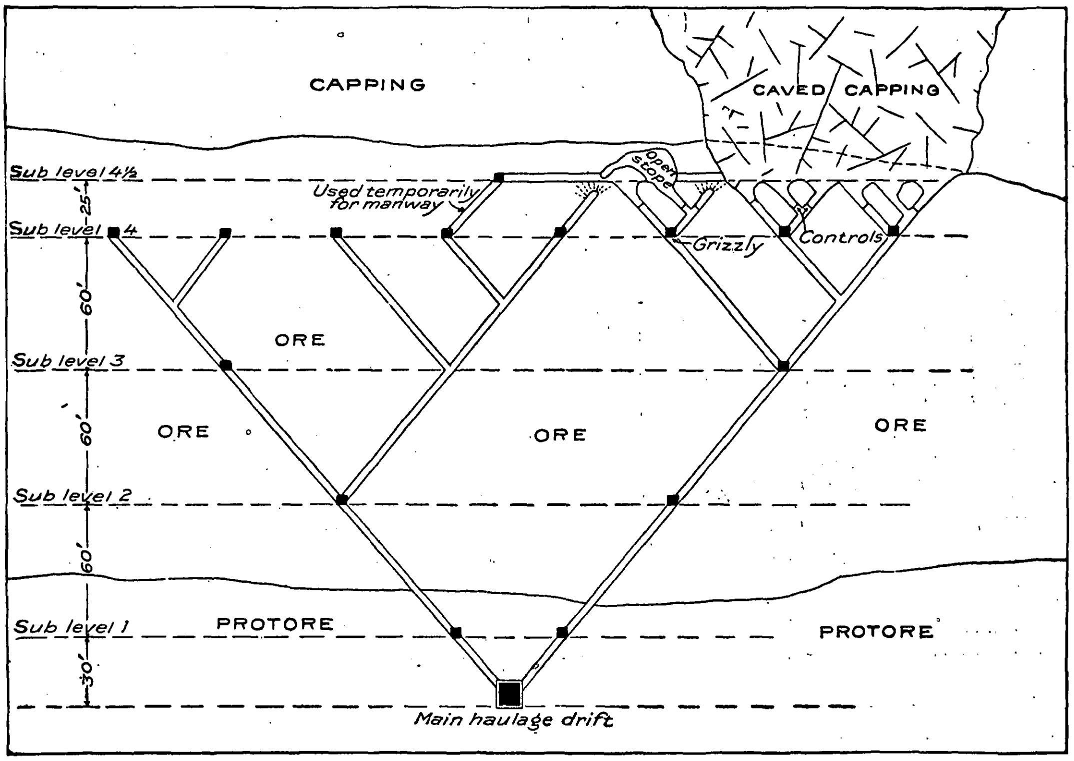


FIGURE 10.—General cross section showing method of stoping with inclined raises as used in the Inspiration mine. After W. C. Browning.)

The Ohio caving system used by the Inspiration Consolidated Copper Co. was adopted after careful experimentation with models to determine the extent to which the waste rock overlying a caving ore body would tend to be drawn downward funnel-wise to the points of discharge. As may be seen from figure 10, taken from sketches by Mr. W. C. Browning, the overburden is caved in sublevel stages of 70 feet drawn off through inclined raises that converge downward to the main haulage level.

The effects produced at the surface by mining in the Miami district are illustrated in Plate XXXV.

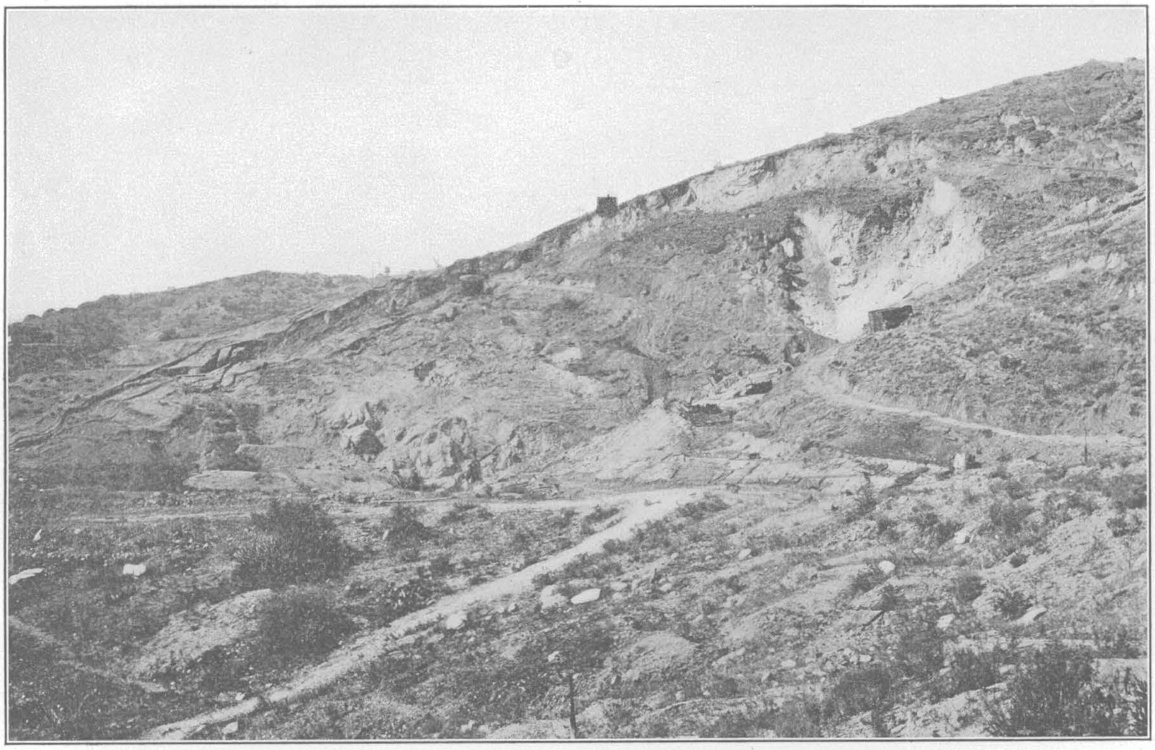
The ratio of concentration ranges from 18 to 21 into 1, and the extraction in 1915 was 75.17 per cent on ore averaging 2.17 per cent copper, and in 1916 was 73.88 per cent on ore averaging 2.07 per cent copper.[2] The concentrates carried 41.91 per cent of copper in 1915 and 42.49 per cent in 1916.

Power for milling as well as for mining purposes is furnished by the company's steam power plant in the town of Miami. Hoisting is at present (1916) done by steam.

[1] Min. and Met. Soc. America Bull., vol. 4, No. 36, pp. 86–89, 1911.
[2] Reports of B. Britton Gottsberger as general manager for the years 1915 and 1916.

A. VIEW WEST OVER THE PIT CAUSED BY MINING THE INSPIRATION ORE BODY NEAR THE FORMER JOE BUSH SHAFT.

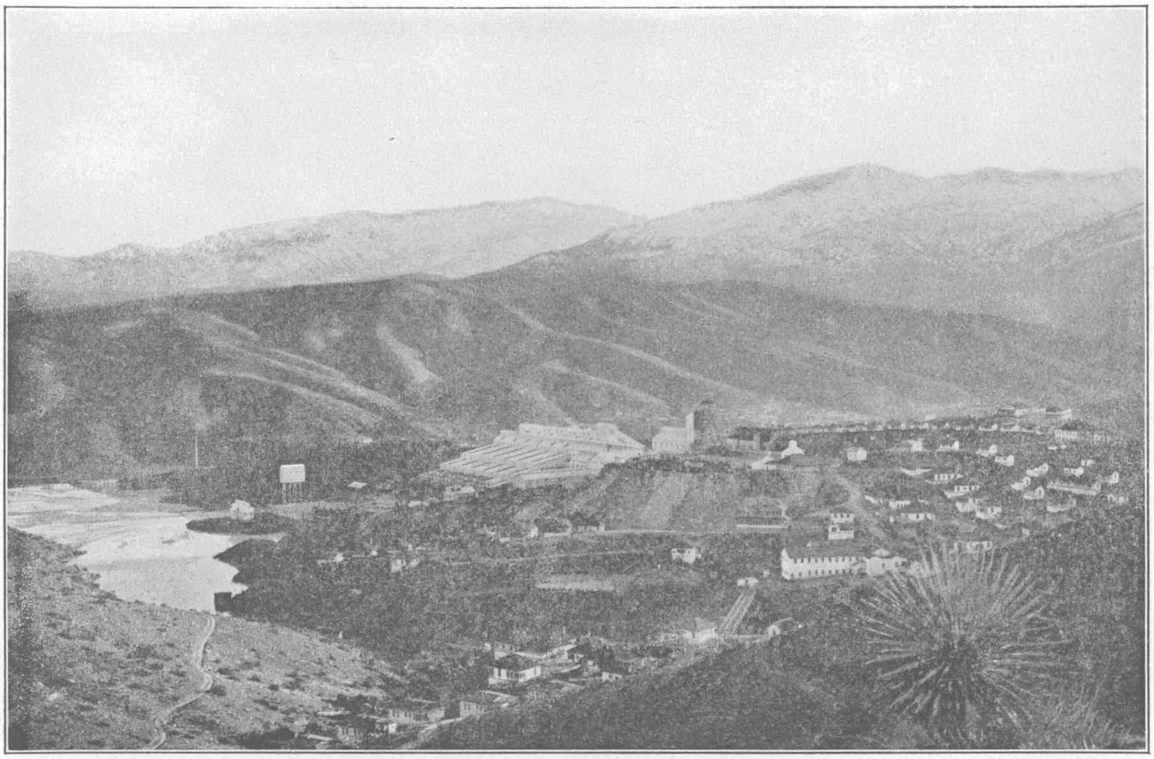
The overhanging cliffs on the left result from the breaking away of the footwall of the Joe Bush fault.



B. VIEW WEST OVER THE SURFACE ABOVE THE MAIN ORE BODY OF THE MIAMI MINE.

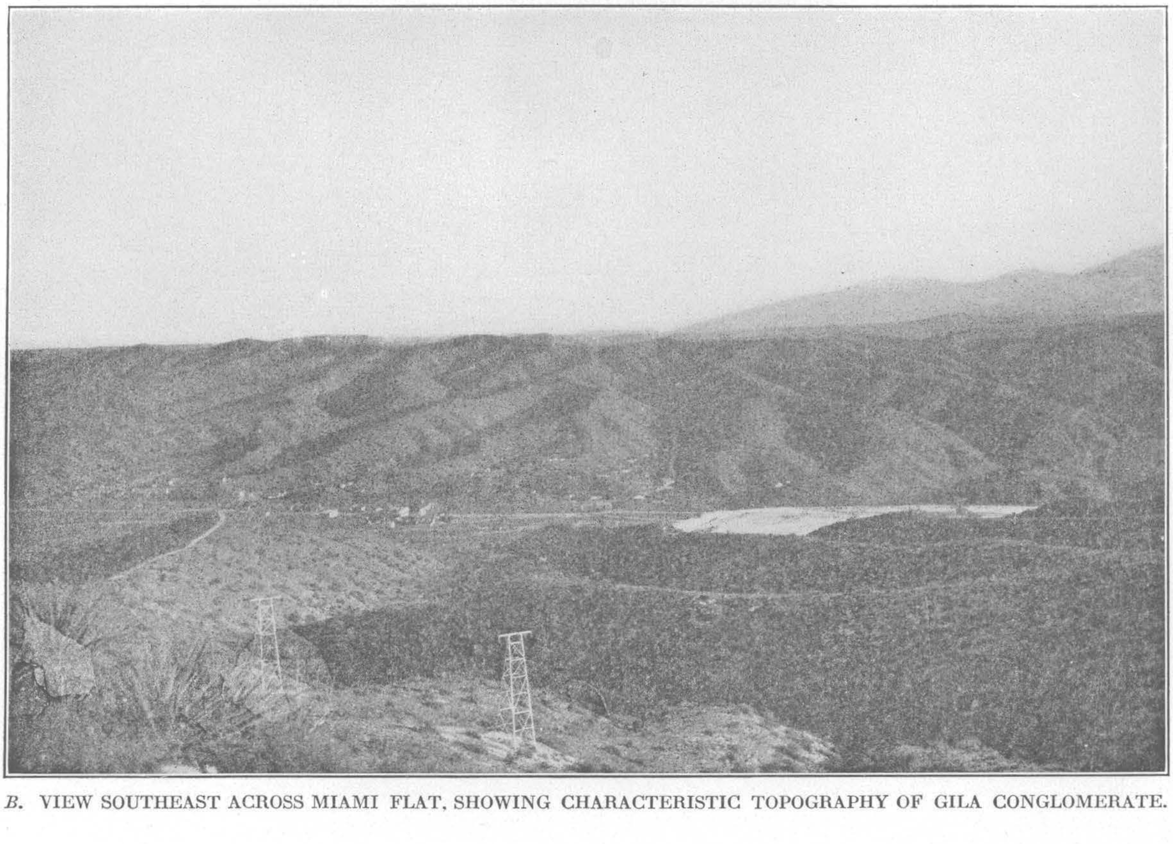
The No. 2 shaft was just to the left of the curved road in the right middle distance.

SURFACE EFFECTS OF MINING BY CAVING SYSTEMS IN THE MIAMI DISTRICT.



A. GENERAL VIEW OF THE MIAMI CONCENTRATOR AND NO. 4 SHAFT, FROM THE NORTHEAST.

Part of the town of Miami may be seen in the valley beyond the shaft, and a portion of the tailings pond on the left. The view shows well the spurs of Gila conglomerate lapping up on the granitic slopes of this part of the Pinal Range.



B. VIEW SOUTHEAST ACROSS MIAMI FLAT, SHOWING CHARACTERISTIC TOPOGRAPHY OF GILA CONGLOMERATE.

Water for milling and other purposes at the Miami mine is obtained mainly from the Old Dominion mine, about 7 miles distant, which supplies 2,000,000 gallons a day. An additional supply, probably from 500,000 to 1,000,000 gallons a day, is pumped from wells near Pinal Creek, a few miles north of Globe.

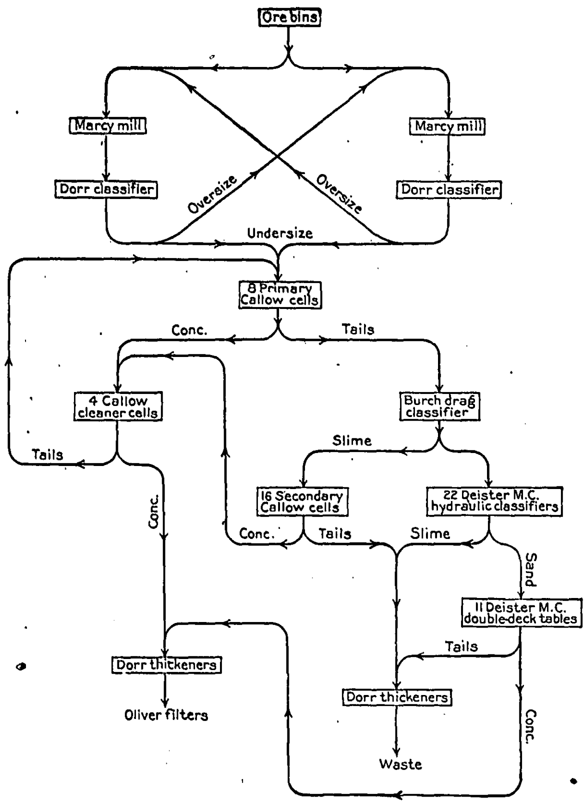


FIGURE 11.—Flow sheet of Inspiration concentrator sections equipped with Callow flotation machines.

The Inspiration mill [1] (Pl. XXXIV, *B*) is in Webster Gulch, about a mile and a half east of the main shaft. After much experimentation a combination of concentration by flowing water and by flotation was decided upon. The mill consists of 18 sections, each with a nominal capacity of about 800 tons a day, or a total of 14,400 tons. In August, 1916, 16,073 tons a day was being milled. The treatment comprises crushing the ore as it comes from the coarse-crushing plant at the mine, already reduced to 1½ inches maximum size, in Marcy ball mills to pass a 48-mesh screen, passage of the crushed ore through flotation machines, separation of the flotation tailings into sand and slimes, treatment of the sand on concentrating tables, re-treatment of the slimes in flotation machines, and removal of water from concentrates by filtration.

[1] See Burch, H. K., Concentration at Inspiration: Eng. and Min. Jour., vol. 102, pp. 411-415, 457-460, 1916 (abstract); Mine and mill plant of the Inspiration Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 707-740, 1917; Gahl, Rudolph, History of the flotation process at Miami, Ariz.: Am. Inst. Min. Eng. Trans., vol. 55, pp. 576-645, 1917.

In 1916 four sections of the mill were equipped with Callow flotation machines, 13 sections with Inspiration flotation machines, and one section with the Minerals Separation Co.'s machines, in which air is injected under stirring paddles. The general flow sheets for these three mill divisions are shown in figures 11 to 13.

In 1916 the average mill run was 14,850.1 tons of ore a day, carrying 1.548 per cent of copper. The average saving on all ores was 74.86 per cent and of the copper in sulphide form 90.95 per cent. It required 26.5 tons of ore to make a ton of concentrates. Not all the mill sections were running at the beginning of 1916, so that the above average does not measure the total capacity of the mill. The average in February, 1917, was 17,013 tons.

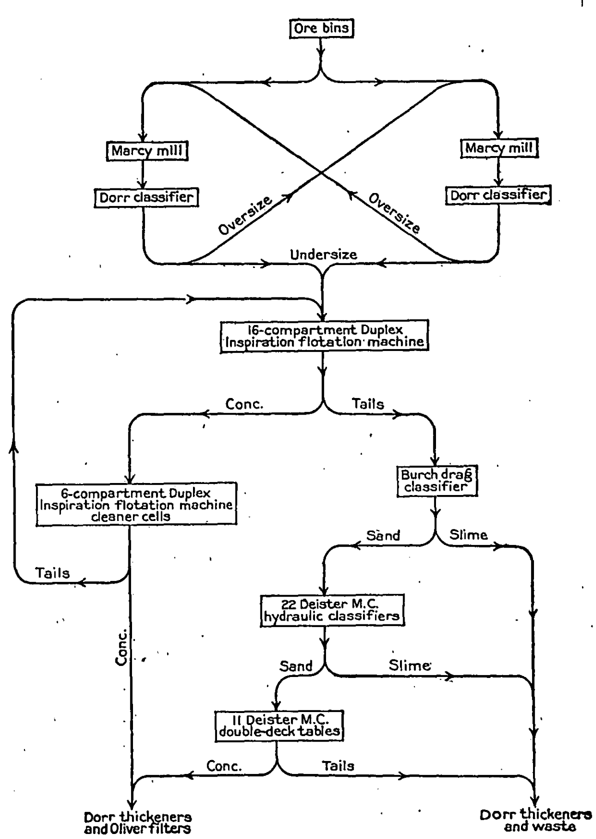


FIGURE 12.—Flow sheet of Inspiration concentrator sections equipped with Inspiration flotation machines.

Power for mining and milling is supplied from the hydroelectric plant of the Salt River project under a 10-year contract with the United States Reclamation Service. The company also owns, jointly with the International Smelting Co., a complete steam-power plant amply sufficient for all needs in case of failure of the electric current.

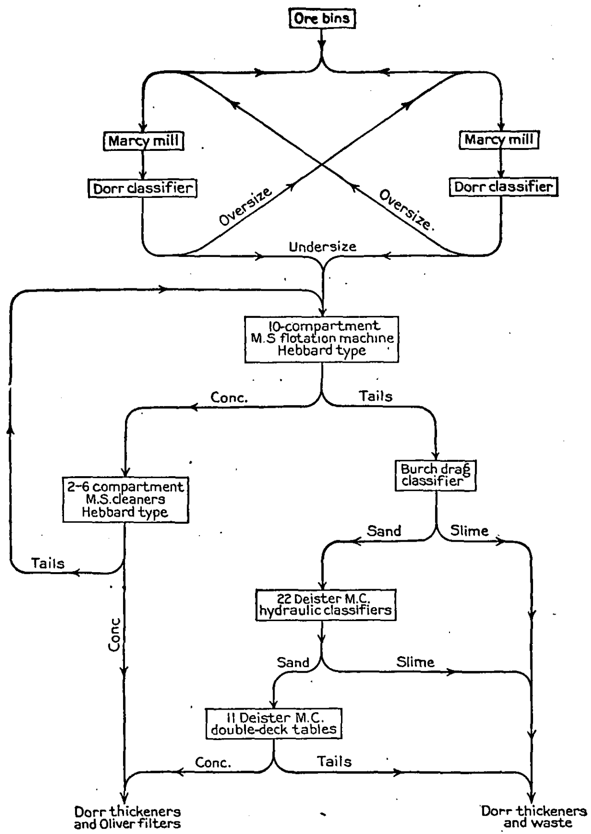


FIGURE 13.—Flow sheet of Inspiration concentrator section equipped with Minerals Separation flotation machines.

SMELTING.

Prior to 1915 the concentrates from the Miami mine were smelted at Cananea, Mexico. In that year, however, the reverberatory smelter of the International Smelting & Refining Co., about a mile west of Miami, was completed, and the concentrates of the Inspiration and Miami mills are now treated at this plant, which has a daily capacity of 250 tons of copper. A description of the smelter has been given by Kerns,[1] and a general view of it appears in Plate XXXIV, *B*.

The normal charge, containing 28.4 per cent of copper, is as follows:

	Per cent.
Concentrates	84.9
Crushed siliceous ore	.2
Converter secondaries	7.1
Pyrite	2.1
Limestone	5.7
	100.0

This is treated in the drying plant, which consists of five Wedge furnaces, and passes thence to three oil-fired reverberatory furnaces 21 feet wide by 120 feet long. The matte from these furnaces, containing 51 per cent of copper, is charged into five 12-foot converters of the Great Falls type. From these the copper is carried in 18-ton ladles to two tilting furnaces, which pour into two casting machines. These machines deliver the copper in slabs weighing about 274 pounds each. The daily output of copper in September, 1916, was 95 tons.

RAY DISTRICT.

MINING COMPANIES AND CLAIM GROUPS.

By far the strongest and most active company in the Ray district and the one with the largest holdings is the Ray Consolidated Copper Co., which, after acquiring the property of the Gila Copper Co. in 1910, absorbed the Ray Central Copper Mining Co., leaving only the Arizona-Hercules Copper Co.[2] as an important outside factor in the development of the disseminated deposits. The general relations of the claim groups to one another and to the area underlain by developed ore are shown in figure 14.

The Ray Consolidated Copper Co. is organized under the laws of Maine with an authorized capital of $14,000,000 in shares of $10 par value. It controls also the Ray & Gila Valley Railroad Co., capitalized at $2,500,000.

The land holdings of the Ray Consolidated Copper Co. are large, embracing nearly 2,000 acres in the Ray district, considerable ground in the vicinity of Kelvin, and a tract of 3,750 acres in the vicinity of Hayden, where the concentrator and smelter are situated. (See fig. 15.)

[1] Kerns, R. W., International smeltery at Miami: Eng. and Min. Jour., vol. 101, pp. 421-424, 1916. See also Ricketts, L. D., Dust losses in copper smelting: Eng. and Min. Jour., vol. 102, pp. 396-397, 1916.

[2] The ground of this company at the date of writing (November, 1916) is operated by the Ray-Hercules Copper Co.

The Arizona Hercules Copper Mining Co. is capitalized at $10,000,000, with shares of $10 par value. It owns about 250 acres of mining claims and a mill site; the most valuable part of the mining ground is inclosed by the property of the Ray Consolidated Copper Co. Details of the organization of the Ray Hercules Copper Co. are not at hand. The company is reported to be building a concentrator near Kelvin.[1]

[1] Since this was written the Ray Hercules Copper Co., now owning more than 99.9 per cent of the stock of the Arizona Hercules Copper Co., has issued its first annual report, in which it is stated that the company has developed 9,500,000 tons of 1.77 per cent ore. The company has carried out extensive underground work and has equipped the mine for production on a large scale. At Belgravia, a new settlement just north of Ray Junction and about 6 miles from the mine, a concentrating mill with a capacity of 1,500 tons a day has recently been completed and is now in operation.

DRILLING.

Prior to extensive underground work the ore-bearing area at Ray was explored by churn drilling, the holes as a rule being situated at the intersections of rectangular coordinate lines 200 feet apart. The Ray Consolidated Copper Co. tested in this way an area of about 185 acres. The total number of holes drilled is 353, and their average depth is 418 feet. The average thickness of capping or overburden, as calculated by the company's engineers, is 252 feet, and the average thickness of the ore 101 feet. Although drilling had been discontinued in 1912, the extreme limits of the ore body, particularly in its western part, have not yet been fully ascertained.

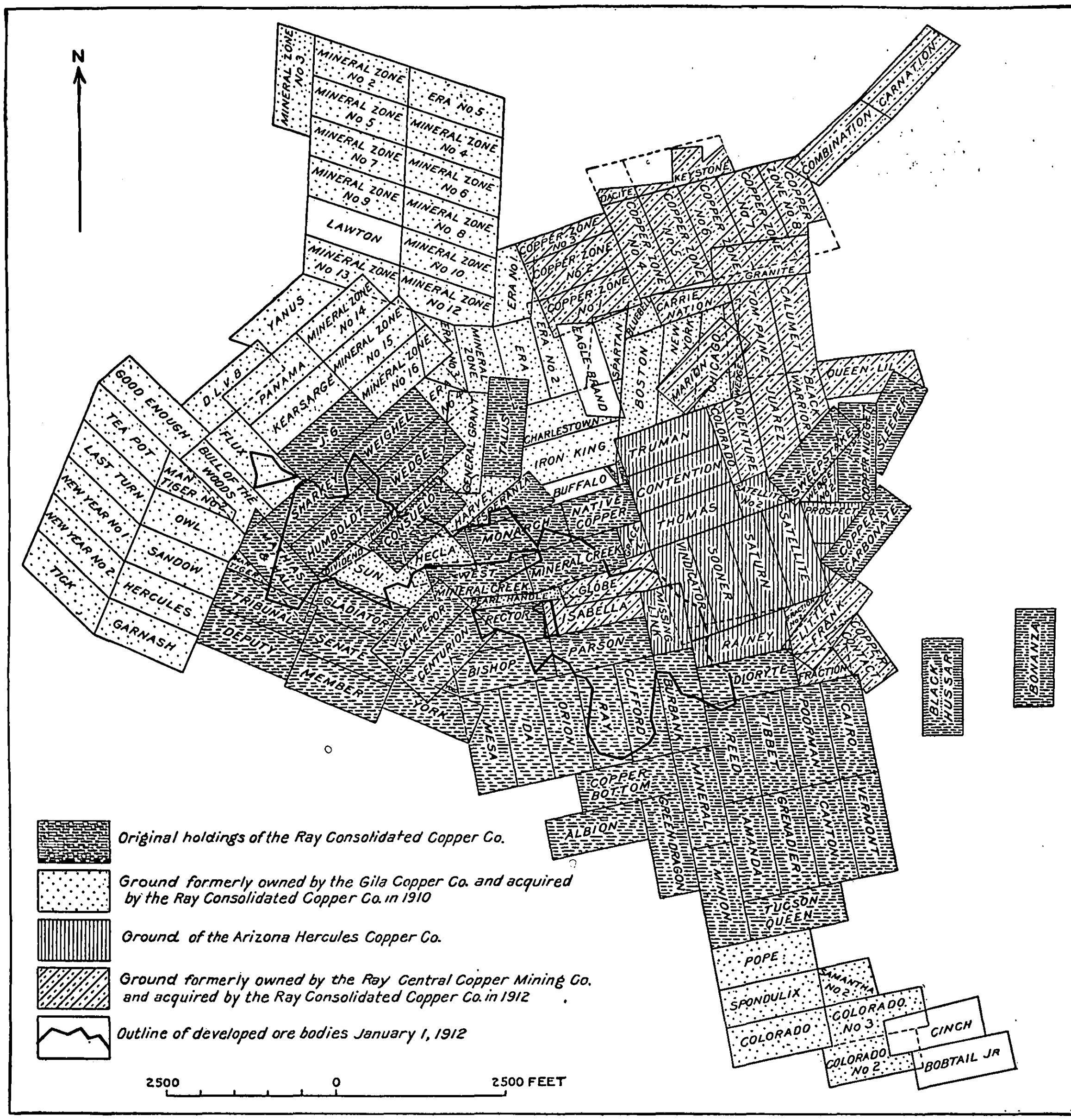


FIGURE 14.—Claim map of the central part of the Ray district.

The average cost of drilling at Ray was between $2 and $3 a foot. Some of the later holes, which were not very deep and were not closely sampled, cost only $1.50 a foot.

In general, the results obtained by drilling agree fairly well with those obtained by drifting in the same ground. It has been found, however, that holes which passed through soft crushed schist into "diabase" gave results that were too high—that is, the drill record indicated that the ore continued some distance downward into material that subsequently proved to be barren. Although underground work has thus curtailed the supposed quantity of ore in certain places, it has exposed fully compensating additions elsewhere.

UNDERGROUND DEVELOPMENT.

The general plan of development of the Ray Consolidated Copper Co.'s mines is indicated in Plate XXXVII. This map, however, shows only the main haulage levels and therefore represents but a small part of the actual workings. These at the end of the year 1916 had a total length of about 107 miles, of which about 54 miles had been destroyed by stoping op-

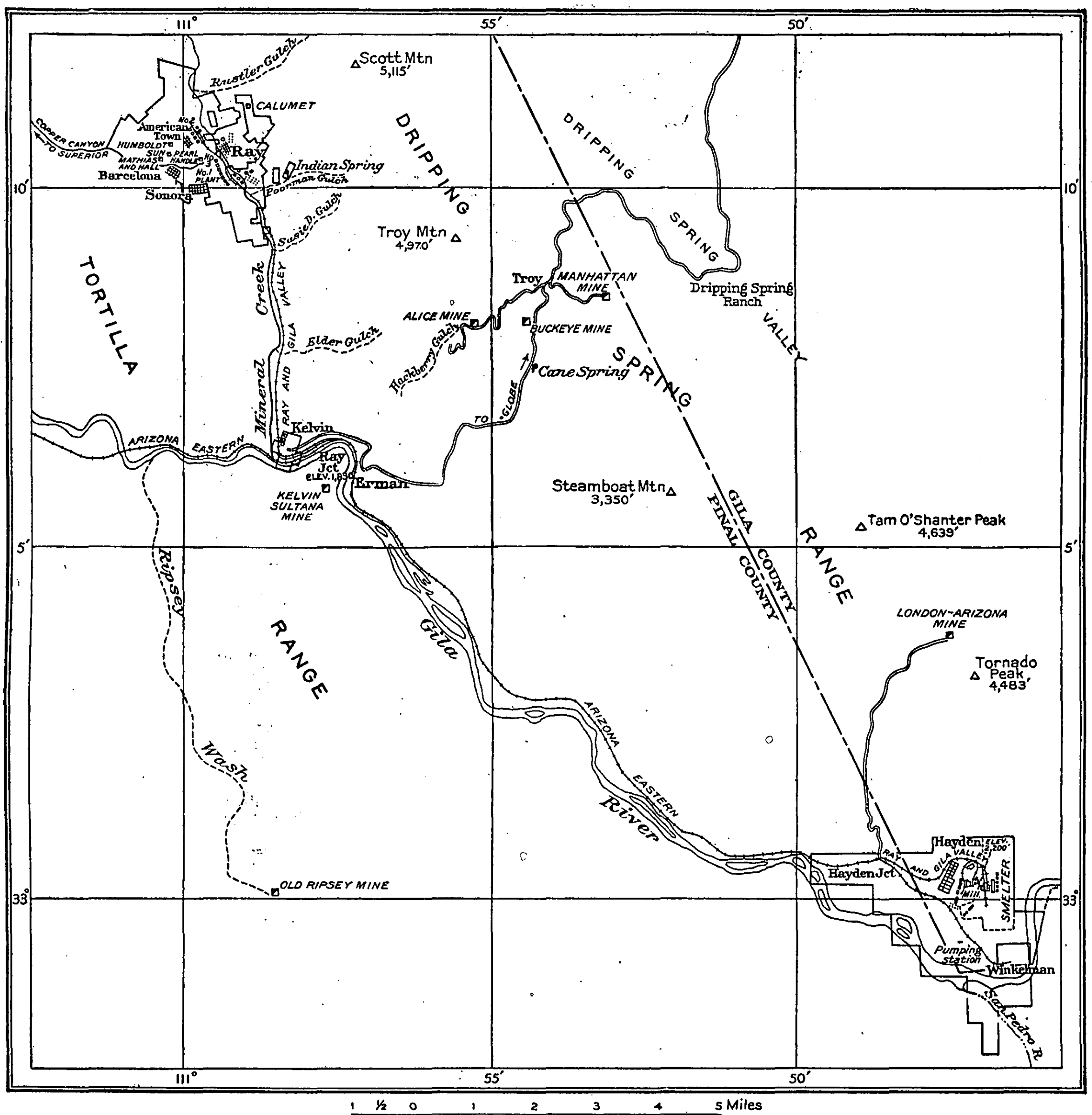
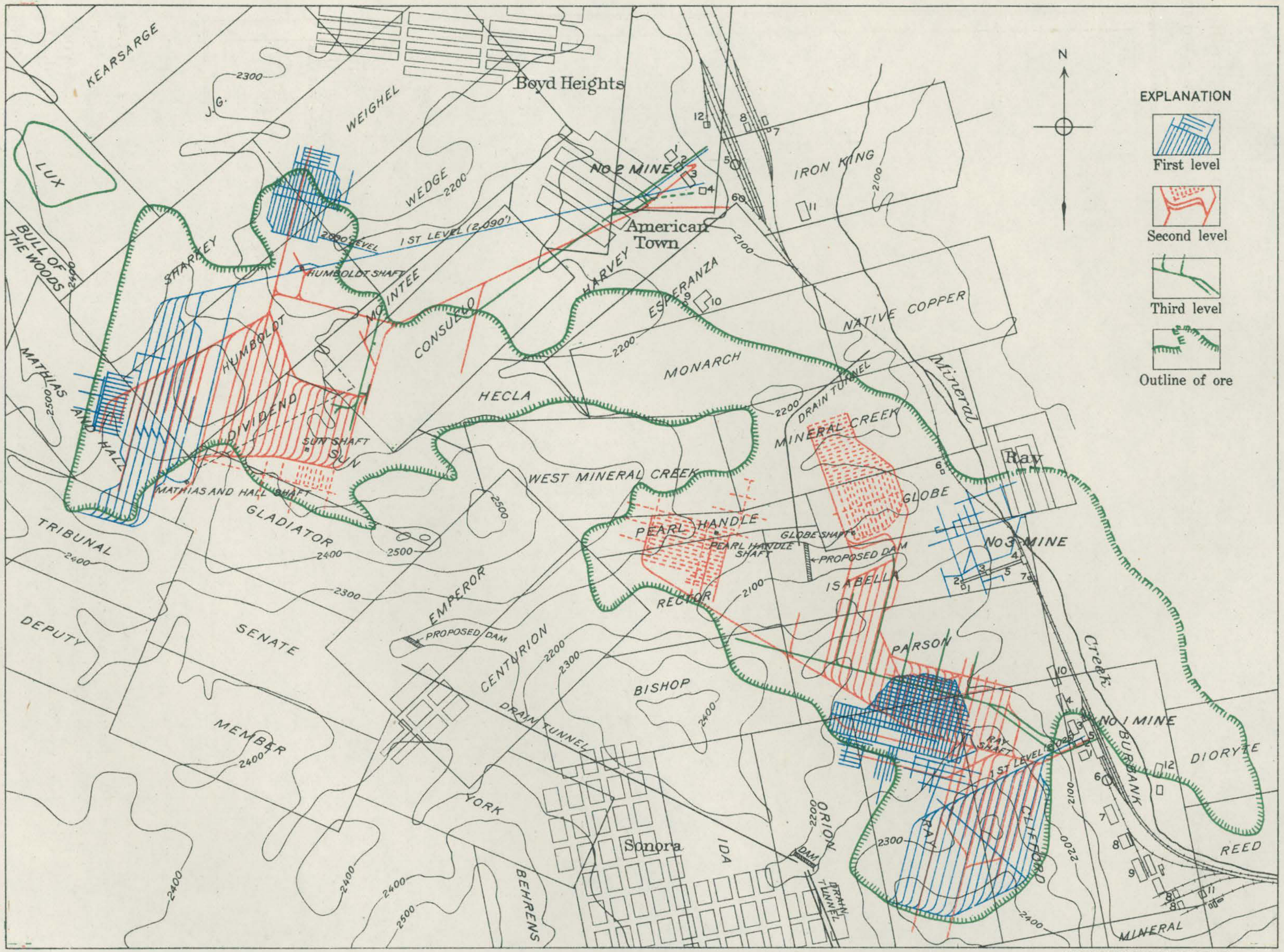


FIGURE 15.—Outline map showing the relative positions of the Ray Consolidated Copper Co.'s mines and mills.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

No. 1 MINE
1. Hoist
2. Head frame
3. Crusher
4. Temp. power plant
5. Ore bin
6. Waste bin
7. Compressors
8. Warehouse
9. Machine shop
10. Change house
11. Framing shed
12. General office

No. 2 MINE
1. Hoist
2. Head frame
3. Crusher
4. Incline hoist
5. Ore bin
6. Waste bin
7. R. R. depot
8. Framing shed
9. Mess house
10. Hospital
11. Change house
12. Lime bin

No. 3 MINE
1. Hoist
2. Head frame
3. Crusher
4. Ore bin
5. Conveyor
6. Waste winze
7. Waste winze

MAP SHOWING GENERAL PLAN OF DEVELOPMENT OF THE RAY CONSOLIDATED COPPER CO.'S MINES ON JANUARY 1, 1917.

500 0 500 1,000 1,500 Feet

erations. The underground workings driven in 1916 amounted to 66,863 feet. There are three mines, known as No. 1, No. 2, and No. 3.

The plan of the ore body (Pl. XXXVII) shows a marked constriction about 700 feet north of the Pearl Handle shaft, which practically divides the ore body into two parts. No. 1 and No. 3 mines are laid out to work the part of the ore body east and south of this constriction, and No. 2 mine the part west of it. The greater part of the southeast lobe of the ore body, including the ore in the western part of what was formerly the Ray Central ground, is being worked through the No. 1 mine. The comparatively high-grade ore in the eastern part of the former Ray Central ground is worked through the No. 3 mine by methods different from those employed in the two other mines. Between the workings of the No. 1 and No. 3 mines a wall of ground about 100 feet thick is left standing as a precaution against any possible flooding of one mine from the other.

No. 1 shaft and adit are close to Mineral Creek, at the northeast base of Ray Hill. The levels of this mine are as follows:

Levels of No. 1 mine of Ray Consolidated Copper Co,

Usual designation.	Approximate distance above (a) or below (b) collar of No. 1 shaft (feet).	Elevations above sea level (feet).
2175 sublevel	102	2175
2125 sublevel	52a	2125
A or adit level	2a	2075
Collar of No. 1 shaft	....	2073
No. 1 sublevel	23	2050
First level	47b	2025.8
1990 sublevel	83b	1990
1980 sublevel	93b	1980
1970 sublevel	103b	1970
No. 2 sublevel	133b	1940
Second level	155b	1917.7
1850 sublevel	223b	1850
Third level	300b	1773

Most of the levels above the first have served their purpose and have been abandoned.

The No. 1 shaft, 300 feet deep, is used solely for hoisting ore; it is equipped with 12½-ton skips, run in balance by an electric hoist at a speed of 300 feet a minute.

The 2175 sublevel is a tunnel level, opening to the surface at two points on the east face of Ray Hill. The 2125 sublevel has similar surface connection. The A or adit level has its portal about 350 feet north-northwest of No. 1 shaft and connects directly with the old Ray shaft. It was run in part by the English company. No. 1 sublevel is not directly connected with the surface or with the main shaft. The first level opens directly to the surface at the base of Ray Hill just east of No. 1 shaft, with which it also connects. All the ore tributary to this level has been mined, and the level was abandoned as a haulage level in 1916. The 1990 and 1970 sublevels connect with the old Ray shaft but not directly with the No. 1 shaft or surface. The No. 2 sublevel communicates with the main levels only through raises. The second level is directly connected with the No. 1 and old Ray shafts and with a 30° incline, opening to the surface about 200 feet southeast of the No. 1 shaft. Men, timbers, and such waste as must be hoisted all pass through this incline. The third level communicates with the surface through the same openings as the second level.

An idea of the general plan of the levels may be had from Plate XXXVIII. It is essentially that of a rectangular grid with 50-foot intervals, the whole intersected by a trunk haulage drift. In some places the ore is divided into 25-foot blocks; in others only those drifts that open into the trunk drift (laterals) are developed, the cross drifts being omitted. In terms of a permanently adopted "magnetic north" of 13° 41′ 23″ east of true north, the drifts in general run north and east. Some of the wide drifts on the first level, southwest of the Ray shaft, were run by the English company.

North and east of No. 1 mine is the No. 3 mine, which includes what was formerly the eastern part of the Ray Central mine. When this property was purchased by the Ray Consolidated Copper Co. it had been developed through the Madeline shaft, on the south side of Copper Canyon, principally on the 200, 300, and 400 foot levels. The Ray Consolidated Co. drove its second level north past the Madeline shaft and works the western part of the Globe and Isabella claims as part of its No. 1 mine, but in order to mine separately the high-grade portion of the Ray Central ore body, a new shaft was sunk 500 feet east-southeast of the Madeline shaft. This new shaft with its connecting levels constitutes the No. 3 mine. The levels of the No. 3 mine are laid out on the original Ray Central coordinate lines, 20° west of north and 20° north of east, and are six in number. Their elevations in feet above sea level are as follows:

First	2,042
Second	1,946
Third	1,843
Fourth	1,760
Fifth	1,730
Sixth	1,672

The No. 2 vertical shaft and incline of the Ray Consolidated Copper Co. are three-fourths of a mile nearly northwest of the No. 1 shaft, on the west side of Mineral Creek, just south of the mouth of Sharkey Gulch, and are similar in size, arrangement, and equipment to those of the No. 1 mine.

The levels are as follows:

Levels of No. 2 mine of Ray Consolidated Copper Co.

Usual designation.	Approximate distance above (a) or below (b) collar of No. 2 shaft (feet).	Elevation above sea level (feet).
2190 sublevel	56	2,190
2140 sublevel	6 a	2,140
Collar of No. 2 shaft		2,134
2090 sublevel	14	2,120
2090 level	44 b	2,090
2046 sublevel	88 b	2,046
2020 sublevel	114 b	2,020
1925 sublevel	184 b	1,950
1925 level	209 b	1,925
1860 sublevel	274 b	1,860
1775 level	359 b	1,775

The 2090 level is an adit, with its portal just east of the No. 2 shaft. It connects with this shaft and also with the Humboldt, Sharkey, and Matthias & Hall shafts. The 1925 level connects with the No. 2 shaft and incline and with the Sun and Matthias & Hall shafts. Both these levels have been planned for the extraction of the part of the ore body under and adjacent to Humboldt Hill. The 2090 and 2190 sublevels are for the most part under Humboldt Hill and are of comparatively small extent.

STOPING.

The general system of stoping adopted in the No. 1 and No. 2 mines at Ray is that commonly known as the shrinkage-stope caving system, and has been fully described by Blackner.[1] The sills of the stopes are started 25 feet above the main haulage levels, instead of 50 feet, as in the Miami mine. The stopes are carried up from 20 to 22 feet wide, the miners working on the broken ore, of which only enough is drawn to provide working space at the top of the stope. When all the stopes in a given section of the mine have been carried up to the capping, or overburden, the ore is drawn systematically from the numerous chutes, so that the overburden will cave and the pillars crush as evenly as possible over the whole area. No timber is used in the stopes. At Ray the stopes are at right angles with the haulage laterals beneath them; at the Miami mine the stopes are parallel with and directly over the tramming drifts.

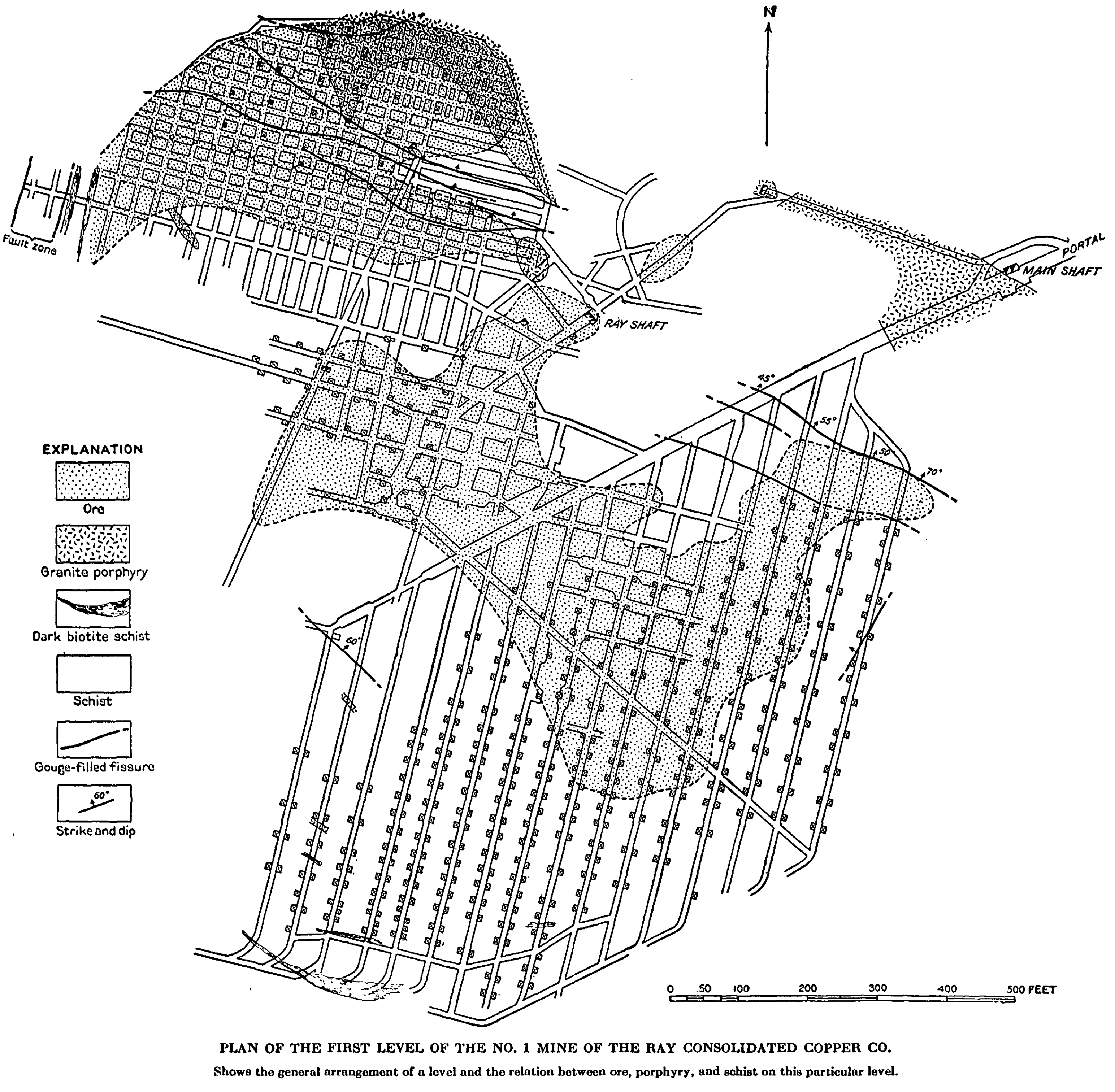
Electric locomotives draw the ore in trains of 5-ton cars to the main shafts, where the cars are dumped in tipples. At the surface self-dumping skips deliver the ore to crushers and coarse rolls, from which it is conveyed into capacious steel bins, capable of holding about a week's supply. From these are loaded the regular ore trains of thirty-two 60-ton steel cars, for the concentrator at Hayden.

The No. 3 mine is worked by square-set stoping, this relatively expensive method, costing about four times as much as shrinkage stoping, being warranted by the character of the ore.

TREATMENT OF ORE.

At Hayden, 20 miles from Ray, the ore is concentrated in a mill designed in accordance with the practice at Garfield, Utah. There are eight sections, each with an originally designed capacity of 1,000 tons. The actual capacity of this mill in 1916, however, was 9,475 tons, and changes were in progress to increase the output still further. At first concentration was effected wholly by running water, but later a flotation section was added.

[1] Blackner, L. A., Underground mining systems of Ray Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 52, pp. 381-422, 1916.



PLAN OF THE FIRST LEVEL OF THE NO. 1 MINE OF THE RAY CONSOLIDATED COPPER CO.

Shows the general arrangement of a level and the relation between ore, porphyry, and schist on this particular level.

The operations of the mill up to the end of 1918 are summarized in the following table:

Operations of Ray Consolidated Copper Co.'s mines and mill, 1911–1918.

Year.	Total ore milled.	Average contents in copper.	Cost of mining per ton.[a]	Cost of milling per ton.
	Tons.	*Per cent.*	*Cents.*	*Cents.*
1911	681, 519	1. 83	81. 60	59. 45
1912	1, 565, 875	1. 68	77. 55	46. 88
1913	2, 365, 296	1. 72	73. 22	51. 93
1914	2, 427, 700	1. 76	62. 42	49. 88
1915	2, 848, 969	1. 67	62. 68	50. 86
1916	3, 332, 340	1. 61	80. 07	55. 35
1917	3, 560, 900	1. 62	109. 00	82. 86
1918	3, 411, 000	1. 61	176. 00	101. 00
	20, 193, 599	1. 68	90. 32	62. 27

Year.	Mill extraction.	Cost per pound of copper.	Copper produced.[b]
	Per cent.	*Cents.*	*Pounds.*
1911	63. 01	10. 765	15, 721, 520
1912	68. 28	9. 828	35, 861, 496
1913	66. 09	9. 784	53, 745, 937
1914	67. 88	8. 839	58, 020, 955
1915	64. 11	9. 497	61, 114, 514
1916	70. 20	10. 267	75, 182, 915
1917	74. 53	12. 141	86, 797, 586
1918	74. 92	17. 695	82, 445, 710
	68. 62	11. 102	468, 890, 633

[a] Includes all fixed and general charges as well as coarse crushing.
[b] Does not include copper from ore sent directly to the smelter.

In addition to the ore milled the company shipped directly to the smelter ore containing the following quantities of copper:

	Pounds.
1913	412, 372
1914	1, 023, 745
1915	1, 425, 682
1916	2, 673, 798
1917	5, 409, 770
1918	4, 473, 560
	15, 418, 927

The concentrates as a rule contain from 18 to 23 per cent of copper.

Alongside of the concentrator is a smelter built and owned by the American Smelting & Refining Co. on ground leased from the Ray Consolidated Copper Co. This has been described by Vail.[1] It was completed in May, 1912, and has treated all the concentrates from the Ray mill. Since July, 1913, it has smelted also concentrates from other mills.

At Hayden also is a power plant, capable of developing over 15,000 kilowatts, which, in addition to operating the concentrator and smelter, supplies the mines at Ray.

[1] Vail, R. H., Smelting Ray concentrates at Hayden, Ariz.: Eng. and Min. Jour., vol. 98, pp. 553–558, 1914.

Some idea of the magnitude of the task of preparing for mining and treating from 8,000 to 10,000 tons of ore a day may be gained from the statement that the net expenditures of the Ray Consolidated Mining Co. for property and development to December 31, 1911, amounted to $14,635,314.81.

Those who desire more information about the substantial and modern equipment of the Ray Consolidated Copper Co. than can be compassed in a few brief paragraphs may find many technical details in the annual reports of the company and elsewhere.[2]

ORE AVAILABLE.

Estimates of the quantity of ore available in the mines of the Ray and Miami districts vary with the data used in computation. As the ore is in most places not definitely bounded, the calculated available tonnage depends very largely upon the fixing of an arbitrary line between those assays that correspond to ore and those that do not. If everything above 1.3 per cent be classed as ore the tonnage, for example, will be much greater than if 2 per cent be taken as the lower limiting tenor. Moreover, material that on assay gives 3 to 4 per cent of copper may be of less value or even of no value as ore if the copper is in one of the oxidized forms that can not readily be concentrated with the sulphides. In general the lower limit of ore is taken to be from 1 to 1.5 per cent.

It is believed that the engineers of the different companies have been careful in their estimates of the available quantity of ore for their respective mines and that there has been no attempt at exaggeration. It is to be remembered, however, that the results are estimates—not exact measurements.

On January 1, 1917, the Miami reserves stood as follows:

	Tons.
Sulphide ore carrying 2.40 per cent of copper	16, 400, 000
Sulphide ore carrying 1.06 per cent of copper	28, 000, 000
Partly oxidized ore carrying 2 per cent of copper (not fully developed)	6, 000, 000
	50, 400, 000

[2] Dinsmore, C. A., The Ray Consolidated Copper Co.: Min. and Sci. Press, vol. 103, pp. 282–285, 1911.
(Anon.), Electric hoist at Ray: Min. and Sci. Press, vol. 103, pp. 310–311, 1911.
Herrick, R. L., Ray Consolidated mines: Mines and Minerals, vol. 297, pp. 544–546, 1909.
Edholm, C. L., Ore handling at Ray, Ariz.: Eng. and Min. Jour., vol. 92, pp. 1142–1144, 1911.
Penny, A. N., Mining low-grade copper ore by Ray Consolidated: Eng. and Min. Jour., vol. 99, pp. 767–770, 1915.
Blackner, L. A., Underground mining systems of Ray Consolidated Copper Co.: Am. Inst. Min. Eng. Trans., vol. 52, pp. 381–422, 1916.

At this time 6,839,606 tons of ore had been mined, chiefly of relatively high grade, which added to the above total gives 57,239,606 tons as the quantity of ore originally present in the ground. Future development is more likely to increase than diminish this estimate.

The estimated reserves of the Inspiration Consolidated Copper Co., without subtraction of the 1,152,556 tons extracted to the end of 1915, were given as follows in the company's report for that year:

Estimated ore reserves of the Inspiration Consolidated Copper Co.

Classification of material.	Developed in original exploration.		Developed by drilling in 1913.		Originally developed but not reported.		Keystone ore through purchase of property, 1914.		Total.	
	Tons.	Per cent of copper.	Tons.	Per cent of copper.	Tons.	Per cent of copper.	Tons.	Per cent of copper.	Tons.	Per cent of copper.
Sulphide ore	45,000,000	2					1,252,000	2.24	46,252,000	2.01
Low-grade sulphide material			2,839,000	1.45	25,483,000	1.24	376,000	1.13	28,698,000	1.26
Oxidized material			3,767,000	1.33	8,678,000	1.34	5,015,300	1.25	17,460,300	1.31
Mixed carbonate and sulphide material			252,000	1.53	3,634,000	1.22	856,700	1.62	4,732,700	1.31
	45,000,000	2	6,858,000	1.39	37,785,000	1.26	7,500,000	1.45	97,143,000	1.63

These estimates give a grand total of 143,282,419 tons of known ore originally present in the Miami district.

The known reserves of the Ray Consolidated Copper Co. at the end of 1916 are given in the company's report for that year at 93,373,226 tons, averaging 2.03 per cent of copper. There had been mined at this date 13,293,854 tons. Consequently the original ore body according to the latest estimate available contained 106,667,080 tons. This includes about 500,000 tons of ore averaging between 5 and 6 per cent, originally present in the ground formerly owned by the Ray Central Co.

The Arizona Hercules Copper Co., on the basis of drill records, estimated in 1914 that in its property there is at least 3,200,000 tons of 2.44 per cent ore and possibly as much as 9,000,000 tons in all, of a little lower average grade. The present operating company, the Ray Hercules Copper Co., has done considerable drilling since this estimate was made.[1]

The total quantity of known ore originally present in the Ray district and averaging between 2 and 2.5 per cent may be taken as between 110,000,000 and 116,000,000 tons. There probably remains a considerable quantity yet to be developed.

[1] This company's report for the period from the beginning of operations to Oct. 31, 1917, gives 9,500,000 tons of 1.77 per cent sulphide ore.

CHAPTER V.—GEOLOGY OF THE MIAMI DISTRICT.

TOPOGRAPHY.

The Miami district lies near the western edge of the broad conglomerate-filled basin in which is situated the town of Globe, and through which Pinal Creek flows northward to join Salt River. The main part of the Pinal Range lies to the south of the district. Its masses of pre-Cambrian crystalline rock rise rather more boldly than is suggested in Plate XXII, *C* and *D*, above the intricately dissected flanking deposits of Gila conglomerate. To the north is the cluster of irregular hills which, as explained on page 81, is also a part of the Pinal Range. These hills are composed largely of minutely faulted Paleozoic rocks with masses of overlying dacite, also faulted, and inclose small lowland areas of diabase and pre-Cambrian granite. Southwest of the district the range, owing to the comparative ease with which the Schultze granite is eroded, is relatively low, the depression forming a broad, irregular, and rather rugged pass from the drainage basin of the northward-flowing Pinal Creek to the headwaters of the southward-flowing Mineral Creek. This route was formerly much used by the Indians and was the one taken by Marvine in his reconnaissance from Fort Apache to the valley of the Gila in 1871. Bloody Tanks Wash, the flat-bottomed streamway along which the town of Miami has been built, heads in this pass. Its sinister name is said to commemorate an Indian conflict near certain water holes in granite at the head of the wash.

The topography of the district itself as mapped on Plate XXXIX is fairly rugged and irregular, the relief ranging from 3,400 feet at Miami to 5,050 feet on Needle Mountain, at the western edge of the area. The dominant feature is the east-west Inspiration Ridge (Pl. XL) separating Bloody Tanks Wash and its tributary arroyos on the south from Webster Gulch on the north. The north side of this ridge is generally much steeper than the south side, although Webster Gulch is considerably higher, within the confines of the area here described, than Bloody Tanks Wash.

The topography in detail is to a considerable extent expressive of the rocks from which its forms have been fashioned. Areas of Gila conglomerate show much branching but on the whole rather even crested ridges and spurs; the drainage is typically dendritic and does not record the influence of any rock structure. (See Pl. XXXVI, *B*.) Rarely, as at Needle Mountain, the conglomerate is hard enough to stand conspicuously above the general erosion surface.

The Schultze granite area shows the rough bouldery outcrops characteristic of the weathering of granite in arid regions and varies sufficiently in its resistance to erosion to give considerable topographic diversity. The existence of a sheeted structure in parts of the mass also contributes to this result. The topography of the porphyry facies north of Bloody Tanks Wash is less bold than that of the coarser-textured granite. Little pointed hills and steep-sided ravines with no regularity in their arrangement and with few prominent rock outcrops characterize this part of the granite area.

The topography of the schist areas is in general fairly rugged, with steep slopes and acute hill crests. It exhibits considerable diversity, dependent on differences in the structure and character of the schist from place to place.

It does not appear that ore deposition has had any share in determining the present configuration of the surface, although its effects as regards the coloring of the surface are evident in any general view over the country.

Miami Wash, at times swept by formidable torrents, is dry throughout most of the year. Webster Gulch, except in seasons of unusual drought, carries a little water above Inspiration.

FORMATIONS LOCALLY REPRESENTED.

The rocks of the Miami district comprise the Pinal schist, the Pioneer shale (with which, as mapped on Pl. XXXIX, is included the basal

Scanlan conglomerate), diabase, the Willow Spring granite, the Schultze granite (including marginal porphyry facies), dacite, and the Gila conglomerate. Each of these formations has been described in connection with the geology of the region (pp. 30–75), and all that is necessary here is the supplementing of those general descriptions with a few local details.

The Pinal schist of the district is as a rule thoroughly crystalline and glitters with abundant silvery foils of sericite. The schist folia are generally contorted, and in certain localities, as along Webster Gulch near Inspiration, they are intensely crumpled and the rock contains much quartz, partly in small fissures and partly in spaces opened between the crumpled and separated leaves of the schist. Although most of the Pinal schist is essentially a quartz and sericite rock, some varieties, such as that along Liveoak Gulch in the central part of the district, contain biotite also. This dark mica as a rule is rather unevenly distributed through the schist, to which its presence thus gives an indistinct mottled appearance.

The older sedimentary formations, which at other places in this region are so thick and conspicuous, have been almost completely eroded from the Miami district. They are represented solely by a few remnants of the Pioneer shale and the basal Scanlan conglomerate, which are exposed in narrow areas north of Inspiration. A thick sheet of diabase has invaded and displaced the shale, in consequence of which only the lower beds between the intrusive rock and the schist are now present. Masses of the shale have been included also in the diabase. The Scanlan conglomerate is locally well developed and attains a thickness of 20 to 30 feet. It is composed of rather angular fragments of quartz in a hard matrix made up chiefly of particles of schist. The shale is locally baked and hardened by the intrusion of the diabase.

The diabase is the normal diabase of the region, which has been described on pages 53–56. It occurs along the northern edge of the district and is not closely associated with the disseminated ore deposits.

The Willow Spring granite has been described on pages 52–53. It is a comparatively small intrusive mass, of which about half of the exposed area is shown in Plate XXXIX.

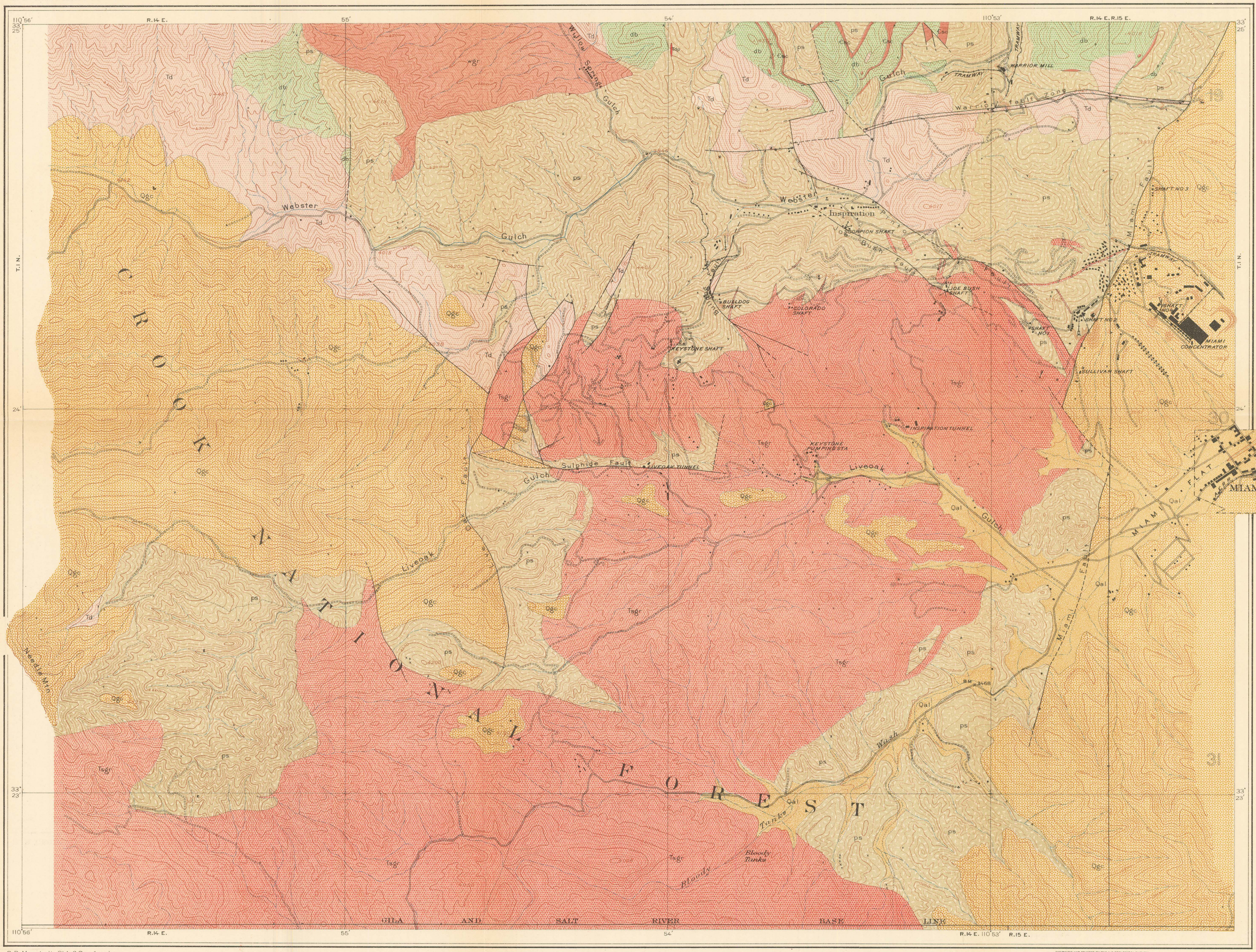
To the general account of the Schultze granite given in pages 59–61 little need here be added. The rock, as may be seen from Plate XXXIX, occupies a large part of the district and is intimately related to the ore zone, which conforms in general to the northern boundary of the intrusive mass, although it does not coincide with this boundary in detail.

Areally the Schultze granite is divided into two parts by a constriction northwest of Bloody Tanks. The main body of the granite lies south of this constriction and, save on its margins, is prevailingly granitic in texture. The northern lobe, on the other hand, is granite porphyry and contains little if any true granite. Both textural varieties, however, are merely facies of one intrusive mass, and the passage from one into the other is gradual.

The rock of the northern lobe, particularly of that part of the lobe lying north of Liveoak Gulch, has been fissured in an extraordinarily minute fashion, and the countless little irregular cracks have been filled with quartz or, less generally, with quartz and sulphides. The result is a very brittle and fragile mass, which the forces of erosion have cut into forms characterized rather by a petty sharpness and irregularity of feature than by the bold simplicity to be expected of a landscape that has a granitic foundation.

The dacite, which occurs only in the northwest half of the district, is for the most part of the same character as that described on pages 68–71 for the general region. The Whitetail conglomerate is locally absent, and the dacite rests in most places directly on the older rocks. Northeast of Inspiration, however, part of the dacite is underlain by dacite tuff, with some layers of schist conglomerate, which apparently represent a very local accumulation in a small hollow in the predacitic surface. This material is so poorly exposed, covers so small an area, and is so difficult to separate satisfactorily from the massive dacite that it was mapped with that rock as a unit, although perhaps it is strictly a local correlative of the Whitetail conglomerate. The tuff is of some economic importance as containing the chrysocolla ore of the Warrior mine.

The Gila conglomerate covers two relatively large areas. One of these stretches along the



EXPLANATION

QUATERNARY

Qal — **Alluvium**
(Gravel, sand, and silt along present streamways)

Qgc — **Gila conglomerate**
(A variable fluviatile deposit of irregularly bedded conglomerate with imperfectly rounded pebbles and boulders. Very coarse in certain localities near the mountains but grades into fine silts in the wider valleys, where deposition was probably in part lacustrine. Contains some beds of tuff and infusorial earth. Thickness very variable; over 2,000 feet north of Miami and may be much thicker between Miami and Globe)

LATE TERTIARY (?)

Td, a — **Dacite**
(A thick and formerly extensive lava flow with, in places, a little tuff at its base. Faulting and erosion have greatly reduced its area)
a=Landslide material

EARLY TERTIARY (?)

Tdp — **Quartz diorite porphyry**
(Small decomposed dike in Pinal schist)

Tsgr — **Schultze granite**
(Irregular intrusive mass. Chiefly granite but grades into porphyry near margins. Closely associated with the copper ores)

MESOZOIC ?

db — **Diabase**
(Intrusive, irregular sills with many cross-cutting connections in the Paleozoic and older rocks. The prevalent sill form not so well shown in this area as elsewhere in region. Typically a medium-grained ophitic olivinitic diabase or dolerite)

wgr — **Willow Spring granite**
(Small intrusive mass. Age relation to diabase and Schultze granite uncertain)

CAMBRIAN

€sc — **Scanlan conglomerate and Pioneer shale**
(Remnants in part included in diabase)

PRE-CAMBRIAN

ps — **Pinal schist**
(Quartz-sericite schist with locally some biotite. The principal copper-bearing rock in the Miami district)

Fault

R.B. Marshall, Chief Geographer.
T.G. Gerdine, Geographer in charge.
Topography by Albert Pike and R.W. Berry.
Control by A.H. Thompson and Thomas Winsor.
Surveyed in 1910.

GEOLOGIC MAP OF THE MIAMI DISTRICT, ARIZONA

Scale $\frac{1}{12000}$

0 $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 Mile

1000 500 0 1000 2000 3000 4000 Feet

200 100 0 500 1000 Meters

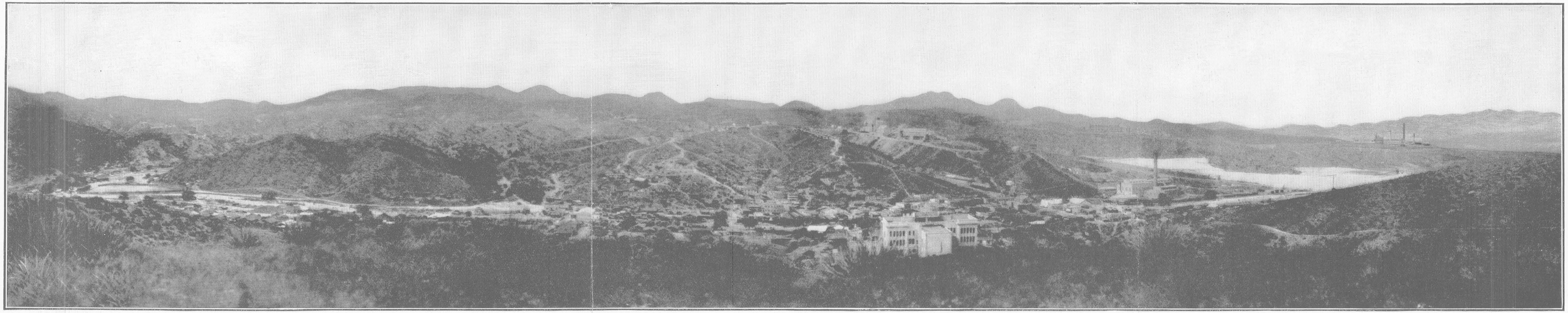
Contour interval 25 feet.
Datum is mean sea level.

1919

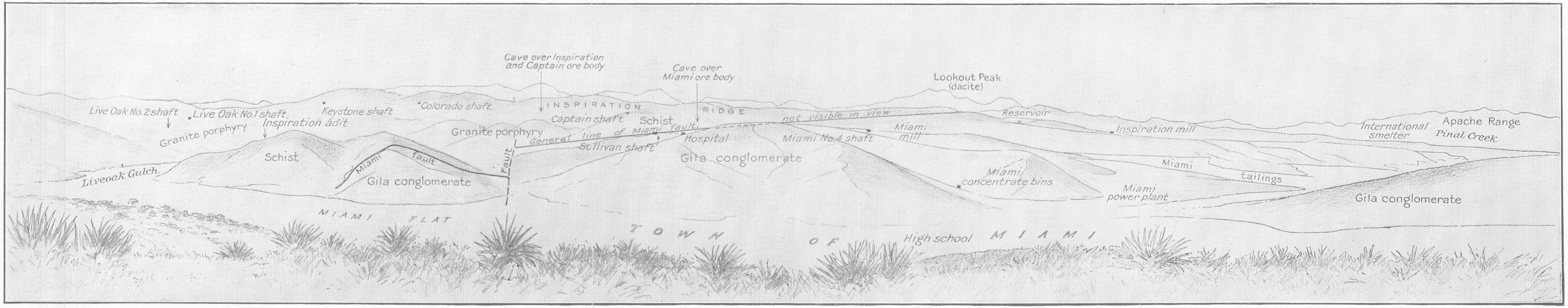
TRUE NORTH MAGNETIC NORTH 13½°
APPROXIMATE MEAN DECLINATION 1910.

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

Geology by F. L. Ransome
and J. B. Umpleby
Surveyed in 1911



GENERAL VIEW OF THE MIAMI DISTRICT FROM THE SOUTH.



eastern margin of the district and is merely a small part of the great mass of conglomeratic material that occupies the valley of Pinal Creek and constitutes the terrane adjacent to the town of Globe. The other area lies west of the Live Oak mine and for the most part north of Needle Mountain. The portion shown in Plate XXXIX is a little more than half of an isolated body of the conglomerate, which, as shown by a chain of small residual masses on the ridge south of Liveoak Gulch, was once connected with the conglomerate to the east.

As usual, the materials of the conglomerate show much local variation. In the eastern part of the district the formation presents what may be called its prevailing or typical aspect. As exposed on the lower levels of the Miami mine the conglomerate consists of angular or subangular masses of Schultze granite and schist, as much as 5 feet in diameter, with varying proportions of sandy matrix. The constituents are very poorly assorted, and many of the large boulders are surrounded with much finer material or are in contact with streaks of sand. The bedding, as might be expected, is crude, and in many places there is only a suggestion of stratification. Here and there, however, lenticular layers of sand or fine gravel show distinct local bedding. Most of the large schist fragments are slabby and lie with their flat sides roughly parallel with the sandy layers.

The conglomerate of the Needle Mountain area is made up in its southern part chiefly of the Schultze granite and in its northern part chiefly of dacite. Both varieties have in places been cemented to hard rocks. As already mentioned (p. 71), some of the granitic fragments are of remarkable size.[1]

No ore in workable quantity occurs in the Gila conglomerate, and the chief economic interest of the formation lies in the fact that it covers parts of the ore bodies and in places must be penetrated by the drills before the metallized schist can be explored. Although, as will be explained later, there is good reason to suppose that the ore bodies were formed before the deposition of the conglomerate, fragments of metallized schist are extremely rare in that formation. In a drill hole bored for a well near the railway station at Miami bits of schist with native copper in small seams were obtained from the conglomerate at a depth of about 500 feet. A fragment of schist, apparently in place in the conglomerate on the roadside between the office and store of the Miami Copper Co. and containing a little chrysocolla and malachite, was called to my attention in 1912 by Mr. H. P. Bowen, who informed me that it was the only mass containing copper that he had seen in the conglomerate. The Barney shaft was sunk in Gila conglomerate said to consist exclusively of schist fragments. A little copper is reported to have been detected in this material, but in what form is not known.

Churn-drill hole No. 75 of the Miami Copper Co. was put down in the Gila conglomerate about 1,600 feet east-southeast of No. 4 shaft. It had been the intention to go through the Gila, but in October, 1916, the hole had to be abandoned at a depth of 2,050 feet, without entirely penetrating the conglomerate. Native copper was first detected in the sludge from a depth of about 1,000 feet and continued to be found to the bottom of the hole, the proportion of copper apparently increasing downward. The highest assay obtained was 0.95 per cent of copper. Samples of sludge were sent by the Miami Copper Co. to Prof. L. C. Graton, of Harvard University, who reported that some of the particles of copper showed derivation from chalcocite and suggested that probably all the native copper found in the hole had the same origin. From the observed relation of native copper to chalcocite seen in parts of the mine workings this suggestion appears highly probable, and the occurrence is interpreted as indicating that the Gila conglomerate in its deeper portions contained originally, near the Miami ore body, fragments of chalcocitic ore derived by erosion from that ore body.

STRUCTURE.

PRIMITIVE ELEMENTS.

Originally deposited as beds of sedimentary material, the Pinal formation before or during its change to schist was folded and perhaps faulted; but all traces of bedding have disappeared and the schist is so uniform in character as locally to give no clew to its ancient stratigraphic structure. Accordingly consideration of recognizable structural features starts from the conception of the Pinal schist as the homogeneous and fundamental rock

[1] These varieties of the conglomerate have been described more fully in U. S. Geol. Survey Prof. Paper 12, pp. 53–54, 1903.

overlain unconformably by the beds of the Paleozoic series in horizontal attitude and in apparently conformable sequence.

EFFECTS OF POST-PALEOZOIC INTRUSIONS.

The first recognizable disturbance of these simple conditions appears to have been associated with the intrusion of the diabase, which is supposed to have taken place in early Mesozoic time, although there is some uncertainty attached to the geologic date of this event. As elsewhere in the region, the diabase was intruded mainly as thick irregular sills connected with many crosscutting bodies of still more irregular form. The larger masses of diabase north of Webster Gulch are parts of such a sill which was intruded principally along a horizon in the Pioneer shale a few feet above the Scanlan conglomerate. In many places, however, the diabase is in intrusive contact with the schist.

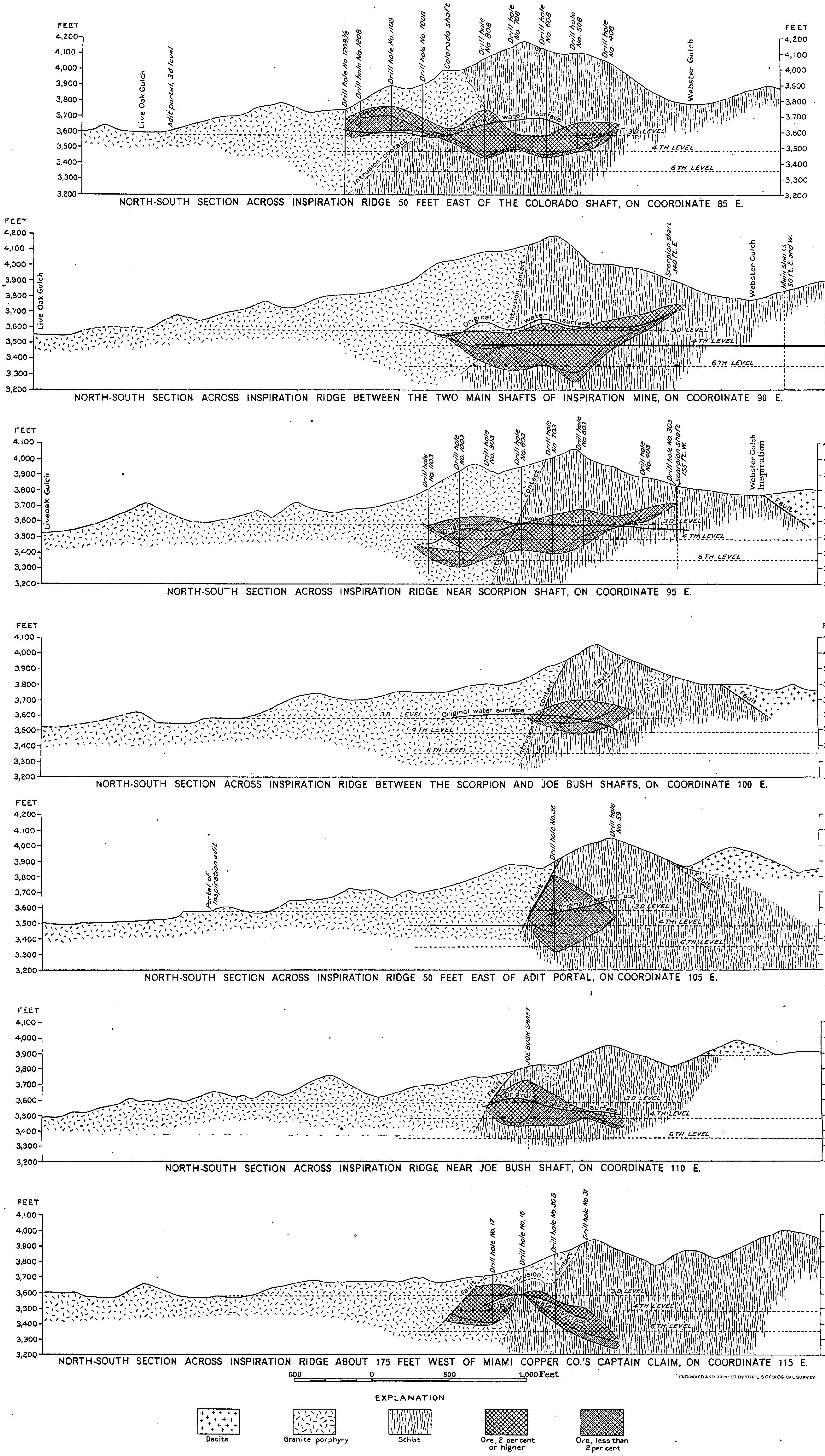
As usual in this region, masses of the invaded strata were split off, were completely inclosed in the magma, and were displaced by the movement of the molten material. The old pre-Cambrian surface, as shown by the narrow outcrops of the Pioneer shale and Scanlan conglomerate north of Inspiration, is no longer horizontal but has been locally tilted to the south or southwest, probably since the intrusion of the diabase.

The next event definitely recorded in the structure was the intrusion of the Schultze granite and probably also at nearly the same time that of the Willow Spring granite.

The part of the Schultze granite south of the constriction near Bloody Tanks forms an irregular stock, which as a whole probably extends to great depth. Its contact with the schist, as visible at the surface, indicates that in some places the stock becomes larger downward and that its sides in general are steep. Most of the exploration by churn drilling has been carried on to the north of the main granite mass, and consequently there is little to confirm or disprove the tentative suggestion as to its general shape drawn from surface exposures. Drill hole No. 3 in the Schultze group of claims, situated southeast of Needle Mountain, in a lobe of schist inclosed on three sides by granite, is about 950 feet deep, and although the granite at the surface is only 650 feet away the hole is said to be entirely in schist.

North of the Bloody Tanks constriction the granitic magma solidified for the most part as porphyry, and this difference in texture is associated with a difference in the form of the mass. This porphyry lobe may be considered in two parts—one north and the other south of Liveoak Gulch. The southern part is outside of the known ore-bearing area, and, as it has not been prospected with drills, nothing is known of its shape beyond what may be deduced from surface exposures. The northern part, on the other hand, has been extensively drilled, and this work, in connection with surface relations and with mining exploration, has brought out the interesting fact that much of this porphyry is underlain by schist. It is, in part, at least, a laccolithic sheet, not a stock. This is particularly true of the area southwest of the Bulldog shaft. Here the numerous drill holes on the Live Oak ground show that schist everywhere underlies a sheet of porphyry which in places is 700 feet or more in vertical thickness. In general the under surface of the sheet, as shown by drill records, dips west-southwest. In the western part of the Live Oak ground, near the Live Oak No. 2 shaft, which passes from porphyry into schist at a depth of 510 feet, the contact is fairly regular and the angle of dip is about 30°. East of the No. 2 shaft the porphyry lies flatter and its under surface is less even. An attempt to visualize the form of this surface by tentative contours plotted from the drill records suggested the homely comparison of a shallow bowl or basin, much battered and dented, with a deep notch on its west side. The deepest part of the basin, 3,560 feet above the sea, is about 900 feet east-northeast of the No. 2 shaft. (See Pl. XLII.)

A part of the schist that underlies this sheet of porphyry is exposed as a narrow strip along the north side of Liveoak Gulch, west of the Sulphide tunnel. Along its northern edge this belt of schist is apparently in igneous contact with the porphyry and, as shown by the drilling, the contact dips steeply to the north. A nearly north-south section on Live Oak coordinate line K, constructed from drill records, is



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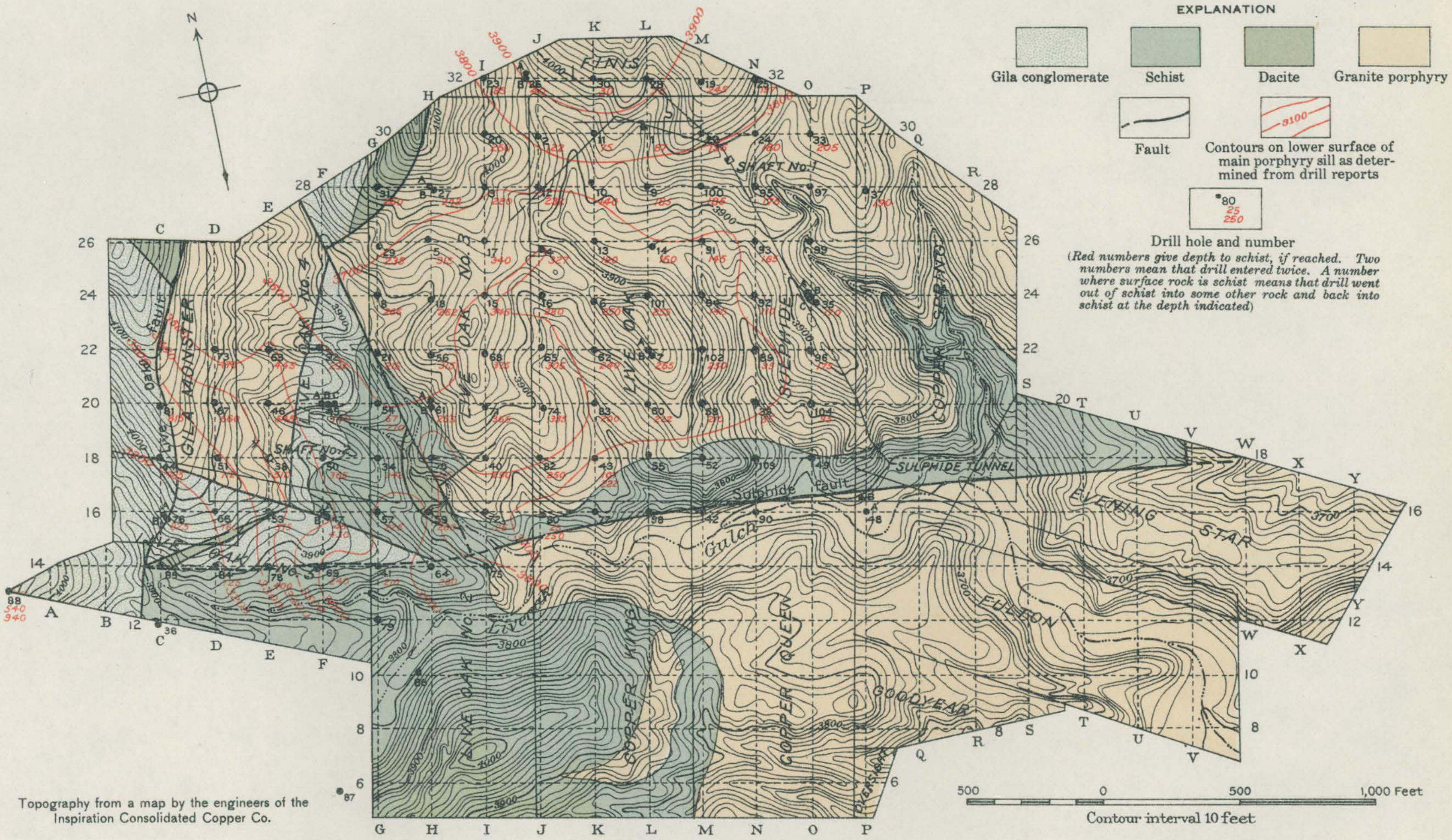
SECTIONS ACROSS INSPIRATION RIDGE SHOWING RELATION OF ORE BODIES TO TOPOGRAPHY AND COUNTRY ROCK



GEOLOGIC MAP OF THE LIVE OAK DIVISION OF THE INSPIRATION CONSOLIDATED COPPER CO.'S GROUND

ENGRAVED AND PRINTED BY THE U.S.GEOLOGICAL SURVEY

shown as figure 16. Apparently a fault with a throw of about 100 feet is crossed by the section, but no corresponding fissure has been noted in the porphyry at the surface. This section is about 100 feet west of the portal of the Sulphide tunnel. East of that tunnel the porphyry sheet becomes thinner and its under surface is more nearly horizontal than it is to the west, as is indicated by the relation of the schist and porphyry contact to the topography northeast of the portal of the Sulphide tunnel. (See Pl. XXXIX.)

The porphyry mass lying between the Bulldog and Sullivan shafts is for the most part south of the ore zone and has not been penetrated by many drill holes. Consequently its shape is not well known. The northern boundary of the mass is irregular, and the porphyry extends many tongues and one considerable dike, that of the Miami mine, into the

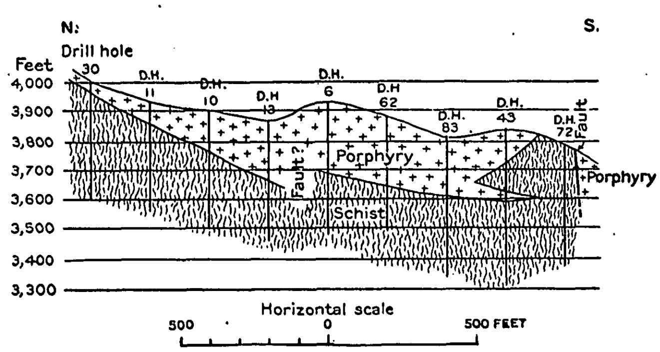


FIGURE 16.—Geologic section on Live Oak coordinate line K.

schist. Some information on the character of this contact is furnished by the sections across Inspiration Ridge shown in Plate XLI. The drill-hole data upon which these sections are largely based leave much to be desired, especially as to the extent to which faulting has determined the form of the porphyry body.

In general the contact dips south, and part of the porphyry thus overlaps the schist. It is by no means certain, however, that all the porphyry north of Liveoak Gulch rests on schist. There may be places where the eruptive rock continues down to that indefinite region of great though unknown depth whence the magma came.

The mass of schist in the vicinity of the No. 1 or Captain shaft of the Miami mine apparently extends to no great depth and is probably an inclusion in the porphyry. There is some schist near the Captain shaft on the 80-foot level, but at the 135 and lower levels the shaft is in porphyry. Most of the Captain ore body is in porphyry, in part directly under the isolated body of schist exposed on the surface. On the other hand, on most of the Captain levels schist is present in the northwest corner of the claim, although the rock at the surface is porphyry. This deeper schist in the northwestern part of the Captain levels is probably continuous with the main mass of schist north of the porphyry. The strip of porphyry shown in Plate XXXIX just east of the No. 1 shaft coincides in general with the barren zone between the main Miami ore body and the Captain ore body. Consequently there are few drifts under it.

The main ore body of the Miami mine, which is chiefly in schist, is bounded generally on the southwest by granite porphyry. The contact appears to have been originally an intrusion contact, but there has been considerable later disturbance, and in many places porphyry and schist are faulted together. The general dip of this contact is northeasterly, steep near the surface but much lower under the Miami ore body. The No. 2 shaft of the Miami mine, which was 720 feet deep, is said to have penetrated granite porphyry for a few feet when sinking stopped.

From the rather fragmentary data available it appears that the lobe of porphyry exposed on the south slope of Inspiration Ridge between the Bulldog shaft on the west and the Gila conglomerate on the east is probably in the main a thick sheet very irregularly intruded into the schist along its margins. On the north the schist appears in general to dip under it. Half a mile west of the town of Miami, on the other hand, the schist appears to overlap the porphyry from the east. How thick this porphyry may be near the center of the lobe, say at the portal of the Inspiration tunnel, it is impossible to determine without drilling.

EFFECTS OF FAULTING.

In common with the region of which it is a part, the Miami district contains numerous faults which probably are not all of the same age and which certainly are not susceptible of systematic grouping. Although the evidence for the existence of most of the faults that are shown in Plate XXXIX is plain, it is generally impossible to ascertain even roughly the displacement involved, owing to the absence of regular and persistent structural features to serve as datum planes from which measurements of dislocation might be made.

The most conspicuous line of dislocation shown on the geologic map of the district (Pl. XXXIX) is the Miami fault, which limits the Miami ore body on the east. The general course of this fault is from 20° to 25° east of north, and the fault plane dips east at angles which vary considerably from place to place but of which the average is probably between 45° and 50°. The footwall in the Miami mine is mainly schist, and the hanging wall is the Gila conglomerate. The fault is thus of normal type, and, in terms of relative displacement, the conglomerate has been faulted down against the schist. The throw of the fault has not been determined, but inasmuch as the conglomerate south of Bloody Tanks Wash rests evenly on the schist at an elevation of about 3,700 feet above the sea and the bottom of the Miami No. 4 shaft is in conglomerate at about 3,000 feet, the difference, or 700 feet, is probably a minimum measure of the vertical displacement. Near the No. 4 shaft, as may be seen in the loop of the 420 level, the sandy layers in the conglomerate dip about 40° NW.—that is, toward the fault. This suggests that the conglomerate is part of a fault block that actually was depressed with a tilt toward the fault and that the throw is probably more than 700 feet. That it may be very considerably more is suggested by the great thickness, over 2,050 feet, of conglomerate found in drilling hole No. 75 (see p. 109), only about 2,500 feet from the outcrop of the fault fissure.

At the surface the Miami fault is less evident than in underground exposures, and from superficial appearance alone the contact between the conglomerate and schist might be interpreted as the result of the disposition of the coarse gravels against a steep slope. It has in fact been suggested by some observers, although not, so far as I am aware, in published descriptions, that faulting and conglomerate deposition went on simultaneously, the conglomerate being laid down against the scarp formed by the relatively uplifted schist on the west side of the dislocation. Were this true, it would appear that the material of the conglomerate close to the fault ought to be markedly different from that farther east. It should contain abundant large fragments of metallized schist derived from the newly formed scarp. On the contrary, the material is largely granitic, and appears to have come for the most part from points west of the Miami ore body and is similar to the material of the extensive conglomerate area west of the Live Oak mine and of the smaller residual areas on the ridge south of Liveoak Gulch. The conclusion that the faulting was, in the main at least, subsequent to the deposition of the conglomerate, involves the supposition that a blanket of conglomerate several hundred feet thick has been removed by erosion from the central part of the district. Such vigorous denudation in Quaternary time seems at first glance a little startling to one who has seen the Gila conglomerate only as it lies in the depression drained by Pinal Creek between the Pinal Range and the Globe Hills. Considered, however, in connection with the topographic and structural relation of the conglomerate as shown in the western part of the Miami district (Pl. XXXIX), the idea of intense local erosion of the conglomerate becomes not merely tenable but inevitable.

The conglomerate perched on the top of Needle Mountain, overlooking ravines cut deeply into schist and granite, the residual masses of conglomerate south of Liveoak Gulch, and the conspicuous faulting of the large, thick mass of conglomerate in the western part of the area against the schist and granite in the upper part of Liveoak Gulch all point unmistakably to active deformation and erosion since the deposit accumulated. The relations of the conglomerate east and west of the Miami fault to the present topography are shown in section as figure 17. The section shows considerable irregularity in the present slope of the preconglomerate surface, perhaps in part explicable through the difficulty of mapping the contact between the conglomerate and an underlying rock and in part to the effect of unrecognized faults in the schist and granite. The illustration, however, makes clear the facts that there has been great local erosion of the Gila conglomerate and that a notable volume of the conglomeratic material has been removed from at least a large part of the area in which older rocks are now exposed.

West of the town of Miami there is an offset of about 1,000 feet in the course of the Miami fault, the southern portion of the fissure being relatively shifted to the east. This offset (see Pls. XXXIX and XL) is interpreted as the effect of a younger cross fault. If this younger fault is a normal fault, it should dip northeast to produce the offset observed. No satisfactory exposure of this fault could be found, and it is shown on the geologic map as a hypothetical or inferred dislocation.

In the Miami mine the Miami fault is not so well exposed as some others of less structural importance. Between the main plane of movement and the ore there generally intervenes more of less barren leached schist, and consequently many of the east drifts stop before they reach the main gouge, some of them at subsidiary slips in the footwall. Where they reach the main fault heavy timbering and close lagging are necessary to hold the ground, and opportunities for observation are thus lost. Nevertheless good exposures of the fault are to be seen at a few places. On the 570-foot level the south haulageway from the No. 4 shaft, which is in the Gila conglomerate, goes through the fault just before the ore body is reached. Here the principal plane of movement, next to the conglomerate, is marked by a thick seam of tough gouge. On the footwall or west side of this gouge, as measured along the drift, there is about 25 feet of crushed oxidized schist separated by a second seam of gouge from the ore. Still other seams of gouge traverse the ore in this part of the mine, and in general the schists which constitute the footwall of the main fault fissure are cut by many subsidiary fissures.

The north haulageway from the shaft shows more complex relations. In going west from the shaft the drift passes from the Gila conglomerate through a strong fault gouge into much shattered dacite, mingled with fragments of oxidized schist. After passing through about 100 feet of this material another gouge is penetrated and the drift goes into shattered oxidized and leached schist. Fifty feet farther on a third gouge seam separates this schist from the ore. Apparently the conglomerate

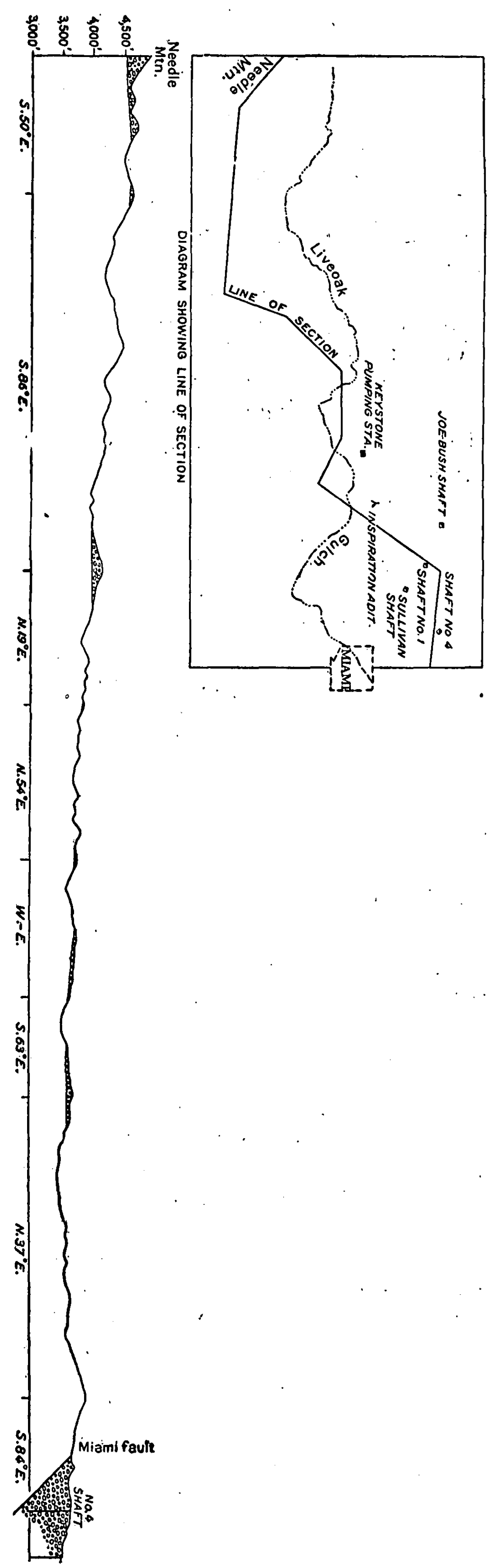


FIGURE 17.—Section across the Miami district showing the present relation of the Gila conglomerate to the topography.

in this vicinity, as in many other parts of the region, is underlain by dacite, and a slice of this dacite, much disturbed, is here included in the fault zone, whereas most of the rock has been carried down to the east by the fault displacement. The relations at this place indicate that the Miami fault is, locally at least, a fairly wide fault zone in which the total displacement is effected by successive down steps to the east.

On the 420 level the Miami fault is also exposed near the point where the drift from the No. 4 shaft enters the ore-bearing ground. Here the Gila conglomerate is separated from the schist by a seam of tough, leathery gouge that in places is 18 inches thick. The local dip of the main fault fissure at this place is 35°. From 40 to 50 feet west of the main fault surface is a second strong fissure which in this part of the mine limits the ore body on the east. The two fissures are approximately parallel, and between them is shattered rusty schist. That much of the movement along the Miami fault zone is later than the enrichment that produced the ore body is shown by the fact that a part of the gouge is triturated oxidized "capping."

Other faults occur in the ground opened by the Miami mine and have been locally important in determining the shape of the ore body. These faults, however, are very obscure at the surface and can more appropriately be described in connection with the ore body than with the general geology as represented on Plate XXXIX.

On the Inspiration ground an obscure fault can be traced rather indistinctly and interruptedly on the surface from the vicinity of the Joe Bush shaft, where it brings together granite porphyry and schist, to the Scorpion shaft, on the north side of Inspiration Ridge. The general course of this fissure is N. 62° W., and the dip, as shown by the position of the fault on the third (3580) level and second (3440) sublevel, is about 85° SW., although measurements made directly on the fault surfaces generally give angles considerably lower than this. The fault, known as the Joe Bush fault, is conspicuous on the levels mentioned, the fissure for about 1,500 feet in the eastern part of the third level separating barren porphyry on the southwest from ore-bearing schist on the northeast. Farther west on this level, at about mine coordinate line 102.5 east, the fault passes into the ore body and could not at the time of visit be traced with certainty west of coordinate line 101 east.

In the eastern part of the mine, near coordinate 113 east, the Joe Bush fault is offset by an irregular fault of generally northeast strike and southeast dip. The effect of this cross fault is to displace the part of the Joe Bush fault that lies southeast of it about 100 feet to the northeast. The displacement by the cross fault is thus apparently normal. If the movement was a pure dip slip, the throw must have been in the neighborhood of 200 feet.

The structural significance of the Joe Bush fault is far from clear. A considerable part of the movement at least was subsequent to the formation of the Inspiration ore body, and as the fissure limits that body sharply for a distance of about 1,500 feet, the supposition that there is or was some ore somewhere on its southwest side appears well founded. Drill holes on that side of it, however, go into protore, and no evidence whatever has been found to indicate that any part of the ore has been dropped by this fault below the general level of the known Inspiration ore body. The most reasonable hypothesis appears to be that the dislocation is a reverse fault and that any ore which may have lain on its southwest side has been relatively uplifted and has been eroded away.

Between the Colorado shaft and the Keystone shaft (see Pl. XXXIX) is a zone of strong faulting, commonly known as the Bulldog fault, from the shaft of that name. The general course of this zone is nearly north, and the dip is low, to the east. The dip and strike, in connection with the steep slopes of Inspiration Ridge, would account for most of the apparent curvature of the fault as drawn on Plate XXXIX; but the surface relations of the fissure are obscure, and it is probable that the displacement has been effected along two or more intersecting fractures instead of mainly along a single fissure as indicated on the map. Where the fault crosses the ridge there is a sharp saddle, within which a small mass of dacite has been let down into the schist between two branches of the fault zone. Here are some prominent outcrops of fault breccia. One of these shows a smooth regular surface of slipping, which, however, does not appear to coincide in strike and dip with the main fissure. Underground workings show that the ground west—that is, in the footwall—of what has been considered to be the main fissure is badly cut up by many subsidiary faults, some of which are nearly horizontal.

The general effect of the Bulldog fault zone has been to displace the ore body so that the ore of the Inspiration mine, east of the dislocation is from 450 to 500 feet lower than the ore of the Keystone mine, west of it.

West of the Keystone shaft faulting is structurally important, as is evident from the distribution of the rocks shown in Plate XXXIX. The structure in the vicinity of the Live Oak No. 2 shaft has some very puzzling features and can probably be best described by reference to the accompanying diagram (fig. 18), which was constructed from the geologic map (Pl. XXXIX) and is of the same scale. The map and diagram should be used together. One of the larger faults of this part of the district is indicated on the diagram as the Live Oak fault. Its general course is nearly north, but its intersection with the surface is an irregularly curved line, the deviations being due in part to the combination of a westward dip with strong topographic relief. The dip, as determined by drill records, appears to be about 75°, but there are no exposures of the fault surface. West of this fault the structure, so far as can be seen from the surface, is comparatively simple. There is a broad mass of the Gila conglomerate which rests along its northern edge on dacite and along its southern edge for the most part on schist. East of the fault lies a mosaic of small fault blocks, in which appear fragments only of the dacite and conglomerate which are so

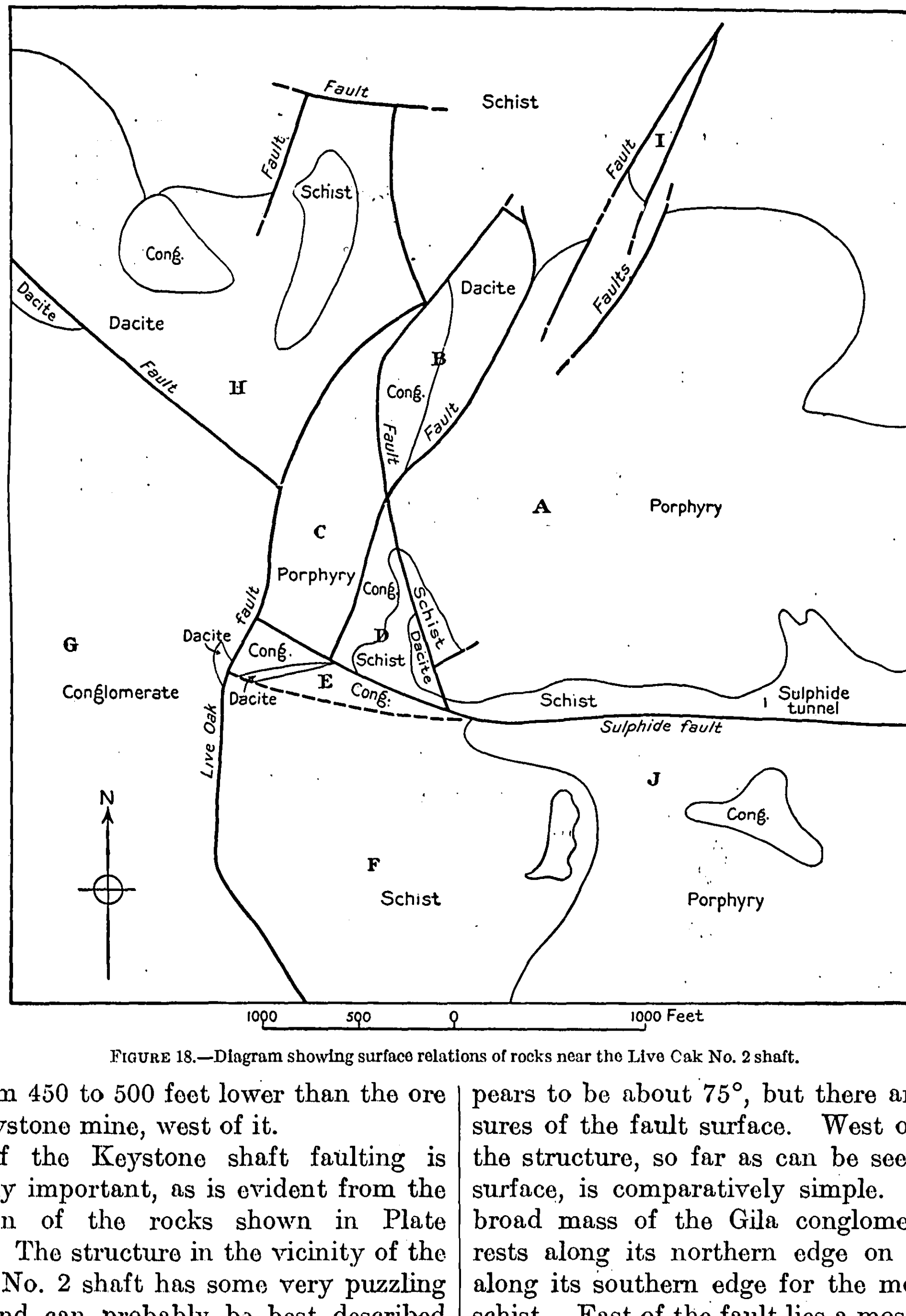


FIGURE 18.—Diagram showing surface relations of rocks near the Live Oak No. 2 shaft.

abundant to the west. In the vicinity of the Miami mine the conglomerate has been downfaulted to the east, but near the Live Oak the relatively downward movement has been to the west. It will be of interest to examine the structure near the Live Oak in some detail.

Block I (see fig. 18) is a little mass of the dacite inset into the schist by two faults, which are probably not of great throw. The larger block B is a similarly inlaid mass in which the dacite is overlain by some of the Gila conglomerate. Here again the vertical throw can hardly have been great, although the block appears to have undergone some rotation, as indicated by the steep westward dip of the conglomerate. Block H appears to have dropped relatively to block C, as shown by the abrupt ending of the dacite against the granite porphyry, and block G is apparently still further downthrown. Blocks C and A, both mainly porphyry at the surface, do not seem to have suffered much relative displacement. Drilling has shown that the porphyry of both blocks rests on schist. In block A the contact is irregular but on the whole dips southwest. The maximum thickness of the porphyry is about 400 feet. In block C the dip of the contact is more regularly to the southwest and is steeper. Drill hole No. 51, near the southwest corner of the block, penetrates about 700 feet of porphyry. Block D appears to have dropped relatively to the blocks east and west of it, as shown by the Gila conglomerate along its western edge.

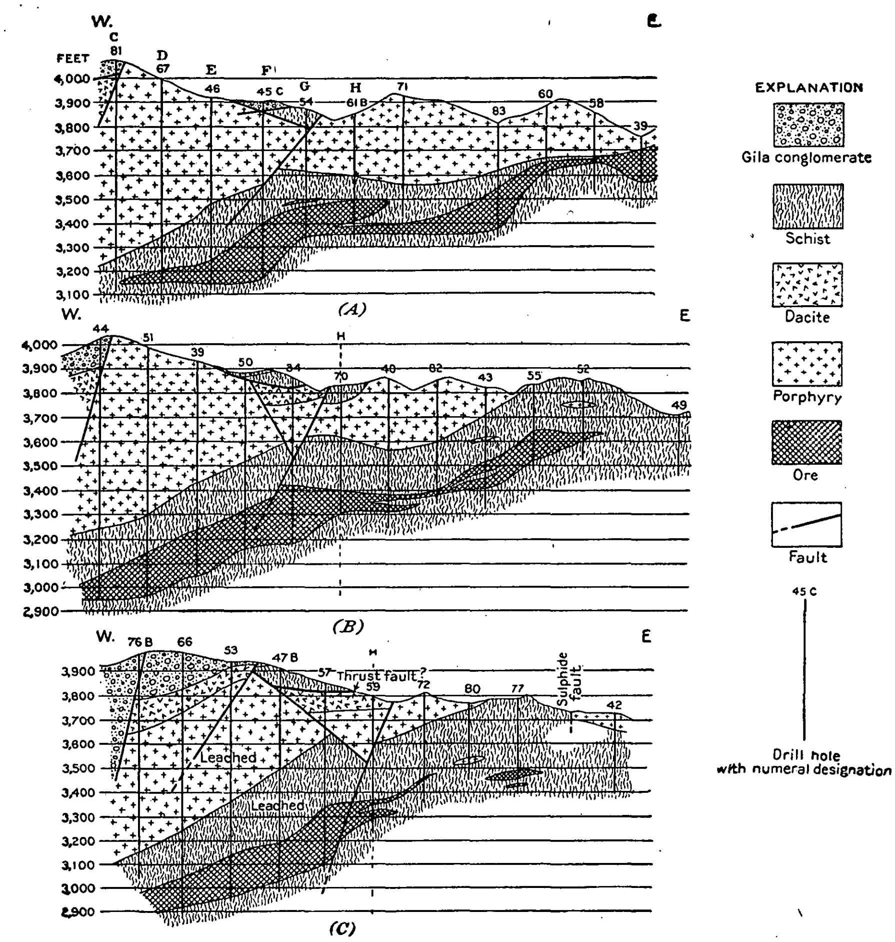


FIGURE 19.—Geologic structure sections of the Live Oak ground based on drill records. *A*, Section on coordinate line 20 (see Pl. XLII); *B*, section on coordinate line 18; *C*, section on coordinate line 16.

The Gila conglomerate in this immediate vicinity rests normally on the eroded surface of a flow of dacite, but in block D the conglomerate overlies the Pinal schist, which in turn overlies dacite. Surface exposures are not locally satisfactory, and their evidence alone might be considered as inadequate to establish so anomalous a vertical sequence; but drill holes 57 and 34 (see Pl. XLII and fig. 19) go through 35 and 60 feet respectively of schist and then through the same layer of dacite that crops out in the ravine east of the Live Oak No. 2 shaft.

Three hypotheses have been considered in searching for an explanation of the apparent superposition of schist on the much younger dacite. These are: (1) The superposed schist is actually clastic material, possibly in part of landslide origin, and is to be regarded as a basal accumulation of schist fragments in the Gila conglomerate; (2) the dacite, where it is overlain by schist, is not a flow but is an intruded sheet; (3) the schist was thrust over the dacite by faulting prior to the local normal faulting. Definite elimination of two out of the three suggestions has proved unexpectedly difficult, and discussion of these hypotheses will be deferred until all the pertinent facts have been described.

The surface of the wedge-shaped block E is covered generally with the Gila conglomerate but is crossed by a narrow and rather obscure outcrop of dacite. This little strip of dacite is supposed to be the top of a very narrow minor fault wedge which is slightly upthrown with respect to the rest of block E. The south boundary of block E is rather indefinite but apparently coincides with a fault or zone of faults that brings conglomerate on the north against schist on the south. Such a fault would be in the line of prolongation of the sulphide fault, as known to the east, which separates blocks A and J. Drill holes 66 and 53 penetrate the conglomerate of block E and show it to rest on dacite.

The direction of dip of the Sulphide fault is not certainly known. At the mouth of the little gulch in which is the Live Oak No. 2 shaft the fault fissure dips north at angles ranging from 75° to vertical. A little farther east the dip is 55° N. Here about 1 foot of gouge and breccia separates the porphyry and schist. Still farther east, near the portal of the Sulphide tunnel, drill hole 42 (Live Oak) is said to have gone through 50 feet of porphyry and then into schist. As the hole is close to the line of the fault and the schist at the surface is north of that line, this would indicate a dip to the south. If the fault is normal and if the porphyry on the south side of Liveoak Gulch was once directly continuous with the higher porphyry on the north side, then the general dip of the fault plane should be to the south.

Drill holes 64, 41, 69B, 78, 84, and 85 are all in or very close to the fault that is supposed to separate blocks E and F, and interpretation of their records is therefore full of uncertainty. Holes 85 and 84 are of especial structural interest. Hole 85, apparently just south of the east-west fault zone, went through 270 feet of schist into dacite and continued in dacite for 207 feet, to the bottom of the hole. Hole 84, 200 feet east of hole 85, went through 165 feet of schist and then through 315 feet of dacite into granite porphyry. Drill hole 78, supposed to be a few feet north of the fault, went through 35 feet of conglomerate and then presumably through the fault plane into dacite, continued in that rock for 365 feet, and then passed into schist.

Block G, separated from blocks C, E, and F by the strong Live Oak fault, is a comparatively large structural unit which consists superficially of the Gila conglomerate. A little dacite exposed in the gulch west of the Live Oak No. 2 shaft and just northwest of drill hole 85 is believed to be the top of the flow upon which the conglomerate locally rests.

Southwestern Miami drill hole 5 (Live Oak 88), situated at the point where the Live Oak, Montezuma, and Barney claim groups come together, about 500 feet west of the Live Oak fault at the surface, went through 430 feet of conglomerate, 105 feet of dacite, 285 feet of schist, 125 feet of dacite, and 65 feet of schist to the bottom. In this hole, therefore, the top of the lower dacite is at a depth of 820 feet, or at an elevation of about 3,230 feet above the sea. Chalcocite is reported from the bottom of the lower dacite to the bottom of the hole.

Southwestern Miami drill hole 7, about 400 feet nearly south of hole 5, also goes through a lower body of dacite. For the first 60 feet the hole is reported to go through schist, but this is highly improbable. The hole is well within the conglomerate area, and the so-called schist is probably a facies of the conglomerate consisting chiefly of schist fragments. From 60 to 310 feet the rock is undoubtedly the Gila conglomerate. Below this comes 720 feet of schist, the upper dacite being apparently absent, then 60 feet of dacite, and finally 175 feet of schist to the bottom. These relations are graphically represented in figure 20, which is a nearly north-south section through the Barney No. 2 and Southwestern Miami Nos. 5, 7, and 4 holes, all of which are nearly in line. Hole 4, started at an elevation of about 3,925 feet, shows 520 feet of conglomerate, whereas holes 7 and 6, both started at an elevation of about 4,000 feet, show considerably less; hole 7, if the first 60 feet of "schist" is included, went through 370 feet of conglomerate, and hole 6 went through 365 feet.

Hole 4 is roughly 350 feet west of a line between holes 7 and 6, a position which, taken in connection with the different thicknesses of the conglomerate, indicates a westward or southwestward dip of the base of the conglomerate, in the eastern part of block G, of about 33°. A line connecting the little exposure of dacite in the ravine near Live Oak hole 85 with the top of the upper dacite in Southwestern Miami hole 5 gives an apparent westward dip of 30° to the base of the conglomerate. The agreement between the two angles thus obtained is fairly close and is about the same also as the apparent dip of the formations and ore body in block C, as displayed in the east-west sections of figure 19 (p. 116). Whether the maximum or real dip in block G is, as in block C, south of west remains to be determined by further drilling.

The known facts pertaining to the faulting near the Live Oak mine having thus been briefly presented, a return may now be made to the three hypotheses considered as offering possible explanations of the occurrence of dacite beneath the much older schist. The suggestion that the schistose material above the dacite is really clastic and a part of the Gila conglomerate is not an altogether improbable explanation of the relations shown in block D, where the overlying material is at least thoroughly shattered and is less than 100 feet thick. Conditions under which landslide material might mingle here and there with the abundant coarse fluviatile detritus during the early stages of the vigorous local deposition recorded by the Gila conglomerate can readily be imagined. If the shattered schist was deposited on the dacite as a part of the Gila conglomerate then the material in its present condition occupies its normal stratigraphic position and accords with the chronologic sequence of rock formation. Had no drilling been done outside of block D the foregoing interpretation might readily have been accepted as the most probable one. When the records of drill holes in blocks C, E, and G are considered, however, the depth at which dacite is found, the great thickness of the

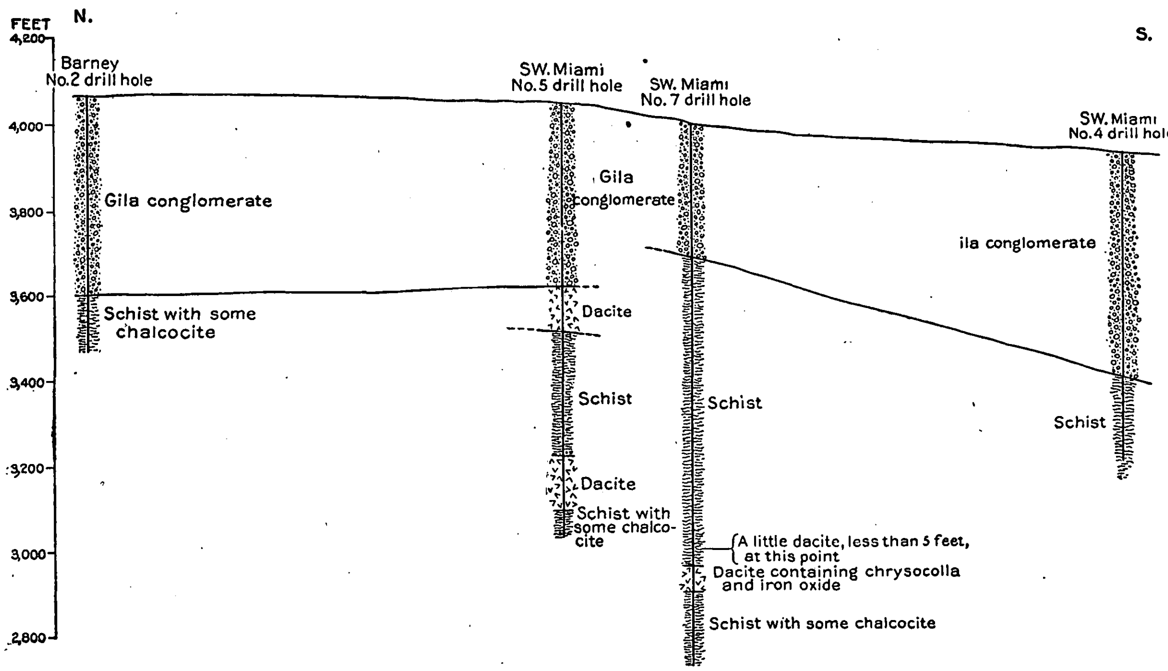


FIGURE 20.—Nearly north-south section between the Barney No. 2 and the Southwestern Miami No. 4 drill holes.

overlying schist, and, above all, the occurrence as in hole 5 of the Southwestern Miami group of dacite both in its normal position just under the Gila conglomerate and also at greater depth under what is undoubtedly schist in place, all render this first suggestion improbable as a complete explanation of all the puzzling relations in this locality.

The suggestion that the dacite is in part intrusive is attractive because it offers a ready explanation of structural irregularities and avoids the necessity of attempting to interpret complex faulting from inadequate data. Against it, however, may be arrayed the following considerations: (1) The dacite, although it has been studied carefully over two quadrangles and has been examined at numerous points in the outlying region, has nowhere been found intrusive, although of course it must somewhere have had direct connection with intrusive magma. (2) The dacite exposed at the surface in block D has the same petrographic character as rock known to be extrusive. It might be said that the dacite visible in block D is extrusive and that the supposed schist in the same block is part of the Gila formation, whereas the deeper dacite in block G is, on the other hand, intrusive. This does not appear highly probable but nevertheless is a possibility to be reckoned with, and as the deeper dacite has been seen only in the form of drill sludge its petrographic character can not be considered as accurately known. Microscopic examination of the powder indicates, however, that this dacite contains glass, which is suggestive of extrusive rather than intrusive eruption.

In support of the third suggestion, that the schist and overlying rocks have in places been thrust over the dacite, may be adduced the fact that a number of dislocations of this general kind are known in the district. In the Keystone mine nearly horizontal, undulating seams of gouge and zones of brecciation are prevalent. Some of these are apparently the result of considerable displacement, but this, owing to the character of the rock, is not measurable. Similar low-angle billowy surfaces of displacement are exposed in the Taylor and Mercer tunnels, in the hanging wall of the Bulldog fault zone. At the Old Dominion mine, near Globe, shattered pre-Cambrian quartz diorite (Madera diorite) overlies dacite, much as the schist does at the Live Oak mine. According to an earlier report,[1]

The principal exposures of this material extend from Copper Gulch, half a mile east of town, to the old Buffalo smelter on Pinal Creek, a mile northwest of Copper Gulch. The surface exposures are generally of such a character that an observer might readily conclude solid Madera diorite to be in place beneath them. Some of the ravine sections, however, as well as mine workings, show that the diorite occupies a position at the base of the Gila conglomerate and rests on dacite. In some places it actually grades into the characteristic fluviatile conglomerate, and the deposit was described in Professional Paper No. 12 as a local basal phase of that formation. The homogeneity of the material, however, and the lack of evidence indicating water transport of much of it were recognized as facts imperfectly accounted for in the explanation offered. During the past eight years the granitic deposit has been much exposed in road and railway cuttings and in underground workings. It appears in some of these new openings as a thoroughly shattered mass, in which the largest single fragments observed are from 5 to 6 feet in diameter. Wherever penetrated underground the material shows the same thorough shattering. Crosscuts through it, such as the lower drain tunnel of the Old Dominion mine, have to be closely lagged. In one place, in Copper Gulch, the Gila conglomerate may be seen lapping up over a slope of this shattered Madera diorite, the contact between the two being definite. In other places the broken quartz diorite has supplied so many angular or slightly rounded fragments to the overlying Gila conglomerate that there is a gradation between the two formations, and to this fact, together with the position of the quartz diorite above the dacite, was due the former assignment of it to the Gila formation. The better opportunities for study now available have suggested another hypothesis, namely, that the shattered Madera diorite is a thin wedge that has been thrust over the dacite from the southwest by faulting. Investigation has fully confirmed this view. Wherever a shaft has gone through the quartz diorite it is found to be separated from the dacite by a zone of trituration and slickensiding that is plainly due to fault movement.[2] One of the best exposures of this fault plane is to be seen in a small prospect tunnel about 2,000 feet northeast of the Old Dominion smelter. This tunnel runs N. 15° E. for about 150 feet through the shattered Madera diorite and then passes for 20 feet through a fault breccia in which rounded polished fragments of the quartz diorite are embedded in a sheared gouge composed of triturated quartz diorite and dacite. This is separated from the solid underlying dacite by a smooth slip plane dipping 37° SW. The course of events was as follows: After the Paleozoic sediments and diabase had been much faulted and eroded, they were covered by the flow of dacite. This in turn was probably eroded and then a thrust was developed southwest of Globe, probably in the area now deeply buried under Gila conglomerate, and a mass of the pre-Cambrian Madera diorite was shoved over the dacite to the north-northeast. The shattered mass thus

[1] Ransome, F. L., Geology at Globe: Min. and Sci. Press, vol. 100, p. 257, 1910.

[2] The C shaft of the Old Dominion mine penetrated about 250 feet of loose shattered quartz diorite before reaching the dacite.

bodily thrust over the dacite was readily attacked by erosion and supplied much detritus to the Gila conglomerate. Finally the Gila conglomerate, the remnant of the underlying wedge of shattered diorite, and of course all of the underlying rocks were affected by the normal faulting already discussed in connection with the description of the Old Dominion mine in Professional Paper No. 12.

In general, low-angle thrust faults are very obscure structural features, and probably many of them escape recognition. They may not crop out at all in the region studied unless strong topographic relief has been developed since the faulting took place. Underground they are likely to be cut in shafts and raises, where ordinarily they are soon hidden behind timbers and lagging. They may be penetrated by drill holes, but one hole gives no clue to the attitude of the fault surface, and if, as is likely to be the case, the driller does not note and record the existence of gouge or breccia the geologist has no means of supplying the missing data.

So far as it goes the evidence now available appears to favor the view that the schist now on top of the dacite was thrust into that position by faulting and that all the dacite known in the district is an extrusive rock. The thrust faulting must have taken place before the normal faulting and, in the area explored by drilling, appears to have displaced only the rocks above the ore body. The thrust plane apparently dips west on the whole, at about 30°, but in consequence of the later normal faulting and because of the imperfect character of drill records it must for the present remain a very obscure and little understood element of the geologic structure.

The faults described in the immediately preceding pages are those connected with the ore bodies of Inspiration Ridge. North of that ridge, in the northeast corner of the district, there has been some irregular block faulting of the kind characteristic of this region. The most interesting faults of this part of the district are those which constitute the nearly east-west zone of displacement which traverses the Geneva, Dadeville, Montgomery, Winnie, and Black Copper claims and with which are associated the silicate ore of the Warrior mine.

As shown on Plate XXXIX, there are apparently two nearly east-west fissures with a narrow down-dropped block between them. These fissures are not clearly exposed at the surface, and scarcely any indication of their presence has been found where dacite forms both walls. The down-dropped strip is from 100 to 160 feet wide. The throw could not be accurately determined but apparently varies from place to place. The material between the two fissures as seen underground in the Warrior mine consists of dacite tuff interbedded with conglomerate, with a layer of coarse fragments at the base, resting on schist.

Another fault of considerable interest drops dacite against schist northeast of the settlement of Inspiration (Pl. XXXIX). This, which has been called the Pinto fault from its supposed effect in dropping the Pinto ore body lower than the main Inspiration ore body, is perhaps identical with the fault in Plate XXXIX as bringing schist against porphyry between the No. 2 and Captain shafts of the Miami Copper Co. The fault in the Miami ground has about the same strike and is nearly in line with the Pinto fault. It also drops the bottom of the zone of oxidation down to the northeast and like the Pinto fault has a rather low dip in that direction. The suggestion of identity is not supported by the geologic mapping of Plate XXXIX, but it is possible that further study of the surface north of the old Joe Bush shaft might lead to some modification of the mapping done in 1911 and bring to light evidence of the extension of the Pinto fault into the Miami ground.

The faults described are only a few of many that occur in the district. Some of these are shown on Plate XXXIX. Many others are indicated by thick seams of gouge visible in underground workings but not recognizable on the surface. So far as known these faults do not affect the areal distribution of the rocks.

EROSION.

In the Miami district, as in the Globe-Ray region as a whole, there is a record of long and vigorous erosion prior to that which carved the present topography. The surface over which the dacite flowed as a lava had been well worn down, and its hollows had been filled with detrital material, represented, just outside of the area shown in Plate XXXIX, by the Whitetail formation. It is probable, as will be shown later, that most of the enrichment to which the ore bodies are due was effected during this period of denudation. There is no means at present of definitely fixing the geologic date of this erosion, but it is believed to be Tertiary.

After the dacitic eruptions by which the country far and wide was buried under lava and tuff, the rocks were faulted and tilted, the entire aspect of the land was changed, and the streams began the active cutting and transportation that are recorded in the Gila conglomerate, supposedly of early Quaternary age. There was some faulting and deformation of this conglomerate, followed by the stream cutting of the present erosion cycle and the stripping away of the conglomerate from a large part of the Miami district.

Chapter VI.—Geology of the Ray District.

TOPOGRAPHY.

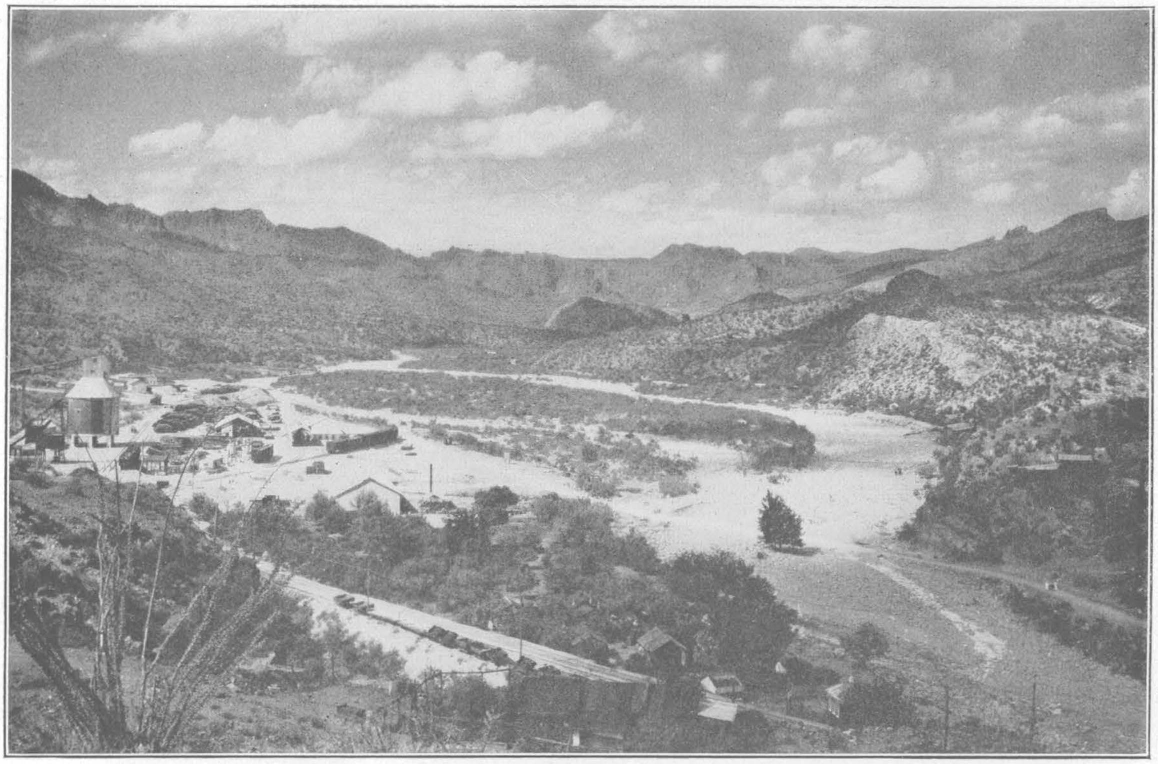
For the first 10 miles of its generally southward course, Mineral Creek traverses a succession of gorges cut in a thick, faulted flow of dacite. About 8 miles north of its mouth, however, the creek emerges from its narrow confines into a more open valley (Pl. XLIII), which continues southward (Pl. XXVII, *B*) to Gila River. The Ray district, as the name is used in this report, is situated at the head of this valley, which, while broadly open, contains very little level ground. The district itself is perhaps best characterized as a confusedly hilly area in which the various eminences are distributed without any recognizable plan or structure. It is overlooked from the east by the steep and, in some places, precipitous slopes of the Dripping Spring Range, which culminates locally in Scott Mountain, 5,115 feet in elevation, or about 3,000 feet above Ray. On the west is a more gradual ascent to the crest of the Tortilla Range. The lower grade of this slope is due partly to the fact that Copper Creek is tributary to Mineral Creek on the west side and heads between Granite and Teapot mountains in a pass that is only 800 feet higher than Ray. North of the pass, however, the crest rises boldly to the summit of Teapot Mountain (Pl. XLIII, *B*), 4,500 feet in elevation. This summit, with the characteristic outline which gave the mountain its name, is a prominent feature from nearly all parts of the district. Teapot Mountain is capped with dacite and is the southern point of a deeply dissected lava plateau which partly incloses the district on the north and stretches in rugged desolation for many miles in that direction (Pl. XXI, *A*).

On the south a group of curious pinnacles (Pl. XXIV) carved from indurated Gila conglomerate, of which the largest, Big Dome, rises precipitously to a height of about 450 feet above Mineral Creek, suggest a topographic separation of the Ray district from the valley immediately north of Kelvin. This separation, however, is not so real as it appears to the traveler who approaches the district in the usual way, up the channel of Mineral Creek. A broader outlook over the country, such as may be had from the adjacent mountains, reduces these pinnacles, which are sufficiently imposing near at hand, to their true proportions in the general landscape and shows that there is no constriction of the valley proper.

It thus appears that, as a whole, the district has the aspect of a small hilly basin, traversed from north to south by Mineral Creek, and very imperfectly closed on the south. As seen from a moderate elevation the central part of this basin bristles with a huddled assemblage of little, rusty, sharp-topped hills, of which Humboldt Hill (Pl. XLIV, *A*) is a type. Most of these hills stand from 300 to 500 feet above the deepest adjacent ravines, or probably from 100 to 300 feet above what may be considered the general level of the district.

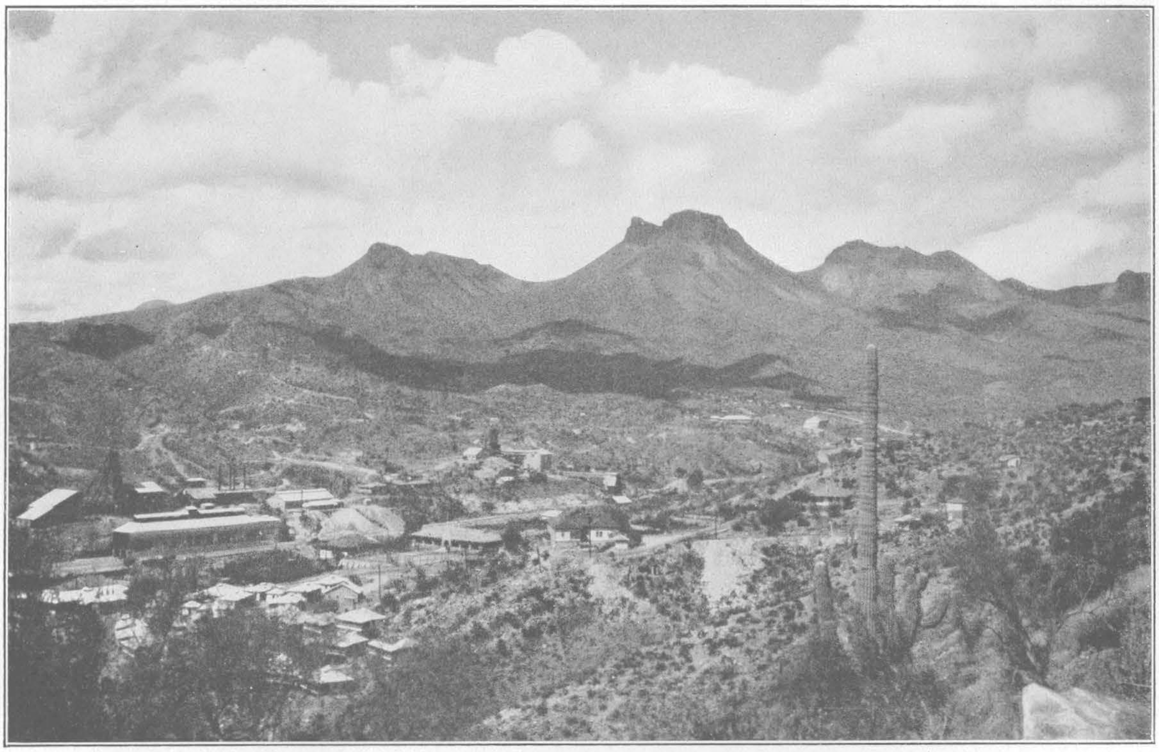
The area characterized particularly by this topography is of elongated earlike outline; its longer axis trends a little north of west, and the concave side of the area lies to the south. Its length, from the east end of Ray Hill to the saddle west of Last Turn Hill, is about 2 miles, and its greatest width is about three-quarters of a mile. Most of the area, which corresponds in general to that showing more or less metallization, lies between the lower part of Amanda Gulch and the upper part of Copper Canyon, on the south, and Sharkey Gulch, on the north.

North of Sharkey Gulch and to a less extent south of Copper Canyon broad, low, gently sloping spurs (see Pl. XLV), which have evidently been formed by the dissection of superficial layers of stony or gravelly detritus, give to the basin floor a general smoothness which is in marked contrast with the craggy topography of the central area.



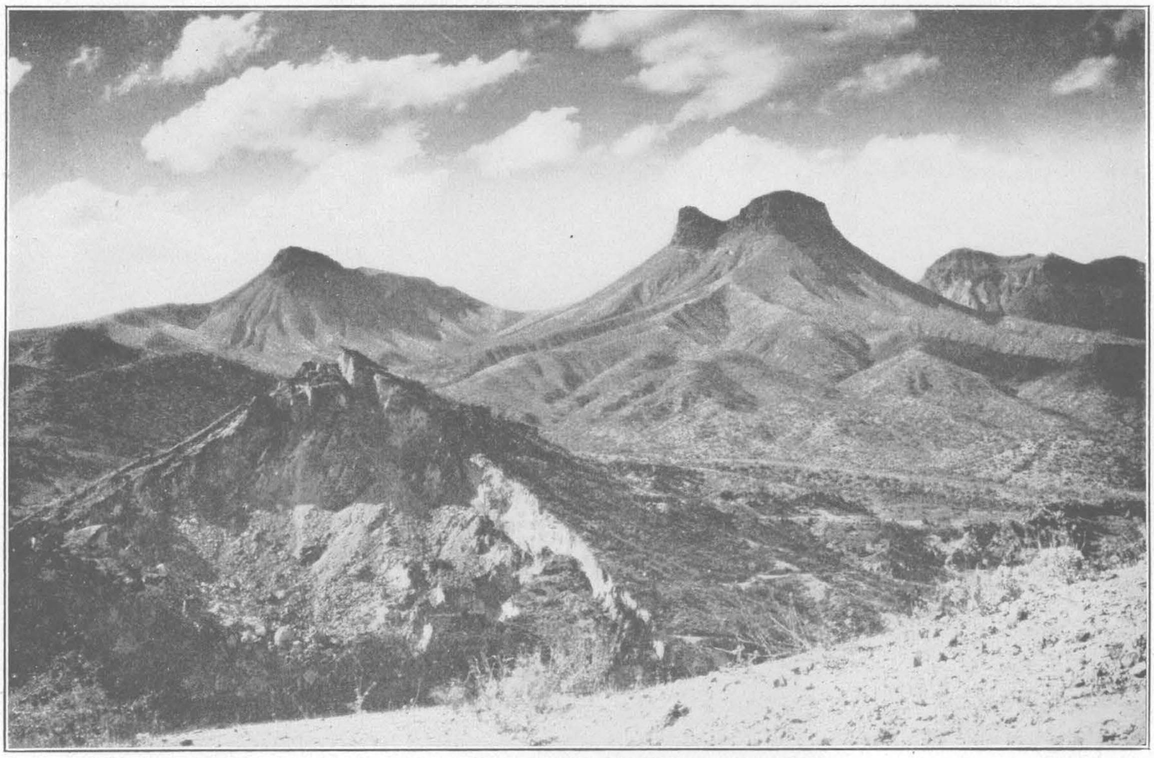
A. VIEW NORTH UP MINERAL CREEK FROM POINT NEAR RAY.

The cylindrical ore bin of the No. 2 mine and the railway station are on the left.



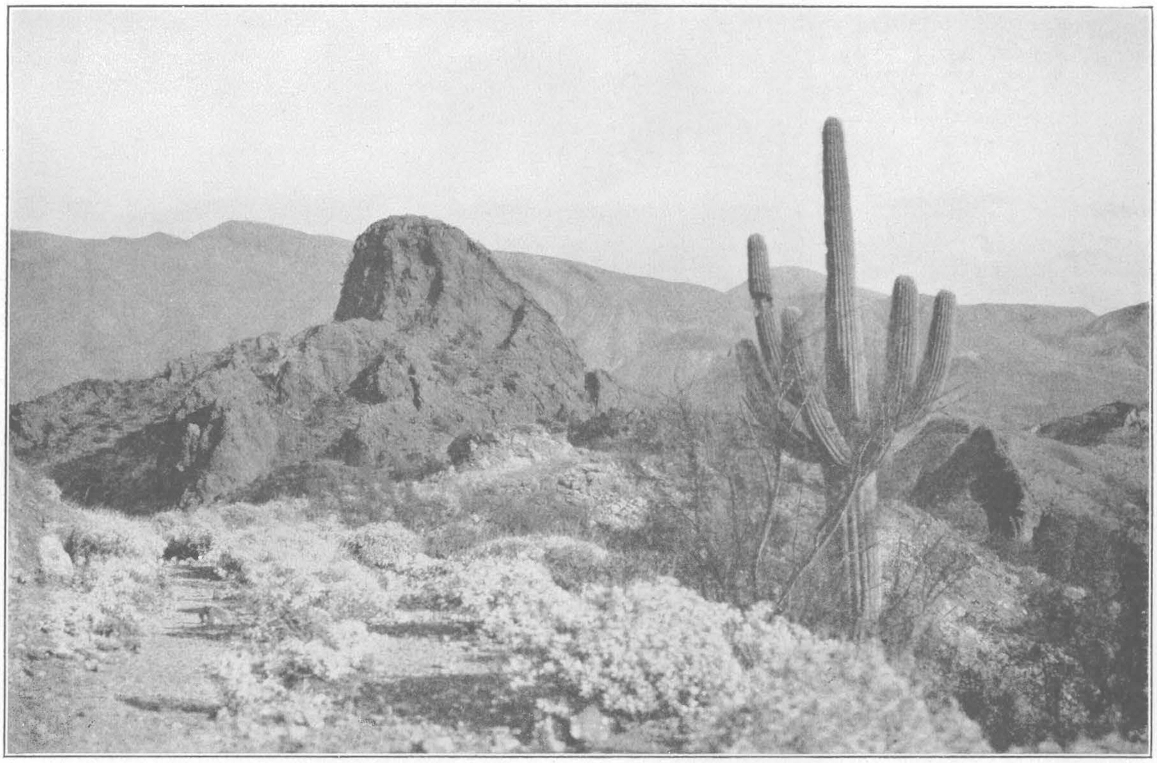
B. GENERAL NORTHWEST VIEW OF THE RAY DISTRICT FROM THE EAST SIDE OF MINERAL CREEK.

On the left, across the creek, is the No. 1 mine of the Ray Consolidated Copper Co. Farther to the right are the head frame, crusher house, and ore bin of the No. 2 mine, and still farther to the right, nearly in line with the tall cactus, are the corresponding structures of the No. 3 mine. The prominent peak near the middle of the sky line is Teapot Mountain. The lighter-colored, indistinctly stratified rocks under the dark dacite capping are the Whitetail conglomerate.



A. HUMBOLDT HILL FROM THE SOUTH.

Shows the effect of stoping in the thick mass of ore beneath the hill. Teapot Mountain in the distance.



B. VIEW ON RIDGE NORTH OF COPPER CANYON.

A characteristic outcrop of leached hardened schist. The distant hills are part of the Dripping Spring Range and the rounded summit behind the cactus is Troy Mountain.

TOPOGRAPHY OF THE RAY ORE AREA.

GEOLOGY.

FORMATIONS REPRESENTED.

In the area mapped on Plate XLV pre-Cambrian rocks, mainly Pinal schist with a little granite and quartz-mica diorite, occupy most of the surface or are concealed under merely superficial deposits of much later age.

Of the Paleozoic section only the lower part is represented in the district, mainly along its eastern border, where the Scanlan conglomerate, Pioneer shale, and Dripping Spring quartzite are exposed in numerous small fault blocks. The Mescal limestone, although prominent in the mountain front east of Ray, does not occur in the Ray district as a mappable formation. It probably underlies the Troy quartzite, which is exposed at the surface of one block in the northeast corner of the district, and a few small masses of the limestone are associated with the Dripping Spring quartzite and diabase at the east base of Teapot Mountain. The Devonian (Martin) and Carboniferous (Tornado) limestones do not appear in this area, although they are prominent in the vicinity of Scott Mountain.

Intrusive rocks of post-Paleozoic but probably pre-Tertiary age are represented by diabase, quartz diorite, and two varieties of quartz monzonite porphyry, distinguished as the Teapot Mountain and Granite Mountain porphyries, and by dikes, chiefly of quartz-mica diorite porphyry. The variable Whitetail conglomerate and the overlying flow of dacite that generally accompanies it both occur in the area mapped on Plate XLV. The eruption of the dacite was followed by the deposition of the Gila conglomerate, probably in early Pleistocene time, and later Pleistocene time is presumably represented by the unconsolidated terrace deposits, which appear to be better developed in the Ray district than elsewhere in the general region.

DISTRIBUTION AND LOCAL CHARACTERISTICS OF THE FORMATIONS.

The lithologic character of each formation represented in the Ray district has been described in Chapter III, and the facts of local distribution are graphically shown in Plate XLV. Very little additional explanatory comment is necessary, therefore, to prepare the way for some consideration of the geologic structure.

PINAL SCHIST.

As Plate XLV shows, the prevailing surface rock is the Pinal schist, and this areal importance is considerably increased if the comparatively thin deposits of Quaternary detritus, which cover much of the surface west of Mineral Creek, are disregarded. The schist, moreover, as shown by its exposure in a number of fault blocks, is the prevalent fundamental rock of the northern part of the Dripping Spring Range and as such is undoubtedly present under most of the rocks exposed along the eastern border of the Ray district.

In the northern and eastern parts of the district the schist, as shown in Chapter III, consists chiefly or wholly of metamorphosed sedimentary rocks. South of Copper Canyon is an irregular branching belt of schist which appears to be a metamorphosed rhyolite. At Barcelona this belt disappears under terrace deposits and perhaps abuts against a body of quartz monzonite porphyry. At all events, efforts to trace this exceptional variety of schist eastward across the metallized area toward Ray shaft No. 1 have been unavailing. Around the borders of the large quartz monzonite porphyry mass of Granite Mountain the schist, as already described on page 36, has undergone a second metamorphism in connection with the intrusion of the porphyry.

Mapped with the schist is a little triangular area lying just west of Mineral Creek, between Americantown and Ray. This mass is bounded on the west and south by faults. The rock is tremendously shattered and is generally rusty, although it is nearly white on fresh fracture. It shows no recognizable schistosity and in general appearance is suggestive of shattered weathered quartzite. It lacks the hardness of typical quartzite, however, and in places is decidedly soft. The microscope shows the harder portions of the mass to consist of grains of quartz about 0.5 millimeter in maximum diameter, rather widely separated in a matrix of sericite and quartz. Softer varieties of the rock contain more sericite and less quartz. The quartz grains, although more or less rounded in outline, show no evidence of having been smoothed by water. Their surfaces are rough, and they are penetrated to some extent by foils of sericite.

In the No. 2 mine, on the 1775 level, the rock near the main shaft is a much sheared and jointed schist, in which granular quartzose layers alternate with very fine grained, fissile sericitic layers. Under the microscope the granular layers show the same texture and constitution as the rock just described. Here there can be no doubt of its being part of the schist series, and it is apparently a metamorphosed sandstone originally interbedded with thin layers of shale.

PRE-CAMBRIAN INTRUSIVE ROCKS.

Intrusive rocks of pre-Cambrian age in the Pinal schist are not areally important. On the edge of the area mapped (Pl. XLV), south of Sonora, appears the extreme north end of a large mass of coarse pre-Cambrian granite which extends southward beyond Gila River. (See Pl. II.) In the northern part of the district between Teapot Mountain and Rustler Gulch are a few small irregular masses of medium-grained, sheared, sheeted, and altered intrusive rock which is probably quartz-mica diorite. The largest body occurs in what are known as the Red Hills, where owing to the prevalent pyritization, followed by oxidation, the rock is not very easily distinguished from the schist.

PALEOZOIC SEDIMENTARY ROCKS.

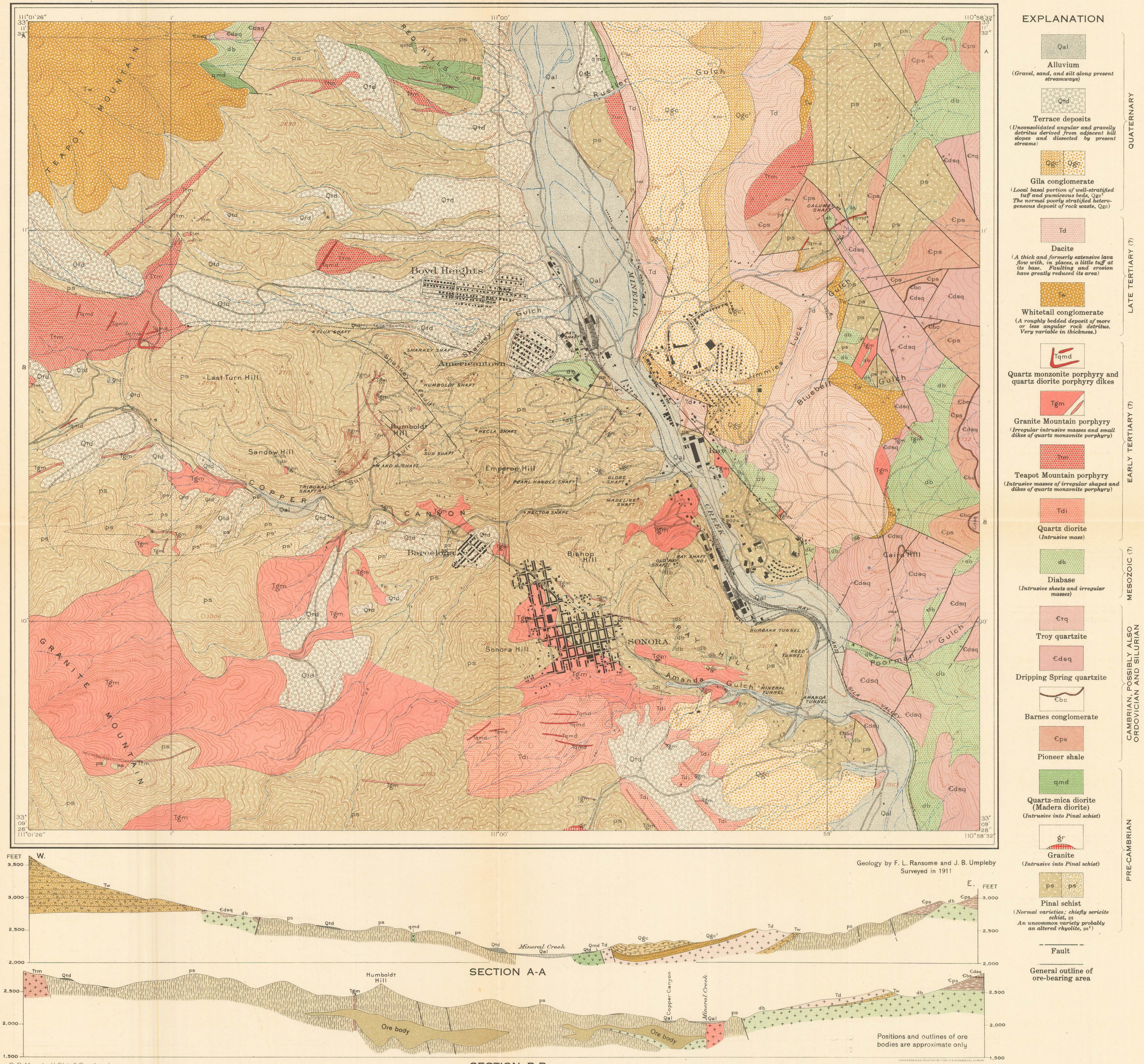
The Scanlan conglomerate, Pioneer shale, Barnes conglomerate, and Dripping Spring quartzite, as already mentioned, are exposed in a number of small fault blocks along the eastern border of the district, in a manner thoroughly illustrative of the occurrence of these rocks generally in the much shattered Dripping Spring Range. There are three small masses of the quartzite in the northwest corner of the area, at the east base of Teapot Mountain. These are intruded by diabase and are separated from the Pinal schist on the east by a fault (Pl. XLV). A little Mescal limestone occurs on the top of the largest body of quartzite and as inclusions in the diabase. Southeast of Americantown is a small mass of rusty siliceous material, which, as stated on page 123, may possibly be quartzite.

DIABASE, BIOTITE SCHIST, AND RELATED ROCKS.

The character of the prevalent diabase of the region has been fully described on pages 53-56. It may be recalled that the rock is composed principally of calcic plagioclase, augite, and olivine, in rather coarse and typically ophitic aggregation. Diabase of this kind is abundant in the part of the Dripping Spring Range northeast of Ray and north of Scott Mountain, but does not occur in close association with the ore bodies of the Ray district. The diabase in and near the ore-bearing area has all been subjected to alteration whereby the augite, the olivine, and in many places the feldspar have been changed to aggregates of secondary minerals.

Southeast of Ray is a body of diabase that is faulted on the southwest against Pinal schist and passes to the east and north under dacite. This rock is massive and in general appearance closely resembles rather fine grained facies of the normal diabase. Closer inspection, however, especially of unweathered material such as may be obtained from the dump of the abandoned Blue Bell shaft, on the ground of the Ray Hercules Copper Co., shows that the rock sparkles with minute scales of biotite, which suggests some recrystallization. Microscopical study confirms this suggestion. Although the original texture of the diabase is still recognizable in thin section, the rock retains no vestige of olivine or augite. These minerals have been changed to aggregates of green amphibole and greenish-brown biotite. The plagioclase crystals are in part cloudy with secondary crystal particles too small for identification and in part replaced by aggregates of quartz, biotite, and green hornblende. In many places the hornblende and biotite project into and have partly replaced fairly clear and fresh feldspar.

The biotite particularly has developed at the expense of the feldspars. In some specimens its formation has begun along cracks and has spread out irregularly into the walls of the fracture. The mineral also occurs as minute foils disseminated all through the altered rock. Magnetite has in part been altered to pyrite. Some of the rather abundant apatite of the original rock remains unchanged; much apatite in slender crystals appears to be secondary. Epidote, chlorite, and calcite are absent. The metamorphosed diabase from the Blue Bell shaft and elsewhere shows chalcopyrite in veinlets and minutely disseminated in the vicinity of joint cracks. Generally, wherever the altered diabase is fissured the presence of copper is superficially evident in the form of chrysocolla or carbonates. Most of the ore reported in the drill records of the Arizona Hercules Copper Co. as occurring in



R. B. Marshall, Chief Geographer.
T. G. Gerdine, Geographer in charge.
Topography by W. M. Beaman.
Control by T. M. Bannon and Thomas Winson.
Surveyed in 1910.
Culture revised in 1917 by W. M. Beaman.

GEOLOGIC MAP AND SECTIONS OF THE RAY DISTRICT, ARIZONA

Scale $\frac{1}{12000}$

Contour interval 25 feet.
Datum is mean sea level.

1919

Note: The sections accompanying this map are not to be regarded as expressive of fully ascertained fact. They are largely interpretations of incomplete data and, as such, are more or less inferential.

diabase is probably in rock such as has been described, enriched in part by the deposition of chalcocite. Altered diabase of the same general character has been found by underground exploration to lie just west of and under the ore body of the No. 1 and No. 3 mines. This is apparently an intrusive sheet which dips gently northeast, under the ore. It is not known at the surface.

Similar local alteration of the diabase, outwardly evident from the sparkling appearance imparted to the rock by the abundant secondary development of biotite, has taken place elsewhere in the region near the contacts with granitoid intrusive masses, especially at Troy and at the London-Arizona mine. There can be little question that the metamorphism at Ray is likewise an effect of the intrusion of one or both variants of the granite porphyry magma.

The diabase dike on Ray Hill, in which was found the first ore worked at the Ray mine, before the possibilities of the schists were realized, is too decomposed near the surface for satisfactory petrographic study, and as it has not been recognized in the modern mine workings, no fresh material is obtainable. The rock is of finer grain than the prevalent diabase of the region, and the felted arrangement of the numerous small feldspar crystals as visible on weathered surfaces suggests a textural approach to basalt. Thin sections indicate that before decomposition by superficial agencies the rock had undergone the same kind of metamorphism as that just described for the diabase southeast of Ray.

At many places in the No. 1 mine of the Ray Consolidated Copper Co. there occur in the generally rather uniform gray siliceous schist small bodies of darker and much softer rock, commonly spoken of as diabase. Some of the smaller of these cut irregularly across the planes of schistosity and are undoubtedly little irregular dikes. They are not themselves schistose, or only slightly and locally so, and close inspection of them reveals the outlines of small lath-shaped feldspars.

Other bodies, some of which are of considerable size, conform to the general structure of the schist, are of more or less lenticular form, and are thoroughly schistose. These masses are traversed by innumerable slippery joints, and as a rule the rock is too soft to afford good specimens for study. Owing to their softness and the readiness with which they are decomposed, these masses of dark schist are elements of structural weakness, and accordingly have been subjected to much of the movement whereby stresses in the rock mass as a whole have been relieved.

On fresh fracture the rock is dark gray and very fine grained and sparkles brilliantly from minute crowded faces of biotite. This material in places grades, through gray schists containing both biotite and sericite, into the normal siliceous, sericitic schist and appears to have undergone the same process of metamorphism as that rock. In other words, it is apparently an integral part of the Pinal schist.

This raises some difficulties of interpretation. For, although the dark biotite schist in the No. 1 mine does not look much like diabase, it seems to be connected by transitional varieties with the altered basaltic dikes in the same mine, with the diabase of the Ray Central mine, and with the normal diabase of the region. Microscopical study has supplied no criteria for separating these rocks. If all were originally the same, then, as the prevailing diabase of the region is post-Carboniferous, the dark schist of the No. 1 mine must be much younger than the associated sericitic schist—it must, in fact, have been intruded into the Pinal schist long after that rock had received its present schistose structure and must then itself have been rendered equally schistose by a distinct process of metamorphism. This is scarcely credible. An alternative and more probable view is that the biotite schist represents diabasic or basaltic material of pre-Cambrian age that was metamorphosed when the Pinal schist as a whole received its present general lithologic character; and, finally, the apparent petrographic gradation of the biotite schist into the diabase is explained as the result of similar processes of alteration affecting materials of different age but of essentially identical composition.

The fact that the soft biotite schist in places grades into or is interleaved with harder varieties containing much quartz and sericite suggests that the igneous material from which the biotitic schists were derived may have been in part tuffaceous, and thus have graded originally into siliceous sediments.

QUARTZ DIORITE.

Quartz diorite occurs only in one body south of Sonora, where it is intrusive into the Pinal schist and is cut by quartz monzonite porphyry. Its petrographic character has been described on pages 57–59.

QUARTZ MONZONITE PORPHYRY.

Of the two varieties of quartz monzonite porphyry, the Granite Mountain porphyry occurs almost wholly in the southern half of the district, and the Teapot Mountain porphyry is characteristic of the northern half.

The principal body of the Granite Mountain porphyry is the irregular intrusive mass which makes up much of Granite Mountain (Pl. XLV). East of it a smaller mass is exposed west and south of Sonora, and a still smaller body lies along the south side of Ray Hill. Other masses are clearly associated with the metallized schist area, and much of the ore of the Ray No. 1 mine occurs in the body of porphyry between Ray Hill and the town of Ray, which is mapped on Plate XLV. The small porphyry dikes abundant near Humboldt Hill and occurring here and there in other parts of the metallized schist area, although for the most part much altered, appear to belong to the Granite Mountain porphyry.

The largest exposure of the Teapot Mountain porphyry is on the ridge south of Teapot Mountain and west of the metallized schist area. Other irregular masses and some dikes of the same rock cut the Pinal schist north of Sharkey Gulch. A mass exposed near the mouth of Rustler Gulch is possibly part of the same body as that farther east, northwest of the Calumet shaft. (See Pl. XLV.)

WHITETAIL CONGLOMERATE.

The Whitetail formation is much thicker in Teapot Mountain than anywhere else in the whole region, so far as known. This thickness has not been accurately measured but certainly exceeds 500 feet and is probably between 800 and 1,000 feet. East of Mineral Creek, on the other hand, the formation is thin, probably nowhere in the district 50 feet thick, and in places is entirely absent. (See Pl. XLV.)

The general character of the Whitetail formation has been described on pages 67–68. On Teapot Mountain (Pl. XLIV, *A*) and on some peaks just north of it the material shows a very rough and obscure bedding with a low eastward dip. The constituent fragments are, as elsewhere, chiefly diabase and limestone. A few fragments of quartz monzonite porphyry of the Teapot Mountain variety were noted on the slopes and apparently came from the Whitetail formation. The fragments range in size from small particles to blocks 3 feet in diameter, and are generally angular. As a rule the diabase fragments are covered with a thin rusty film, and the whole formation has a decided reddish tint as exposed in the scarps of Teapot Mountain.

DACITE.

Within the Ray district the dacite occupies a considerable area, about three-quarters of a mile in greatest width, along the east side of Mineral Creek, and occurs as a small remnant on the west side of the creek, southeast of Americantown. The dacite east of Mineral Creek, from the town of Ray northward, is partly covered by the Gila conglomerate.

GILA CONGLOMERATE.

At its base, as elsewhere in the region where the Gila rests on the dacite, the formation contains much dacitic tuffaceous material. In the area north of Ray some of the material is thin bedded, with depositional lamination, and is composed almost entirely of small glassy and pumiceous particles of dacite. Other beds are as much as 6 feet thick and contain scattered blocks of rocks other than dacite. As these beds rest on the dacite they probably do not represent material that accumulated in its present position as the result of ash showers. More probably they are the result of erosion and transportation immediately after the eruption of the dacite. Loose, pumiceous material, including perhaps volcanic ash, was washed from the surface of the recently consolidated lava into a local basin and there stratified, in part at least in quiet water.

The pumiceous beds are distinguished from the normal overlying conglomerate on the accompanying geologic map of the Ray district (Pl. XLV). Their total thickness just south of Rustler Gulch is estimated at 200 feet.

STRUCTURE.

Structurally the Ray district (Pl. XLV) is divisible into two parts, separated by a line of division nearly coincident with Mineral Creek. The general difference in structure as reflected in the distribution and relations of the rock formations on the two sides of the creek is evident from a glance at the geologic map. On the east side is the structure characteristic of the Dripping Spring Range as a whole—a fault mosaic. The Paleozoic and older rocks have been intruded by diabase and cut by faults into polygonal blocks, for the most part less than one-fourth of a square mile in area. The displacement of these faults is in general normal. On the west side of the creek is a large area of Pinal schist, invaded irregularly by various intrusive rocks and covered extensively by terrace deposits. This schist is not wholly unaffected by faulting and is doubtless traversed by some faults that, owing to the fact that the same schist occurs on both sides of the fracture, have escaped recognition. On the whole, however, underground work and the mapping of the intrusive masses and of the belt of rhyolite schist south of Copper Canyon have brought out little evidence of displacement, and it may safely be concluded that the country west of the creek has been less dissected by faults than the country east of it.

The faults east of Mineral Creek are not all of the same age. Much displacement of the sedimentary formations undoubtedly occurred when the diabase was intruded, but little or none of that displacement is now recognizable as faulting, for most of the fractures formed at that time were invaded by diabase magma, and the blocks of strata were forced apart by the molten material. Most of the faulting appears to have followed the eruption of the dacite, and some of it was later than the deposition of the Gila conglomerate.

Most of the geologists who have studied the Ray district in the interests of the copper-mining companies and some who have merely visited it appear to have accepted the conclusion that the rocks east of Mineral Creek have been faulted down relatively to the rocks west of the creek. Spurr and Cox in their unpublished report to the Ray Consolidated Copper Co. state that the country on the east side of the fault fissure has dropped perhaps from 1,000 to 2,000 feet, and the "Mineral Creek fault" or "Ray fault" has been generally accepted as an important structural element of the district. Tolman[1] writes:

> The Mineral Creek fault separates the dacite and the Paleozoic rocks from the schist. It is by far the most important structural break of the region, is of great displacement, and can not escape the notice of even the casual visitor.

In a recent paper Spurr[2] makes the following reference to this fault:

> At Ray, Ariz., perhaps at about the same geologic period as the phenomena at Dolores and Velardeña—that is to say, near the close of the Cretaceous—a great mass or stock of granite porphyry welled up from below, through the earlier pre-Cambrian schists of the region. The Ray copper district lies near the borders of this stock, in the overlying schist, which is cut by dikes and protuberances from the main mass. There is no evidence of much faulting before the period of intrusion, but about the time of intrusion fissuring was begun. The earliest fissures were of very slight displacement, and in the neighborhood of these the primary copper minerals were deposited, or in crushed zones of schist alined similarly to these fissures. Subsequent to the mineralization growth took place along certain faults, especially along the great Ray fault, and the present main mineralized area was uplifted, relatively to the country on the other or east side, perhaps 1,000 or 2,000 feet. Erosion attacked the uplifted block and reduced it to the level of the other block, and Tertiary deposits were laid down upon the leveled country. Again, at about the end of the Tertiary, the same block west of the Ray fault was again powerfully uplifted, probably upward of a thousand feet, and the uplifted area was again attacked by erosion. The Tertiary rocks were stripped off from the schists, and a Pleistocene desert-wash deposit, called the Gila conglomerate, was formed. Later there was a general uplift of the whole region, and at the same time a reversed movement of a few hundred feet along the Ray fault, the block containing the main mineralized area this time subsiding in contrast to its earlier repeated uplifts.

The evidence upon which rests this conclusion of movements amounting to thousands of feet along the Ray fault has not, so far as I am aware, been published or even fully presented in manuscript form. It appears to be substantially as follows: (1) The general distribution of the rocks suggests faulting. East of the creek is a fault mosaic such as is characteristic of the Dripping Spring Range, the surfaces of the many small blocks showing Paleozoic and younger rocks. West of the creek is a large and apparently little-faulted

[1] Tolman, C. F., jr., Disseminated chalcocite deposits at Ray, Ariz.: Min. and Sci. Press, vol. 99, p. 623, 1909.

[2] Spurr, J. E., The relation of ore deposition to faulting: Econ. Geology, vol. 11, p. 612, 1916.

area of pre-Cambrian crystalline rocks cut by granitic porphyries. (2) East of the creek the dacite and the underlying Whitetail formation lie at comparatively low elevations and dip as a whole to the west. The dacite as exposed along the east side of Mineral Creek north of Ray is in places less than 2,100 feet above sea level, whereas on Teapot Mountain, a mile and a half west of the creek, the base of the dacite (not exposed within the area covered by Pl. XLV) is apparently at least 4,000 feet above sea level. These relations, shown in section A–A′, Plate XLV, may be interpreted as the result of a 2,000-foot fault with downthrow to the east. (3) There is indubitable evidence of faulting along the general course of Mineral Creek. This evidence may now be critically examined.

The general contrast shown by the rock distribution on the two sides of Mineral Creek, striking enough in a hasty glance at the geologic map, partly disappears on closer examination. There are considerable areas of schist on the east side also, at the heads of Rustler, Jimmies Luck, and Bluebell gulches. Moreover, the Paleozoic rocks represented are chiefly the Pioneer shale and Dripping Spring quartzite—that is, the basal part of the Apache group. The Troy quartzite and the Devonian and Carboniferous limestones appear in force just east of the area mapped in Plate XLV, and generally higher in the Dripping Spring Range. In other words, anyone descending the steep western slope of that range and continuing westward over the Ray district would in general, and so far as concerns the Paleozoic and pre-Cambrian formations, cross successively older rocks. There would be local exceptions due to faulting, but the general succession would be stratigraphically downward. Such being the case, not only does the rock distribution make no demand for a profound fault along Mineral Creek, but rather it discredits the supposition that such a fault may exist. If the rocks to the east had been dropped 1,000 feet or more relatively to those on the west there should be found just east of the dislocating fissure some of the higher beds, such as the Martin limestone, not more schist with rocks that normally belong just above the schist.

The general relations between the dacite and Whitetail formation west of Mineral Creek and the same formations east of the creek are shown in Plate XLV. If, as is apparently the case, these two formations lie nearly horizontal on Teapot Mountain, the obvious interpretation of section A–A′ is that the rocks east of Mineral Creek have been faulted down. The dacite on Teapot Mountain is not shown in the section, as it lies just outside of the area mapped, but the elevation of its base above sea level is estimated at about 4,000 feet. The same rock just east of Mineral Creek is less than 2,100 feet above sea level. This difference, in accordance with the fault interpretation, would give a minimum throw of 1,900 feet. In connection with what is known of the general geology of the region and in the absence of any conflicting evidence, this would be a very natural interpretation to place upon the facts as presented in the section.

Other interpretations, however, are possible and, in the light of what follows, are perhaps more probable. It is to be observed that the attitude of the Whitetail formation, dacite, and Gila conglomerate north of Ray (Pl. XLV) is generally synclinal. The syncline is irregular and is further distorted by faulting, but apparently here is one of the few places in the region where the rocks have bent rather than fractured under stress. Along the western margin of the syncline the beds in places are steeply upturned, supposedly as a result of drag along fault fissures. It does not seem likely, however, that the structure as a whole can be merely a local accompaniment or result of fault movements. If not, then gentle folding with perhaps minor step faulting can account for the difference in elevation between the dacite west and east of Mineral Creek.

That there is more or less faulting along and near the course of Mineral Creek is unquestionable. It remains to inquire how far this faulting supports the view that the creek is approximately coincident with a zone of profound displacement. The examination of such facts as are brought out by detailed mapping may conveniently begin in the northern part of the area shown on Plate XLV and proceed southward.

Near the mouth of Rustler Gulch pre-Cambrian intrusive rocks associated with the Pinal schist are separated by a narrow strip of dacite from the Gila conglomerate to the east.

The dacite strip appears to be the surface of a fault block. The throw of the fault which brings the dacite against the Gila conglomerate is probably not over a few hundred feet, for the conglomerate normally rests on the dacite, as may be seen half a mile above the mouth of Rustler Gulch. The fault along the western margin of the block may have considerably greater displacement. Not necessarily so, however, for in the upper part of the gulch the dacite and a rather thin layer of the Whitetail formation rest on Pinal schist, and a throw of 100 feet, enough merely to cut out the Whitetail, could easily account for the observed relations near the mouth of Rustler Gulch.

About a third of a mile south of Rustler Gulch, on the west slope of the 2,376-foot dacite knob, the lower of two prospector's tunnels goes through 165 feet of schist into dacite, and the relations of the two rocks indicate a throw of at least 75 feet. Some of the dacite cut in the tunnel in black and glassy, such as is usually characteristic of the basal portion of the flow, a fact which suggests only moderate displacement. At least three gouge-filled fissures, of which the most pronounced dips 55° E., are exposed in the tunnel. Both dacite and schist are much broken and disturbed, and beyond clear demonstration that some faulting has taken place and that the dacite as a whole has been dropped to the east the tunnel gives no satisfactory evidence as to the character and extent of the movement. South of the tunnel the two main fault fissures which limit the block of dacite come together and, with a branch fault, disappear under the alluvium of the Mineral Creek valley.

About halfway between the tunnel just mentioned and the town of Ray another fault, striking north-northeast, offsets the western border of the syncline in the dacite and Gila conglomerate north of Ray. The throw of this fault is probably not much over 100 feet.

Four fault fissures just north of Ray are shown on Plate XLV. Three of them partly inclose an area of dacite, and the fourth cuts diagonally across that area. Little information is obtainable concerning these faults, which apparently are not of large displacement. The only one which could have a throw of more than a few hundred feet is the one which brings dacite against schist, just north of Ray. The direction of this fault, however, is not that to be expected of the "Mineral Creek fault."

South of Ray the "Mineral Creek fault" appears to be represented by the southeastward continuation of the diagonal fissure referred to in the preceding paragraph. This is a well-marked fault, but there is nothing to indicate that its throw is large. About 450 feet northeast of the outcrop of this fissure, on the Sooner claim, the No. 21 drill hole of the Arizona Hercules Co. penetrated to a depth of 1,062 feet. Between the depths of 885 and 935 feet was found 50 feet of 1.54 per cent ore. This ore is about 400 feet lower than the depth at which the ore known in the Arizona Hercules or Ray Hercules ground west of the fault would intersect the drill hole if projected eastward. In other words, if the ore body is faulted, the throw at this place does not exceed 400 feet. Hole 13 of the Ray Hercules Copper Co. is situated on the south slope of the 2,203-foot hill just north of Ray, from 200 to 300 feet northeast of the fault shown on Plate XLV as cutting diagonally across the dacite area north of Ray. In this hole, which is 1,089 feet deep, ore was reported as occurring at depths of 260 to 300, 325 to 350, and 835 to 845 feet. Even on the unlikely supposition that the thin deep layer is the same as the main ore body west of the fault, the throw could hardly exceed 600 feet.

East of the Ray No. 1 shaft the fissure mentioned in the preceding paragraph ends against a fissure of more northerly trend, which in turn disappears to the south under alluvium. About the mouth of Amanda Gulch, in the southeast corner of the area mapped, nothing recognizable as the "Mineral Creek fault" has been found. Just south of the gulch, on the west side of Mineral Creek, the Pinal schist has been thrust from the southwest over the Dripping Spring quartzite. Erosion has stripped the schist from the harder quartzite, exposing a considerable area of the footwall of the thrust, dipping 45° SW., as shown in Plate XXVIII, *B*. The throw may amount to 400 feet, but no accurate estimate of the displacement is possible. Across a small unnamed gulch south of Amanda Gulch the line of the overthrust is continued by the contact of the Gila conglomerate with the

Dripping Spring quartzite. This contact has the appearance of being a fault, but it is possible that the conglomerate was originally deposited against such a stripped footwall as is shown in Plate XXVIII, *B*.

From the foregoing facts a warrantable conclusion seems to be that although Mineral Creek in a rough way marks the division between a much faulted region on the east and a less faulted region on the west, and although there is undoubted faulting along the general course of the creek, yet there is no profound fault coincident with this line of division. The boundary between the two structural divisions of the district is marked by comparatively short intersecting faults of moderate displacement and of the same general character as those abundant along the eastern border of the area mapped on Plate XLV and in the Dripping Spring Range as a whole.

This feature of the structure has been considered at some length, for the character and age of the faulting along Mineral Creek have a bearing on the possible extension of ore bodies to the east and on the interpretation of drill records. Both with regard to the extent of the movement along the supposed Mineral Creek or Ray fault and, as will appear later, with regard to the time and character of such displacement as may have occurred along the general line of Mineral Creek, the conclusions reached in the present report differ from those set forth in the quotation given on page 127.

In the vicinity of Humboldt Hill two persistent fissures cut the schist and probably have been associated with considerable displacement. One known as the Sun fault has a nearly northeast course from the Tribunal shaft through the Mathias & Hall shaft, terminating apparently just east of the hill, against the second fissure, known as the Sharkey fault, which has a nearly northwest course. The Sharkey fault has apparently brought about the erosion of the saddle just west of the summit of Emperor Hill, passes west of the Humboldt and Sharkey shafts, and curves west toward the Flux shaft. Inasmuch as these fissures are entirely in schist, whatever structural importance they may have is not evident. They are of some interest, however, in connection with the ore bodies, and their characteristic features, as seen underground, will be described later.

The Pinal schist of the Ray district, consisting chiefly of altered sedimentary rocks, was closely folded and compressed before or during the change of these rocks to schist. This folding apparently is the chief cause of the irregularities in the belt of schistose rhyolite south of Copper Canyon. It is possible that by extremely detailed work the old structure in the schist might in part at least be worked out and the positions of the synclines and anticlines determined. There is no reason to expect, however, that the result would have scientific or economic importance in any way commensurate with the labor or time that would be necessary for such a task. The occurrence and distribution of the ore apparently have not been influenced in any way by the pre-Cambrian folding.

EROSION.

The present schist surface in the Ray district, while it undoubtedly owes its topographic features to Quaternary erosion, has not as a whole been very greatly reduced below a surface that existed in Tertiary time. A view over the central part of the district toward Teapot Mountain, such as that of Plate XLIII, *B*, indicates very clearly that the Whitetail formation exposed on the steep slopes of the mountain once covered the copper-bearing area. The Whitetail in turn was covered by the dacite. It was only after the removal of these rocks that erosion of the schist could again proceed. To what extent the schist had been uncovered before the deposition of the Gila conglomerate began and how far that conglomerate extended over the present schist area can not be determined. The terrace deposits, more conspicuously developed in the Ray district than elsewhere in the general region, represent a period when the streams were locally overloaded. Whether this was due to an increase in the quantity of detritus to be moved, a change in climate, or a lessening of stream gradients by earth movements is not known. Recent erosion has dissected the terrace deposits and etched out the rough ravines through which storm waters now escape to Mineral Creek.

Although it happens that most of the mining by the Ray Consolidated Copper Co. has been done under two hills, Ray Hill and Humboldt Hill, there apparently is no constant or significant relation between the topographic details of the present surface and the occurrence of ore. The ore is thick under Humboldt Hill, but it is both thick and of comparatively high grade under the lower part of Copper Gulch. In certain details of erosional sculpturing the fact that the rocks contained disseminated pyrite, with its train of chemical consequences, appears to have left its mark. It has not, however, proved possible to determine from the work of erosion at any one place the result of the physical and chemical processes of enrichment directly beneath.

Owing apparently to variation in hardness or induration from place to place, the Gila conglomerate in some localities has been shaped by erosion into forms having little in common with the even-crested branching spurs that flank the Pinal Range. Such exceptional products of erosion are the curious rounded towers that are conspicuous features along Mineral Creek a few miles below Ray (Pl. XXIV). These are residuals of resistant portions of the conglomerate left behind in the general recession of the conglomerate bluffs along the creek.

CHAPTER VII.—MINERALOGY.

LIST OF MINERALS.

The minerals described in this chapter are those occurring in or closely associated with the ore bodies. As the ores are generally of simple mineral composition the species are not numerous. They will be described in the order followed in Dana's "System of mineralogy."

Minerals occurring in or associated with the copper ores of Ray and Miami.

Copper (native).	Limonite.
Silver (native).	Malachite.
Molybdenite.	Azurite.
Galena.	Feldspars.
Chalcocite.	Amphibole.
Sphalerite (?).	Andalusite.
Covellite.	Zircon.
Chalcopyrite.	Tourmaline.
Pyrite.	Muscovite (sericite).
Quartz.	Biotite.
Cuprite.	Chlorite.
Ilmenite.	Kaolinite.
Rutile.	Chrysocolla.
Melaconite.	Alunite.

FEATURES OF OCCURRENCE.

Copper.—Native copper is rather rare in the disseminated ore bodies. It was noted in small particles in the No. 3 (Ray Central) mine down to a depth of at least 400 feet, and some large masses doubtless occurred also in the oxidized ore worked years ago near the old Ray shaft. Particles were found by Mr. R. C. Nowland in sludge from drill hole G 63, of the Gila Copper Co.'s holes, at a depth of 375 feet. It was observed in the Miami mine on the 470-foot level associated with chalcocite and cuprite. It is here clearly younger than the chalcocite, which it has penetrated along minute cracks. Careful search would probably discover small quantities at other places in the upper part of the chalcocite zone, but nowhere at Ray or Miami does native copper, so far as at present known, form an important constituent of the ore. The ore bodies of these two districts differ in this respect from those of the Chino mine at Santa Rita, N. Mex., in certain parts of which the native metal occurs abundantly both in small particles and in masses weighing several pounds.

In 1911 there were obtained from a churn-drill hole, then over 500 feet deep, which was being bored for water in the town of Miami, fragments of schist traversed by small fractures containing thin films of native copper. These fragments clearly came from a boulder in the Gila conglomerate and are of interest as a bit of evidence tending to show that copper ores had been deposited and oxidized before the conglomerate was laid down.

Native copper was found in the Gila conglomerate also in drill hole 76, 2,050 feet deep, put down by the Miami Copper Co., 1,600 feet S. 63° E. from its No. 4 shaft. This hole was still in conglomerate when work was abandoned. According to Mr. H. P. Bowen, metallic copper was first noted at a depth of 1,000 feet and appeared to increase downward, although not regularly. Assays of sludge from the hole yielded as much as 0.95 per cent of copper. This was chiefly native metal, but a few particles, as reported by Prof. L. C. Graton, to whom a sample had been submitted by the company, showed chalcocite from which the native copper had clearly in part been derived. Prof. Graton expressed the opinion that probably all the native copper had this origin, a conclusion that is in keeping with the observed association of such native copper as has been seen in the Miami mine. At the bottom, at a depth of 2,050 feet, the sludge showed a little pyrite enriched with chalcocite. Prof. Graton estimated that perhaps one-third of the sulphide grains from this depth were all chalcocite, the enrichment being about as great as in the Miami ore body. He remarked that it is not clear whether the enrichment took place before or after the conglomerate was deposited.

A little native copper in Gila conglomerate has been reported also from the No. 1 drill hole of the Barney Copper Co.

Silver.—Native silver is not found in the ordinary ores of the Ray and Miami districts but occurred in a small vein with cuprite and chrysocolla in the No. 3 (Ray Central) mine. This vein was worked near the surface in the early days of Ray, before any attention was given to the low-grade copper ore. The part of the vein in which the silver occurred has been removed in the course of the modern stoping.

Molybdenite.—The sulphide of molybdenum, easily recognized by its bright metallic gray color, lamellar habit, and softness, is widely distributed through the deposits both at Miami and Ray, although it is nowhere present in great quantity. In the Miami mine and in the No. 1 mine of the Ray Consolidated Copper Co. it is most abundant in or very close to the granite porphyry. In the Miami mine the mineral occurs in quartz veinlets which carry also pyrite and chalcopyrite. Here, as shown by the relation of the minerals to the walls of the fissures (Pl. XIV), the order of deposition was (1) molybdenite and quartz, (2) quartz, (3) quartz, pyrite, and chalcopyrite, and (4) sericite in vugs.

Molybdenite was observed in the Sulphide tunnel of the Live Oak mine, in schist just under an intrusive sheet of porphyry. It was noted also on the dump of the Live Oak No. 2 shaft in 1914, but as these workings were temporarily closed at the time of visit no attempt could be made to ascertain the place from which the material on the dump came.

In the ore molybdenite, unless more than usually abundant, might readily be overlooked, because of the lack of strong color contrast between it and the chalcocite.

Galena.—Galena was not observed in the disseminated copper ores in the course of the present investigation, but, according to Mr. C. E. Arnold, assistant mine engineer of the Inspiration Consolidated Copper Co., it has been reported by one of the shift bosses in the eastern part of the Inspiration workings about 70 feet above the 300-foot level. It is certainly very rare in these deposits, if it occurs at all.

Chalcocite.—Copper glance, cuprous sulphide, is the essential mineral of the disseminated copper deposits in the Ray and Miami districts. It is wholly secondary and has been deposited by descending waters partly at the expense of older sulphides, particularly of pyrite and chalcopyrite. The ores exhibit all gradations from pyrite crystals coated with a thin film of chalcocite to complete pseudomorphs and solid veinlets of the cuprous sulphide.

The chalcocite occurs most characteristically as small specks disseminated rather generally through the schist or porphyry of the ore body but distributed particularly along minute planes of fracture and to some extent along planes of schistosity. It also occurs as distinct veinlets, rarely 6 inches wide. Numerous small veinlets, for the most part less than half an inch wide or thick, constitute a considerable part of most of the ore. Many of these veinlets when broken across show numerous residual granules of pyrite.

As seen in freshly broken ore the chalcocite is of compact texture, bright gray color, and metallic luster. In these respects the ore of the Ray and Miami districts differs from that of the Santa Rita (Chino) district, N. Mex., in which the chalcocite is generally dull. The metallic brightness is lost on slight weathering or on attack by underground solutions, the sulphide becoming coated as a rule with melaconite, the black oxide of copper.

Chalcocite pseudomorphous after pyrite and retaining accurately the form and striations of that mineral is fairly common, especially in the Miami district. In some places the chalcocite is a thin film on the pyrite; in other places the pyrite has disappeared or is represented by a small kernel in the center of the pseudomorph. In the Miami mine some exceptionally large cubic crystals of pyrite, over an inch in diameter, were observed to have only a thin shell of chalcocite, and in general the large crystals appear to have undergone chalcocitic replacement to a much less extent than the aggregates of smaller crystals such as usually constitute the filling of veinlets or occur disseminated through the rocks. The replacement, however, is not merely peripheral but may proceed from a network of cracks. Characteristic stages of the replacement of pyrite by chalcocite are shown in Plate LIV, *B* and *C*, and in figures 21 to 23.

Some chalcocite has replaced chalcopyrite, but as the chalcopyrite does not as a rule possess crystal form, the evidence of this replacement is less obvious than for pyrite. Moreover, as chalcopyrite is more readily converted to chalcocite than pyrite is, it is less frequently found as residual kernels. Nevertheless, as will be shown when the ores are described, it is clear that a part of the chalcocite in the ores fills spaces once occupied by chalcopyrite. None of the chalcocite seen in the Ray or Miami districts has its own external crystal form.

In many specimens of ore, especially such as have been taken from an exposed stock pile or

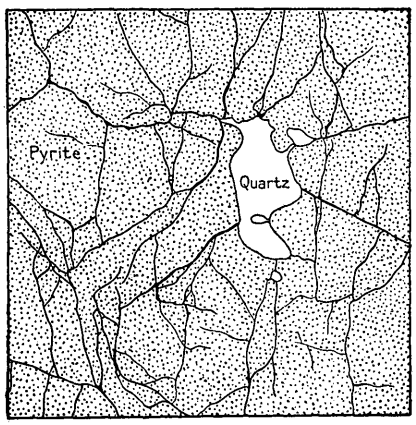


FIGURE 21.—Early stage in replacement of pyrite by chalcocite along irregular cracks. From the Miami mine.

from walls of a drift that has been open for some time, the chalcocite is covered with a dull black film. Small specks of chalcocite are not only covered with a film, but the dull dark-brown or black material has spread out from the original chalcocite speck as a tiny dendritic rosette. The original specks are thus enlarged, and the result is an ore apparently containing more chalcocite than is actually present. The little rosettes closely resemble the familiar dendrites of manganese oxide found on the joint surfaces of many rocks. When tested, however, they showed no manganese but gave a pronounced copper reaction. Tested with a drop of 10 per cent silver nitrate, they immediately began to precipitate crystalline metallic silver. This is a useful test for chalcocite, serving to distinguish quickly this mineral from others with which it might be confused on superficial examination. It was thought at one time that the dull dendritic material might be melaconite; but pure cupric oxide does not throw down silver from solution, whereas cuprous oxide (cuprite) does.[1] This difference in behavior is utilized in the Ziervogel process of silver extraction to determine the stage of oxidation of the argentiferous matte, the oxidation of cuprous to cupric oxide being considered complete when spangles of metallic silver cease to appear upon treatment of a sample of the charge with boiling water.[2]

FIGURE 22.—A typical grain of chalcocite with kernels of pyrite. Granite porphyry ore, second level of the No. 1 mine, Ray district.

The rosettes, then, can hardly be melaconite, although they may be a mixture of cuprous sulphide and cupric oxide. They are too small

FIGURE 23.—Typical pyrite kernels in chalcocite. Schist ore, 1925 level of the No. 2 mine, Ray district.

and too closely associated with chalcocite to permit a reliable test for sulphur.

Further details on the occurrence of chalcocite will be found in the chapter on the ores (p. 156).

Sphalerite.—Zinc blende, the sulphide of zinc, has not been observed in the Ray or Miami ores in the course of the present investigation, and inquiry in both districts among those familiar with the mines and ores failed to discover any recognition of its presence. Tolman and Clark,[3] however, mention the occurrence of sphalerite in the upper part of

[1] The ordinary black oxide of copper supplied as a blowpipe reagent does, however, throw down silver from a silver nitrate solution, probably because it contains some metallic copper or cuprous oxide.

[2] Collins, H. F., The metallurgy of lead and silver, Part II, Silver, p. 183, London, 1900. I am indebted to Mr. Chase Palmer for calling my attention to this reference.

[3] Tolman, C. F., jr., and Clark, J. D., The oxidation, solution, and precipitation of copper in electrolytic solutions and the dispersion and precipitation of copper sulphides from colloidal suspensions, with a geological discussion: Econ. Geology, vol. 9, p. 584, pl. 14B, 1914.

tne Miami ore body and give a photomicrograph showing the replacement of this sphalerite by chalcocite. A fragment of their specimen, kindly furnished by Prof. Tolman, shows the presence of some residual sphalerite when examined by reflected light under the microscope and afforded a distinct chemical reaction for zinc as tested by W. T. Schaller, of this Survey.

That sphalerite may be present also in small quantity in the ore of the Ray district is indicated by the presence of zinc in the water from the No. 3 mine, of which an analysis is given on page 141.

Covellite.—The blue cupric sulphide is extremely rare in the Ray and Miami districts. A very little was noted in the Miami mine as a superficial alteration product of chalcopyrite.

Chalcopyrite.—Chalcopyrite is not a conspicuous mineral in either of the districts here described but is fairly abundant in the protore of the Miami district, occurring with pyrite in veinlets and in disseminated form. In the Miami mine it occurs with molybdenite and quartz as veinlets in granite porphyry and has been found in diamond-drill cores disseminated through porphyry and schist below the chalcocite zone. In places this disseminated chalcopyrite is abundant enough to raise the rock to the grade of ore. To some extent chalcopyrite is probably inclosed in pyrite to form the so-called cupriferous pyrite. Polished sections of the ore and protore, however, have shown few examples of this relation, and in those seen the chalcopyrite is clearly younger than the pyrite and may be of supergene origin. As a rule, the pyrite of the protore is free from other sulphides.

In the Ray district chalcopyrite appears to be less abundant and less generally distributed through the protore than at Miami. In the ordinary schist protore it was not observed, although it is probably not entirely absent. It was noted in granite porphyry protore in the No. 1 mine, on the third level, near the shaft station. It is fairly abundant in the metallized and metamorphosed diabase of the district, partly in disseminated condition but chiefly in small veinlets.

In the process of enrichment the chalcopyrite is converted to chalcocite more readily than pyrite and under equal conditions disappears before the pyrite. Even more noticeably than with pyrite, the change is not merely peripheral but proceeds from an intricate network of tiny cracks. On a polished surface of chalcopyrite the veinlets of chalcocite in the early stages of replacement suggest in their delicate intricacy of pattern the finest lace or the web of the spider.

The relatively small proportion of chalcopyrite in the protore of the Miami district has undoubtedly contributed a large amount of copper to the chalcocitic ore. The mineral is of practical importance in that district, however, chiefly as a source of copper for the natural enriching solutions and only subordinately as a constituent of the ore or as a means of gathering or precipitating additional copper sulphide from these solutions. The principal mineral to be replaced by chalcocite during the process of enrichment in both districts was undoubtedly pyrite.

Some of the chalcopyrite in the Miami mine is tarnished so as to closely resemble bornite, which it was at first supposed to be. No bornite, however, unless as a mere tarnish film, has been seen in either the Ray or Miami districts.

Pyrite.—Pyrite is the most abundant sulphide in the Ray and Miami districts and is the characteristic mineral of the protore, in most of which, especially in the Ray district, it is the only sulphide visible. It occurs disseminated through the schist and porphyry of the metallized areas and in countless stringers or veinlets of all sizes, from mere films along joint cracks to veinlets 6 inches wide. Most of the veinlets are less than an inch wide.

Well-formed crystals with faces sufficiently large to be seen with the naked eye are rather rare. The cube is the usual form. The largest cubic crystals seen were collected on the 135-foot level of the Captain workings of the Miami mine. Some of these are an inch across.

Pyrite may be found in all stages of replacement by chalcocite, from crystals coated or veined with mere films of chalcocite to small residual kernels.

A sample of fresh, bright pyrite from the second level (2 W. 1½ N.) of the No. 1 mine at Ray was carefully washed, and crystal fragments were selected from it for their apparent purity and homogeneity. These were tested in the Survey laboratory by R. C. Wells, who found them to contain 0.042 per cent of copper;

a quantity that is probably rather under than above the average amount of copper reported in analyses of pyrite. In other words, the pyrite of the Ray district, if the sample analyzed is representative, is not especially cupriferous.

Quartz.—One of the most abundant nonmetallic minerals of the ore and protore is quartz. It is the common gangue of the countless pyritic stringers in the protore and of the chalcocitic stringers in the ore. Chiefly as a microscopic constituent it makes up a large part of the metallized rock. As a constituent of the schist and porphyry much of it of course crystallized before the period of metallization. The introduction of the sulphides, however, was attended by extensive recrystallization of the quartz already present, by the production of new quartz through the alteration of silicate minerals, and probably by the deposition as quartz of silica brought from unknown depths by the ore-bearing solutions. Enrichment by descending solutions has also been accompanied by some deposition of quartz, as is shown clearly by the fact that malachite and chrysocolla in the Miami district are covered by drusy crusts of quartz.

Microscopic inclusions of liquid, usually with a gas bubble, are abundant in the quartz of the protore and ore. In protore derived from granite porphyry such inclusions are generally more abundant in the quartz phenocrysts than in the corresponding phenocrysts of the fresh porphyry. Apparently they were introduced during the period of primary metallization.

Chalcedony is not generally present in the disseminated ores but occurs in intimate association with chrysocolla in certain places within the oxidized zone of the Miami district. This occurrence will be described under chrysocolla.

Cuprite.—The red cuprous oxide is rare in the mines of Miami and Ray but has been found in small quantity with native copper in the Ray Central, now the Ray Consolidated No. 3 mine, within the zone of chalcocite enrichment and to a depth of at least 400 feet. Specimens from a small vein worked in early days in this mine show cuprite, chrysocolla, and native silver. In small quantity cuprite was observed on the 470-foot level of the Miami mine, associated with native copper and chalcocite.

The variety chalcotrichite, in which the cubical crystals are elongated into slender acicular forms, was fairly abundant as sparkling ruby-red aggregates of delicate hairlike crystals, in one of the stopes formerly worked from the old Ray shaft. Specimens seen in Ray show it to be associated with ordinary cuprite in small cubes, limonite, and melaconite.

Ilmenite.—Ilmenite has been identified as a finely disseminated minor constituent of some of the Pinal schist and may be present in the schist protore, although this was not determined.

Rutile.—Rutile in minute microscopic crystals is generally present in the metallized schist and porphyry, both protore and ore. In part it is clearly an alteration product of biotite, and generally the little crystals are in groups or nests, a fact which suggests, even when no biotite remains, that the rutile is an alteration product of that or some other mineral.

Melaconite.—The earthy form of the black oxide of copper (cupric oxide, CuO) was noted in small quantity with cuprite in some specimens from the old workings of the original Ray mine.

Limonite.—The common hydrous oxide of iron is an invariable constituent of the so-called capping above the ore and in dispersed condition gives the rusty appearance characteristic at the surface of much of the rock that has been leached of its copper and sulphur. The limonite has resulted chiefly from the oxidation of pyrite. It nowhere forms large masses and is of no economic importance. Whether the hydrous iron oxide is really the mineralogic species limonite or one of the related species turgite or göthite has not been determined.

Malachite.—The green carbonate of copper is not a typical constituent of the ore or capping but is fairly abundant in certain places, especially in the Miami district. The brilliantly colored schist and porphyry that crop out on the Live Oak and Keystone groups and on the Captain claim of the Miami group owe their color to chrysocolla and malachite, partly as thin films and partly as veinlets. Similar rock has been found in the Miami mine extending at least to the 420 level. In this the veinlets of malachite contain kernels of chalcocite, showing that the carbonate has formed in place by alteration of the sulphide. In the Bulldog tunnel of the Inspiration workings malachite is associated with bright-blue chrysocolla, chalcedony, and quartz in aggregates of much beauty. (See Pl. XLVI, *A* and *C*.)

Malachite was noted on the 2025 level of the Ray No. 1 mine, as mammillary incrustations in a small open crevice. In thin crusts, associated with nearly black chrysocolla and with azurite, it coats and cements the pebbles of a recent conglomerate on Copper Creek, a quarter of a mile west-southwest of Ray.

Azurite.—The blue copper carbonate is of rare occurrence in connection with the disseminated ores of the Ray and Miami districts. A little was noted in the northeastern part of the 370 level of the Miami mine and in the recent cemented cupriferous gravels of Copper Canyon, a quarter of a mile west-southwest of Ray.

Feldspars.—The quartz monzonite porphyry of the Ray district and the porphyritic facies of the Schultze granite in the Miami district both contain abundant feldspars, including orthoclase, oligoclase, and andesine. In the processes of metallization, however, these feldspars are converted into sericite, kaolinite, quartz, and other secondary minerals, which as aggregates retain pseudomorphously the outward form of the feldspar. This outline, however, is not sharp, as the sericite scales have grown outward in part into the groundmass. As a rule the change from feldspar to sericite or to sericite and kaolinite is complete, or nearly so. Some of the granite porphyry protore, however, near the main shaft on the third level of the No. 1 mine at Ray, shows only partial sericitization of the feldspars.

In the Ray district some bodies of diabase are closely associated with the ore. Some of this diabase, probably just prior to the metallization, has undergone partial metamorphism in consequence of the intrusion of the quartz monzonite porphyry, whereby the original labradorite or bytownite has been in part rendered turbid by the development of minute mineral particles within it and in part recrystallized as clear secondary feldspar.

Amphibole.—Some of the altered diabase of the Ray district contains common green hornblende in ragged anhedral crystals or aggregates of small prisms. It is secondary. The mineral is not a constituent of the ordinary ore or protore of the Ray and Miami districts.

Andalusite.—Although not everywhere present in the Pinal schist, andalusite is a fairly common constituent in the vicinity of post-Cambrian granitic rocks, where it has been developed by contact-metamorphic action. It was noted particularly in some of the schist of Granite Mountain in the Ray district and in the schists along Liveoak Gulch, south of the Live Oak No. 2 shaft. A little andalusite was identified microscopically in schist protore from the second level of the No. 1 mine at Ray, west of the ore body.

Zircon.—In the usual small, stout prismatic crystals zircon is present as a microscopic constituent of the altered schist and porphyry of the metallized areas. It is nowhere abundant, and its presence has no particular significance in connection with ore deposition.

Tourmaline.—In small prisms without distinct terminal faces tourmaline is a fairly constant minor constituent of the Pinal schist in the vicinity of post-Cambrian granitic intrusive rocks and remains unchanged in the schist protore. It has not been observed in the ore and probably disappears in the process of enrichment.

Muscovite.—The fine-leaved variety of muscovite known as sericite is one of the most abundant and characteristic nonmetallic minerals of the ore and protore. It has been formed at different times and by different processes. It is one of the principal constituent minerals of the normal Pinal schist and as such is a product of pre-Cambrian metamorphism. In the schist it is impossible as a rule to distinguish between the sericite of the earlier metamorphism and that formed during the later period of metallization, in which the schist was converted to protore. In the granite porphyry, which was intruded long after the schist had undergone its first metamorphism, the development of sericite was clearly related to the metallization. It has formed at the expense of the feldspar phenocrysts and with quartz, largely recrystallized quartz, constitutes most of the groundmass of the porphyry protore. It forms characteristic felty aggregates in which the small foils are in part clustered radially into ragged sheaves. In places these scales project into the original quartz phenocrysts of the porphyry, evidently by replacement of the quartz. In some of the granite porphyry protore of the Miami mine sericite was observed projecting from the walls of microscopic vugs in a quartz veinlet containing molybdenite. Here, evidently, the mineral was deposited by solutions in an open space.

Whether sericite was formed also during the progress of enrichment is not known, as there are no means of distinguishing sericite formed by supergene solutions from that formed by hypogene solutions. From all that is known of the occurrence of this mineral, however, it is not probable that it was deposited by cold descending solutions.[1]

Biotite.—Black mica is a characteristic constituent of the granite porphyry and occurs in certain varieties of the Pinal schist. It is abundantly developed in diabase in the Ray district by the metamorphosing action of the granite porphyry. In the granite porphyry it occurs in foils about 3 millimeters in greatest diameter. These are comparatively resistant to the chemical changes effected in the rock as a whole by primary metallization and by enrichment. In the protore particularly the biotite may remain fairly fresh when the feldspars have been completely sericitized. As a rule, however, the biotite disappears in the change from protore to ore.

The typical Pinal schist is essentially a quartz-sericite rock, but some varieties contain biotite with the sericite. These probably were originally tuffaceous sediments.

Certain soft dark schists exposed in the mine workings at Ray consist chiefly of biotite. Comparison of these with diabase in which abundant secondary biotite has been developed by the metamorphosing action of the granite porphyry magma has led to the conclusion that these schists are altered basaltic or diabasic rocks, in places grading through originally tuffaceous material into the normal sericitic Pinal schist. The biotite of these schists is a little lighter in color and less strongly pleochroic than the biotite of the granite porphyry.

As a rule the biotite of the protore shows alteration into sericite, sulphides (chiefly pyrite), and rutile. The change to chlorite, so common in weathered rocks, is rarely seen in the protore.

Chlorite.—Minerals of the chlorite group are rare in the metallized rocks of Ray and Miami. A chlorite is present in small quantity, however, in some of the granite porphyry protore as an alteration of biotite and in some of the altered diabase of the Ray district, where it probably is a derivative of augite or olivine.

Kaolinite.—Kaolinite occurs associated with sericite and quartz in the altered granite porphyry of the Ray and Miami districts in situations where the formation of the mineral can not be ascribed to ordinary weathering. One of these, for example, is in the incline of the No. 1 mine at Ray, below the second level and under the ore body. Another is in the western part of the 420 level of the Miami mine, in unenriched metallized porphyry or protore. In general, as a transition zone between the thoroughly altered quartz-sericite-sulphide rock and the unaltered granite porphyry, or as residual rounded kernels inclosed by intersecting veinlets, there is more or less soft crumbling porphyry in which the biotite is fairly fresh and the feldspars have been

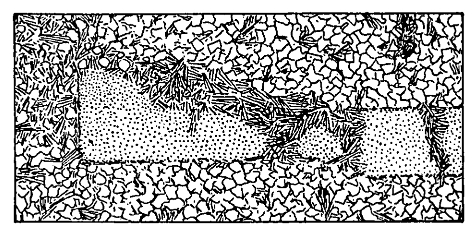
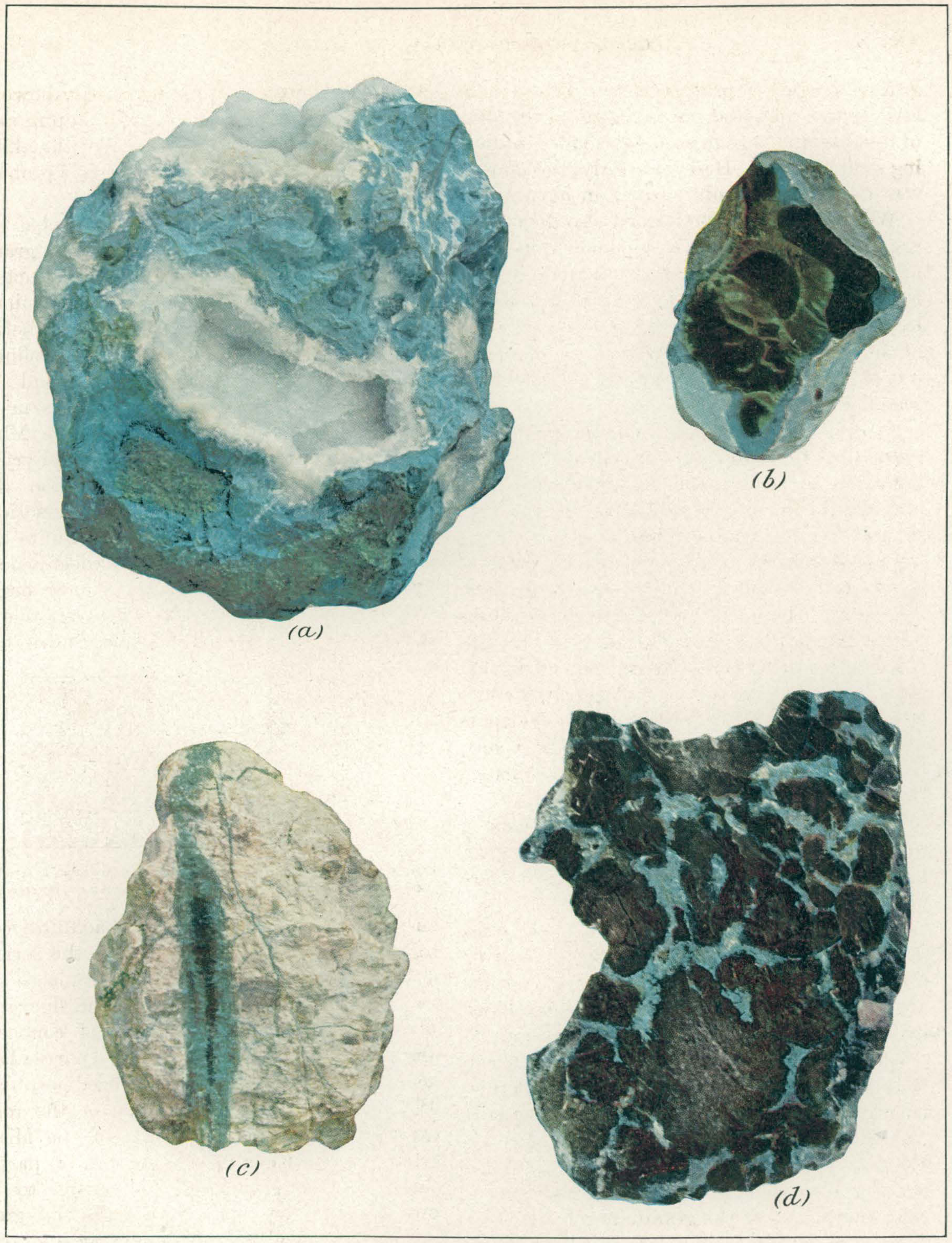


FIGURE 24.—Sketch showing general mode of replacement by sericite of kaolinite pseudomorph after feldspar, as seen under the microscope.

kaolinized. Where sericite and kaolinite occur together in this altered porphyry, the sericite is the younger mineral and has replaced the kaolinite after the manner shown in figure 24.

Chrysocolla.—Hydrous silicate of copper is abundant in the Miami district, particularly near the surface in areas of metallized porphyry. The vivid green and blue tints of the rocks exposed on the Captain claim of the Miami group, on the Keystone group, and on part of the Live Oak group are due chiefly to the presence of chrysocolla, although the green is in part malachite. This general coloration is the effect produced by thin films of the mineral along joint surfaces and by innumerable small veinlets. In the past, before the value of the disseminated deposits was recognized, chrysocolla was an important ore in the district, and veins of the mineral in porphyry were worked on the Keystone and Live Oak groups. These veins did not extend to great depths and were evidently fissures filled

[1] See Rogers, A. F., Sericite a low-temperature hydrothermal mineral: Econ. Geology, vol. 11, pp. 118–150, 1916, for a general review of the occurrences of sericite.



MALACHITE AND CHRYSOCOLLA.

(*a*) Malachite, chrysocolla, chalcedony, and quartz, deposited in the order named. Keystone tunnel, Miami district.

(*b*) Malachite surrounded by a layer of translucent colored chalcedony of gem quality, succeeded in turn by a light-blue chalky material which is chiefly a hydrous silicate of copper.

(*c*) Veinlet of chalcocite almost completely altered to chrysocolla and malachite. From the 270-foot level of the Captain workings of the Miami mine.

(*d*) Black and bluish-green chrysocolla, a replacement of dacite tuff. Geneva claim, Miami district.

directly with chrysocolla during the general oxidation of the disseminated deposits. In other words they were not veins of sulphides oxidized in place to chrysocolla. Chrysocolla, probably also deposited directly as such, in dacite tuff, is the ore of the Warrior mine in Webster Gulch.

Large quantities of this ore, consisting chiefly of a beautifully mottled black and green chrysocolla, have been shipped from the Warrior and the near-by Geneva mine. (See Pl. XLVI, *B*.) Much of this ore is dark colored, owing to the presence of manganese oxide, and that of the Geneva especially is of very striking appearance. It consists of kernels of black or dark olive-green chrysocolla of very irregular shape embedded in lighter-colored varieties of the mineral, ranging in tint from a delicate turquoise-blue to a deep bottle-green, the whole ore having a resinous luster. These paler-tinted varieties are in places arranged in fine concentric bands about the dark kernels, and as they do not always completely fill the interstices between the kernels, the resulting cavities form little vugs, usually lined with pale-blue botryoidal chrysocolla. Field relations show that this ore occurs as a replacement of dacite tuff, and a study of specimens indicates that the dark kernels, which owe their depth of color to the presence of oxide of manganese, probably represent original glassy particles of dacite and possibly small schist fragments in the tuff. Traces of flow structure and of original partly crystalline texture can occasionally be detected, and residual flakes of biotite, such as occurs in the dacite, are not uncommon within the dark chrysocolla. The present boundaries of the kernels are not, however, identical with those of the supposed original clastic particles. The latter have been rounded and embayed in the process of ore deposition and in part replaced by the banded chrysocolla, which apparently occupies in the main the place of the former fine interstitial material of the tuff.

The chrysocolla of the Live Oak and Keystone workings varies in color from blue-green to sky-blue, and much of it is a robin's-egg blue. It is commonly associated with quartz, chalcedony, and in places a little malachite, and many of the aggregates of these minerals possess great beauty. (See Pl. XLVI, *A*.) The quartz occurs in part as clear, sparkling drusy crusts lining vugs in the chrysocolla and in part very intimately associated with the chrysocolla in thin concentric layers. Between quartz with this chalcedonic habit and true chalcedony distinction can be made as a rule only by microscopic study. Both forms of silica are usually present with the chrysocolla and under the microscope show in part the same radially fibrous structure. The quartz fibers are distinguishable by elongation parallel with the axis of least elasticity.

Under the microscope in thin section the chrysocolla shows fine fibrous crystallization much like that of chalcedony. The arrangement of these fibers is usually radial, in concentric shells, and in places spherulitic. The spherules show well-defined dark crosses between crossed nicols. The fibers vary much in double refraction, the interference colors ranging from gray through yellow of the first order to yellow of the second order. In places all the fibers of one of the concentric shells of chrysocolla have a higher double refraction than the fibers of an adjacent shell. In other places the fibers of a single shell show more brilliant colors at one end than at the other. The fibers are extremely fine and can not be resolved with the highest power used with the ordinary petrographic microscope. Certain areas in the thin sections, which in ordinary light are indistinguishable from the rest of the section, show very feeble double refraction with crossed nicols and in places appear almost isotropic. Such material as a rule grades insensibly into the more highly refracting substance of the slide.

Associated with the chrysocolla of the Live Oak and Keystone workings is a beautiful hard translucent material ranging in color from robin's-egg blue through various light shades of greenish blue to apple-green. This material, of which very little is now obtainable, has been cut as a gem under the names chrysoprase, "blue chrysocolla,"[1] "keystoneite," etc., but, as Sterrett recognized, it is really chalcedony colored by copper. (See Pl. XLVI, *C*.) Much of the blue chalcedony contains brushes of malachite needles.

In thin section, under the microscope, the blue chalcedony is nearly colorless. It is

[1] Sterrett, D. B., Precious stones: U. S. Geol. Survey Mineral Resources, 1907, pt. 2, pp. 802-803, 1908; idem for 1909, pt. 2, pp. 756-757, 1911.

dusted with small inclusions, too minute for mineralogic determination, which are not the cause of the color. That is probably to be explained as the result of a submicroscopic intergrowth or mixture of chalcedony and chrysocolla. Microscopically the material, except for the included particles mentioned, appears to be homogeneous. Between crossed nicols the material shows sharply polygonal grains as much as 0.3 millimeter in diameter with obscure and shadowy radially fibrous structure. Such crystal structure as the mass shows was probably developed in a silica gel, each polyhedron representing the development of crystallinity from a single center. The polyhedrons are spherulites faceted by mutual interference with one another's growth.

The blue chalcedony, like the chrysocolla, occurs as veins or veinlets in granite porphyry. Some veinlets consist entirely of hard chalcedony; in others the chalcedony is in isolated nodules inclosed in a soft white chalky material which, according to W. T. Schaller, of this Survey, is a hydrous silicate of copper that has different ratios from chrysocolla and probably represents a different and distinct mineral. The optical properties are very different from those given by Umpleby [1] for chrysocolla from Mackay, Idaho. A study of the minerals generally listed as chrysocolla is in progress by Mr. Schaller, and it appears likely that he will find several distinct crystallized species, one of which is represented by the white chalky material from the Live Oak and Keystone workings. Much of the massive or amorphous chrysocolla proves to be not a definite mineral but mixtures of one or more hydrous copper silicates with different proportions of silica and water.

The chrysocolla of the Miami district is clearly not all of one generation. It is not uncommon to find chrysocolla traversed by veinlets of the same material. Probably the mineral is forming to-day in certain parts of the zone of oxidation.

In 1912 there was noted in process of deposition at many places in the Ray Central mine, on the walls and roofs of unused drifts, a vivid deep-blue deposit. The depositing agent was cold, clear water, probably seepage water from Mineral Creek or Copper Gulch. The deposit, to all appearances solid, formed miniature pools and terraces with scalloped edges and fluted slopes, suggestive of the travertine or sinter deposits built on a much larger scale by certain hot springs. The material, however, proved to be soft and somewhat gelatinous and when squeezed in the hand gave up much mechanically included water.

A sample of the deposit was examined by Mr. Schaller, who found it to have approximately the following composition:

Approximate analysis of hydrous copper silicate.

CuO	47.46
SiO_2	21.20
H_2O	28.05
CaO	1.39
Al_2O_3, MgO, etc	Trace.
	98.10

The deposit is thus essentially a hydrous copper silicate probably related to chrysocolla.

The air-dried material is a light bluish-green crystalline powder. The crystals, which are extremely minute, are apparently prismatic with the axis of least elasticity parallel with the prism axis. Their birefringence is weak.

The water depositing this material had no perceptible taste—a somewhat surprising fact in view of its evident activity in depositing copper. In 1914, although many changes had been made in the mine (now the No. 3 mine of the Ray Consolidated Copper Co.), some of the copper silicate was being deposited on the third level. A sample of the water was collected here and was analyzed in the Survey laboratory by R. C. Wells. The water reacted acid to phenolphthalein and alkaline to methyl-orange. The analysis stated in parts per million and in accordance with Palmer's classification[2] follows:

[1] Umpleby, J. B., Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, pp. 51-52, 1917.

[2] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

Analysis of water from the No. 3 mine, Ray, Ariz.

[R. C. Wells, analyst, 1915.]

Radicles.	Parts per million.	Reaction equivalents in milligrams of hydrogen per liter.	Reaction equivalents adjusted by proportionate reduction of bases.	Reacting values in per cent of total reacting values.	Reacting values of significant groups, in per cent.	Classification.
Na.......	65. 4	2. 8449	2. 8234	6. 89	Strong alkalies...8.33	
K.........	23. 2	. 5939	. 5894	1. 44		
Ca........	205. 6	10. 2594	10. 1822	24. 86	Alkali earths...40.33	
Mg.......	7. 77	6. 3869	6. 3388	15. 47		
Cu........	11. 9	. 3748	. 3720	. 91		*Per cent.*
Zn........	3. 8	. 1163	. 1154	. 28		Primary salinity 16.66
Mn.......	1. 2	. 0437	. 0434	. 11	Metals 1.34	Secondary salinity.... 79.76
Fe'''.....	. 3	. 0161	. 0160	. 04		Secondary alkalinity.. .90
Ni........	Trace.	....	....	....		Tertiary alkalinity.... 2.68
H.........	Trace.	....	....	....		100.00
SO_4......	906. 1	18. 8469	18. 8469	46. 01		
Cl.........	32. 0	. 9024	. 9024	2. 20	Strong acids....48.21	
NO_3......	Trace.	....	....	....		
HCO_3.....	44. 6	. 7314	. 7314	1. 79	Weak acids......1.79	
SiO_2......	43. 6	....	....	....	(Probably colloidal)	
	1, 415. 4	Excess of bases= 0. 1553.	Bases = acids.	100. 00		

The numbered arrows indicate the way in which the different groups of radicles determine the character of the water in this classification and show also the order in which the groups in this particular analysis are balanced against one another.

The water is of low concentration, and its principal characteristic in terms of Palmer's classification is secondary salinity, or, in common parlance, permanent hardness. Of the interesting fact that the water carries and deposits copper that classification takes no account. Unquestionably of surface origin, the water probably has not traveled far from the place where it sank into the ground. That so large a proportion of its dissolved matter should be the constituents of calcium and magnesium sulphates is rather difficult to account for on the supposition that these materials were extracted from the oxidized schist through which the water has percolated. Probably they were in large part gathered before the water began its underground journey. Through the kindness of Mr. W. S. Boyd, superintendent of mines for the Ray Consolidated Copper Co., I was supplied with a copy of an analysis of water from Mineral Creek, collected 6 miles above Ray. This analysis was made by Herman Harms, Utah State chemist, to determine the availability of the water as a source of domestic and general supply and was originally reported in grains per gallon of supposed salts present. It appears below recalculated in parts per million and classified in accordance with Palmer's scheme. The analysis is incomplete, potassa apparently being included with soda and other constituents being lumped together as follows: "Iron oxide and alumina," 0.058 (grains per gallon); "siliceous matter," 3.967; "volatile and organic matter," 1,402; and "undetermined and loss," 290.

Analysis of water from Mineral Creek, 6 miles above Ray, Ariz.

Radicles.	Parts per million.	Reaction equivalents in milligrams of hydrogen per liter.	Reacting values in per cent of total reacting values.	Reacting values of significant groups in per cent.	Classification.
Na	16.80	0.7308	9.1	Strong alkalies ... 9.1	Per cent.
Ca	43.20	2.1557	26.8	Alkali earths ... 40.9	Primary salinity 14.8
Mg	13.83	1.1368	14.1		Primary alkalinity 3.4
SO_4	7.09	.1475	1.8	Strong acids 7.4	Secondary alkalinity .. 81.8
Cl	16.04	.4523	5.6	Weak acids...... 42.6	100.0
HCO_3	208.89	3.4258	42.6		
Silica, alumina, etc	97.86	....	....		
	403.71	....	100.0		

This water is of low total salinity for the arid southwest and differs rather unexpectedly from that collected in the Ray No. 3 mine. It is characterized chiefly by secondary alkalinity or temporary hardness, being essentially a calcium - magnesium bicarbonate water. Either the water of Mineral Creek changes considerably in chemical character in flowing 6 miles or the water collected in the No. 3 mine is not creek water merely modified by the addition of copper.

In this connection the two analyses of water obtained near Ray, calculated in percentage of total solids in solution, are given in the accompanying table, together with eight analyses of river waters from the southwestern United States, taken from Clarke's "Data of geochemistry."[1]

The Ray mine water contains more of the sulphate radicle and less of the carbonate, chloride, and sodium radicles than most of the other waters represented by the analyses cited, but, except in its metal content, is not markedly different in character from the river waters. The Mineral Creek water, however, is shown to be so strikingly different as to raise some doubt concerning the correctness of the analysis. It might be expected that

Water analyses.

	1	2	3	4	5	6	7	8	9	10
CO_3	[a] 3.15	[a] 51.74	7.09	28.60	11.55	17.28	1.54	13.02	12.10	9.61
SO_4	64.02	1.76	25.49	12.48	30.10	31.33	43.73	28.61	16.07	8.29
Cl	2.26	3.97	30.87	17.52	21.65	13.55	22.56	19.92	29.78	41.56
NO_3	Trace.	......	.20	......	......	......	......	......	......	......
Ca	14.53	10.70	11.06	15.45	13.73	14.78	13.43	10.35	8.03	7.15
Mg	5.49	3.43	1.74	5.14	3.03	2.05	3.62	3.14	2.52	2.69
Na	4.62	4.16	20.83	13.07	14.78	14.43	14.02	19.75	24.53	26.38
K	1.64	......	.67	1.50	.85	1.95	.77	2.17	2.31	1.38
SiO_2	3.08		2.01	5.32	3.83			3.04	4.66	2.94
Al_2O_3	......	24.24	......	.92	.48	4.63	.33	......	......	......
Fe_2O_3	[b] .02		.04					......	......	......
Cu	.84	......	......	......	......	......	......	......	......	......
Zn	.27	......	......	......	......	......	......	......	......	......
Mn	.08	......	......	......	......	......	......	......	......	......
Ni	Trace.	......	......	......	......	......	......	......	......	......
H	Trace.	......	......	......	......	......	......	......	......	......
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Salinity, parts per million	1,415	404	1,136	321	791	399	2,384	702	1,023	1,234

[a] As HCO_3. [b] As Fe''.

1. Ray No. 3 mine, Ray, Ariz.
2. Mineral Creek, Ariz.
3. Brazos River, Tex.
4. Colorado River, Tex.
5. Rio Grande, Tex.
6. Rio Grande, N. Mex.
7. Pecos River, N. Mex.
8. Colorado River, Ariz.
9. Gila River, Ariz.
10. Salt River, Ariz.

[1] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, p. 82, 1916.

local surface waters in this arid region would contain more of the sulphate radicle and be generally more saline than the waters of the larger rivers, most of which have their headwaters in regions of more abundant precipitation; but here is a water that does not conform to this expectation, possibly because a considerable part of the flow comes from the high and wooded Pinal Range, where typically arid conditions can scarcely be said to prevail.

The examination of the mine water indicates what, indeed, is strongly suggested by such occurrences as the chrysocolla ores of the Black Warrior, Keystone, and Live Oak mines and the cementation of gravels and talus by chrysocolla in Copper Canyon and elsewhere in the two districts studied—that the ordinary surface water of the region can dissolve and transport considerable quantities of copper without being noticeably acid or ferruginous.

Mr. R. C. Wells has kindly supplied the following note on the chemistry of the deposition of copper by this water:

Any explanation of the chemical changes involved in the deposition of the copper silicate will depend somewhat on the theory of solution used and on the view held regarding the chemical constitution of the copper silicate.

A very simple explanation is that although silica is commonly supposed to exist in natural waters in the colloidal state there is in fact always a very small proportion of it present as silicate ion which can unite the cupric ion to form cupric silicate. One can easily see that if silicic acid is formed continuously from silica and water—thus,

$$SiO_2+H_2O=H_2SiO_3$$

the constant removal of silicate ion would leave the solution acid. This acidity would doubtless be neutralized almost as fast as developed by reaction with carbonate minerals or alkali silicates. The action is, however, probably not as simple as suggested.

It is more probable that the copper exists in solution as a basic ion, say $CuOH'$ and the silicate as an acid ion, say $HSiO_3'$, and the tendency for copper, which is a weak base, to exist in this form may account in part for the fact that the copper silicate is deposited as a hydrous compound.

The conditions which govern the deposition of silica from aqueous solutions are little known. It seems reasonable to suppose that if the silica has resulted from the recent decomposition of a mineral the solution may for a short time be, so to speak, supersaturated with silica, which is soon deposited either in a colloidal form or by union with the basic constituent that is most nearly at the point of deposition. In the Ray mine water copper is clearly one of the weakest and most insoluble bases, although ferric iron is probably still weaker.[1] Progress toward stability would very naturally result, therefore, in the deposition of cupric hydroxide and silica together, or as a definite compound.

As there appears to be a very small amount of bicarbonate in the water under discussion, it is evident that the acidity or alkalinity of the water might be affected by a loss or gain of carbon dioxide. This would produce the same sort of effects as more or less reaction with adjacent rocks, and it therefore appears unnecessary to discuss the matter more fully.

Alunite.—Alunite, a hydrous sulphate of aluminum and potassium, is not known in the Miami district and has been noted at only a few localities at Ray. Here it is associated with fissuring of comparatively late origin and is apparently a product of sulphate solutions from oxidizing sulphides. Its mode of occurrence thus resembles that in the Cripple Creek district[2] rather than at Goldfield, where it is dispersed as an abundant constituent through enormous masses of altered igneous rocks.[3]

In the No. 1 mine, B. S. Butler, of this Survey, during a brief visit collected a sample of white material from a small fissure cut by one of the drifts. The part of the mine from which the specimen came was not recorded. Tests by W. T. Schaller in the chemical laboratory of the Survey proved the material to be alunite.

In the No. 2 mine the mineral was noted in 1912 in S. 42° W. drift on the 1925 level as compact snow-white nodules 6 inches or less in diameter in a zone of crushed schist. The alunite presumably at one time formed a vein which was afterward broken up by movement in the shear zone. This part of the 1925 level is from 400 to 500 feet below the surface of Humboldt Hill.

The presence of alunite in the Ray Central (now the No. 3) mine is mentioned by Probert.[4]

The mineral doubtless is present at other places in the Ray district and will probably be found at Miami. As a rule a chemical test is necessary to distinguish its earthy forms from kaolinite.

[1] Wells, R. C., The fractional precipitation of some ore-forming compounds at moderate temperatures: U. S. Geol. Survey Bull. 609, p. 45, 1915.

[2] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, p. 125, 1906.

[3] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 129–133, 1909.

[4] Probert, F. R., The Three R mine, Patagonia district, Ariz.: Min. and Sci. Press, vol. 109, p. 175, 1914.

Chapter VIII.—Shape and Geologic Relations of the Ore Bodies.

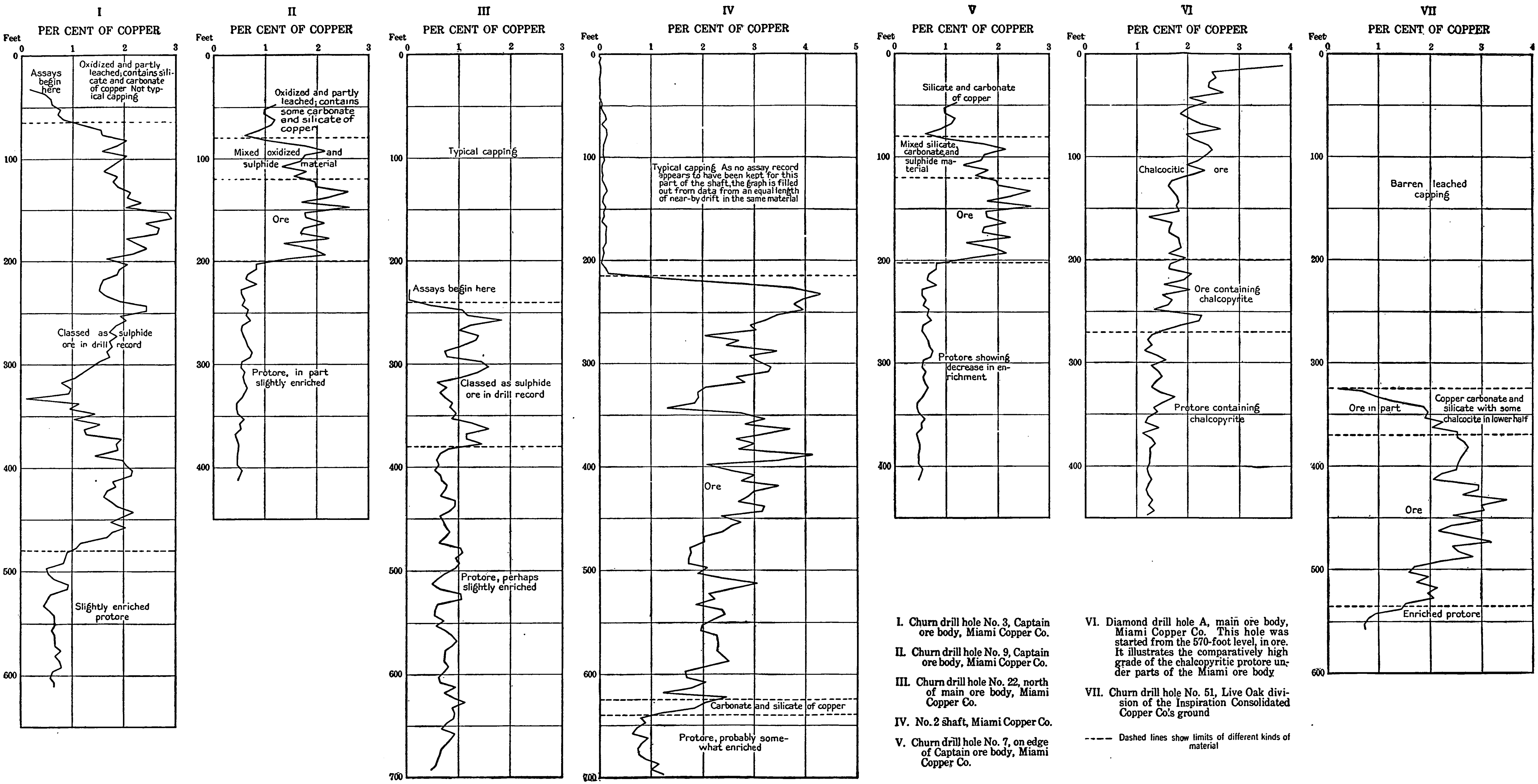
FORM AND DIMENSIONS.

The bodies of disseminated ore in the Ray and Miami districts may be characterized in general terms as undulating, flat-lying masses of irregular horizontal outline and of variable thickness. As a rule these masses lack definite boundaries. No readily recognizable distinction in color, texture, or general appearance marks them off sharply from the inclosing rock, and closely spaced sampling and assays prove that the passage from ore to country rock is in most places gradational. Consequently, to a greater degree than in most ore deposits of other types, the size and shape of the Ray and Miami bodies depend upon the local and current definition of ore. So far as it has been practicable to secure uniformity, the outlines of ore bodies as shown on maps and illustrations accompanying this report are based on a tenor, in all material classed as ore, of at least 1.5 per cent of copper in chemical combination with sulphur. Any change in this definition, such as lowering the required minimum tenor or including carbonates and silicates of copper as ore, would materially modify the outlines as given in the illustrations. The limit chosen is necessarily somewhat arbitrary and is not observed under all circumstances of actual mining. For example, under the stimulus of the high price for copper in 1916 much material containing less than 1.5 per cent of the metal as sulphide was drawn from the stopes and went to the mill as ore. In fact, in August of that year the feed in the Inspiration mill averaged 1.56 per cent of copper, of which only 1.17 was sulphide, while 0.39 per cent was oxidized, probably for the most part silicate and carbonate.

Like most condensed general characterizations, the preceding paragraph requires considerable qualification to make it an accurate statement; for in a preliminary sweeping view many details essential to the completeness of the picture are necessarily for the moment overlooked. The statement, for example, that the passage from ore to country rock is gradational, though true in a broad way, is subject to many exceptions. As a rule the transition downward from the leached overburden, or "capping," as it is locally termed, to the ore is less gradual and far more distinct than the transition from ore to protore. In some places, particularly in the Ray district, there is an abrupt change from the practically barren, rusty-brown "capping" to gray sulphide ore. The same sharp contact between leached oxidized material and ore occurs at several places in the Miami district, but a study of all the available churn-drill records of this district shows that out of 191 holes which penetrated ore, 154, or about 80 per cent, passed through material containing carbonates and silicates of copper, or mixed carbonates, silicates, and sulphides, before reaching ore. This material may contain as much copper as the normal sulphide ore, but inasmuch as it is not equally amenable to the same milling treatment, it is not at present classed as ore, or, if so classed, it is considered separately from the predominantly sulphide ore. Consequently, in records of such holes it is rarely possible to tell merely from the assays for total copper where the ore begins or ends. Account must be taken of the mineralogic character of the material and of the sulphide assays. Assay graphs of typical churn-drill holes showing the relation of ore to overlying and underlying material are presented in Plate XLVII and figure 25. Similar graphs have been discussed by Perry and Locke,[1] chiefly with reference to practical application in planning drill exploration. Horizontal variations, as recorded by assays every 5 feet along drifts, are shown in Plate XLVIII.

In many places there is a very abrupt change from ore to thoroughly leached, oxidized rock containing scarcely a trace of copper, the

[1] Perry, E. H., and Locke, Augustus, Interpretation of assay curves for drill holes: Am. Inst. Min. Eng. Trans., vol. 54, pp. 93-99, 1916.



I. Churn drill hole No. 3, Captain ore body, Miami Copper Co.

II. Churn drill hole No. 9, Captain ore body, Miami Copper Co.

III. Churn drill hole No. 22, north of main ore body, Miami Copper Co.

IV. No. 2 shaft, Miami Copper Co.

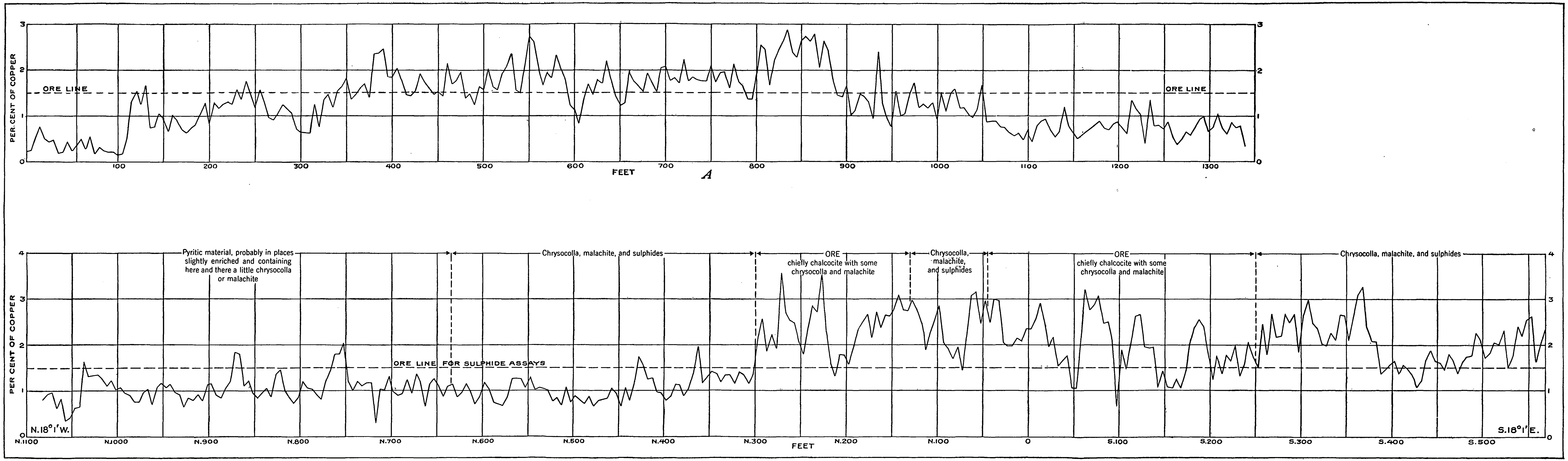
V. Churn drill hole No. 7, on edge of Captain ore body, Miami Copper Co.

VI. Diamond drill hole A, main ore body, Miami Copper Co. This hole was started from the 570-foot level, in ore. It illustrates the comparatively high grade of the chalcopyritic protore under parts of the Miami ore body

VII. Churn drill hole No. 51, Live Oak division of the Inspiration Consolidated Copper Co.'s ground

---- Dashed lines show limits of different kinds of material

ASSAY GRAPHS OF CHURN-DRILL HOLES IN THE MIAMI DISTRICT.



B

ASSAY GRAPHS OF DRIFTS IN THE MIAMI DISTRICT.

A, Drift on the north-south O coordinate on the 570-foot level of the Miami mine; *B*, east-west drift on the fourth level of the Inspiration mine, east of the Colorado shaft.

boundary between the two being a gouge-filled fissure. Some of these fissures are plainly of later origin than the enrichment, and some were probably formed before enrichment. Of the fissures formed after the enrichment some are associated with displacement; oxidized and leached material has been faulted against ore. Others have probably brought about the observed relation between ore and waste not so much by faulting as by directing the downward progress of oxidation in such a way that the ore on one side of the fissure was protected, while that on the other was converted to the so-called cap rock. Still a third group of fissures may have been formed before the enrichment and have influenced in the manner just indicated the enriching as well as the leaching and oxidizing processes.

In some places, particularly in the ground of the Miami Copper Co., chrysocolla and malachite occur vertically beneath the sulphide ore complicating the interpretation of drill records as a means of ascertaining the relations between the ore and the underlying protore.

The general horizontal outlines of the ore bodies as they have been determined by underground exploration are shown in Plates XXXI and XLIX and in figures 6 and 26. The ore body that constitutes the eastern part of the

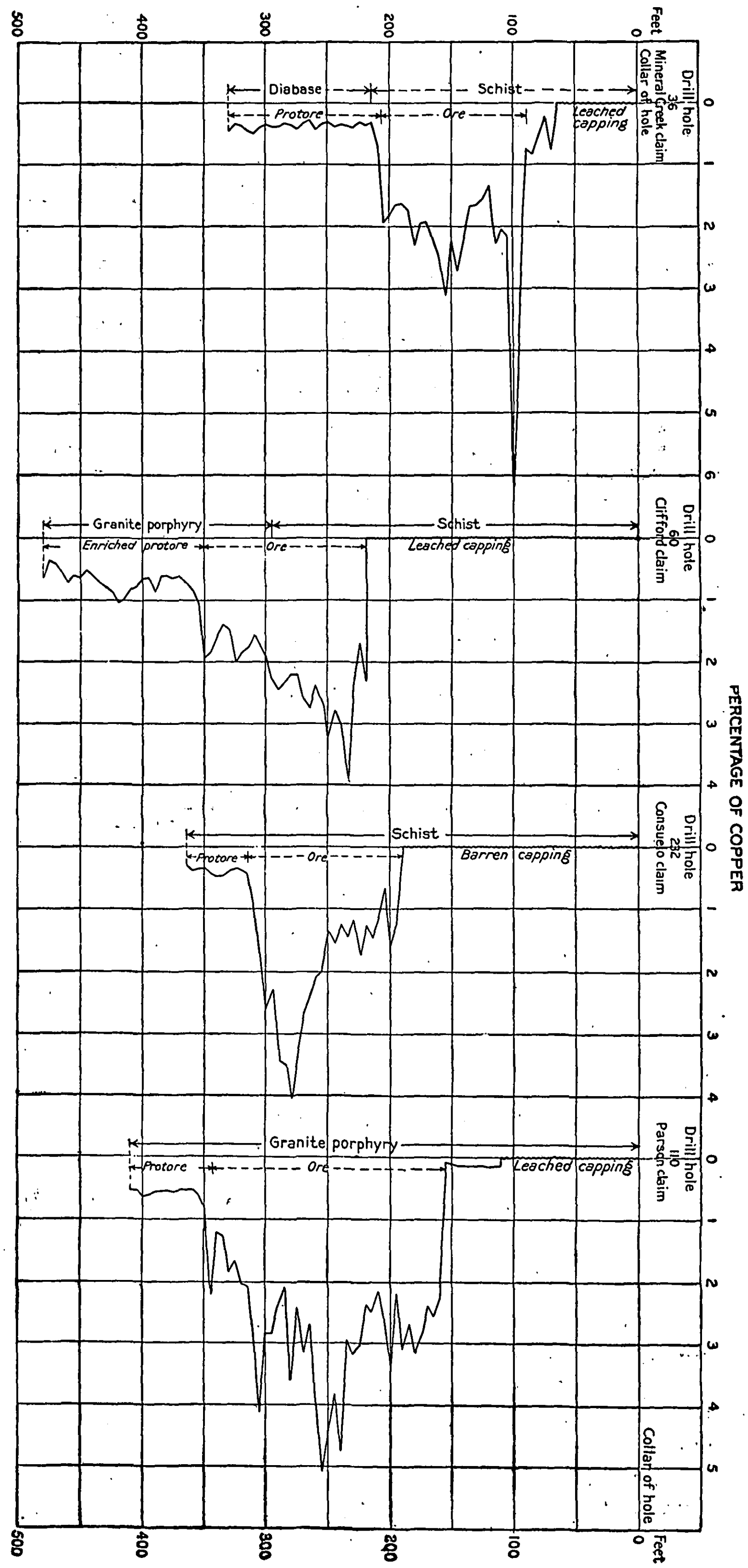


FIGURE 25.—Assay graphs of churn-drill holes in the Ray district.

Miami-Inspiration zone, including the portions locally designated the Inspiration, Pinto, Captain, Northwest (Miami), and Southeast (Miami) ore bodies, has a total length of about 5,500 feet and a maximum width of 1,600 feet.

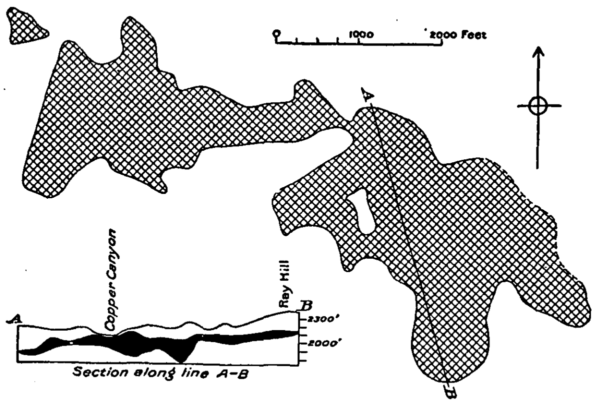


FIGURE 26.—Plan and section of the ore bodies as developed by underground exploration in the Ray district.

The greatest width in its irregular area is under the part of the ridge south of the Inspiration main shafts and between the Colorado and Scorpion shafts. Farther east, near the Joe Bush shaft, the ore in places is only 200 feet wide. The Pinto ore body is a lobe about 700 feet long and 300 feet wide, that projects northwest from the Captain and Northwest ore bodies of the Miami mine. The main Miami ore body, including the Northwest and Southeast ore bodies, which are not really separate ore masses, is about 1,600 feet long and 1,000 feet wide.

The ore body which constitutes that part of the Miami-Inspiration zone west of the Bulldog fault zone comprises the Keystone and Live Oak ore bodies, which are really continuous. It has a total length of at least 4,000 feet and a maximum width, in the Live Oak group, of about 1,900 feet.

The dimensions given are approximate only. In some places, as already explained, the boundary between ore and country rock would be shifted considerably by a slight change in the percentage figure used in calculations as the lowest permissible copper content in material that can be classed as ore. In other places exploration has not been sufficiently thorough to exclude the possibility of additions to the known ore masses.

The irregular variations in the thickness of the ore are brought out in Plates L and LI and figures 26, 27, and 28.

The Ray ore body may range in thickness from 300 feet to 50 feet or less in a distance of 200 to 300 feet, and the Inspiration ore body from 300 or 400 feet to practically nothing within a distance of 150 feet. The thicker portions of the ore bodies, as seen in section, may be convex below and concave above, double convex, or, more rarely, convex above and concave below. These variations bear no regular relation to the present topography and, so far as can be determined, are only in a few places due directly to faulting. The thickness of the ore body at any particular place bears no fixed proportion to its width, as is well shown in the sections across Inspiration Ridge in Plate XLI.

As a whole, the ore bodies in the Miami district are thicker than that at Ray. Mr. Henry Krumb, in his report to the Ray Consolidated Copper Co. in 1909, estimated the average thickness of the Ray ore body, as determined

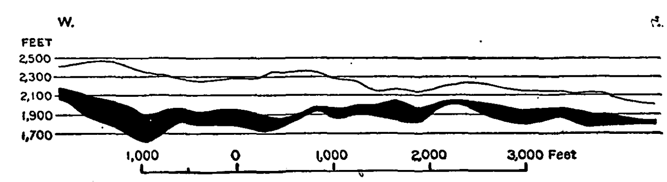


FIGURE 27.—Generalized east-west section of the Ray ore body, constructed by averaging the available sections of a strip of the ore body 600 feet wide. Much reduced from a drawing prepared by the Ray Consolidated Copper Co.

by churn drilling, at 100 feet. A later estimate by the engineers of the company gives an average of 120 feet of ore for the whole body

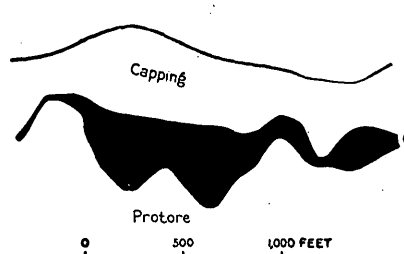
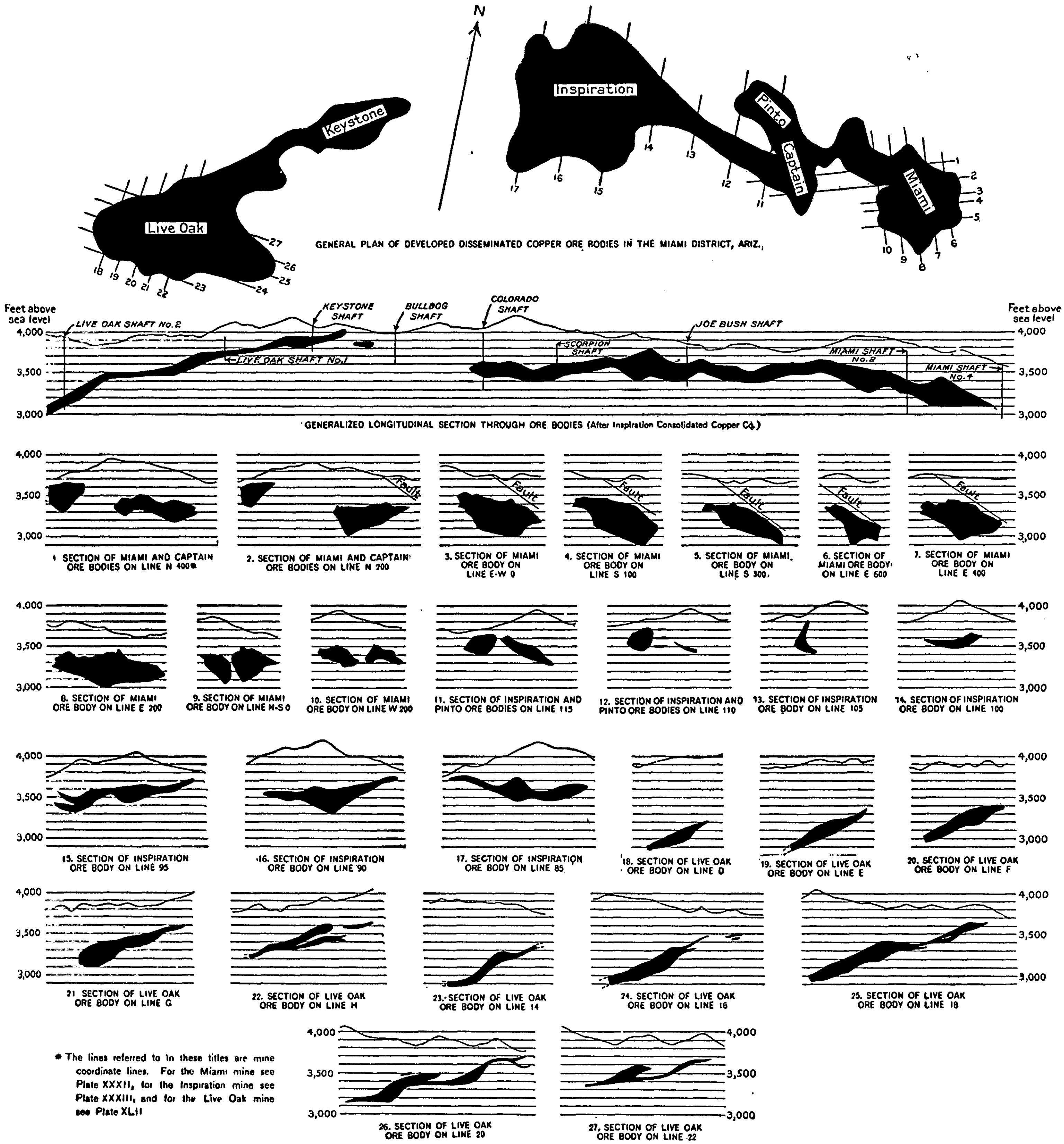


FIGURE 23.—Section across one of the deepest and thickest parts of the Ray ore body.

as at present developed. The western lobe of the ore body is thicker than the eastern, so that although smaller in area it probably contains more than half the ore of the whole body. The maximum thickness of about 400 feet has



PLAN AND SECTIONS OF THE PRINCIPAL PORTIONS OF THE DISSEMINATED ORE BODIES OF THE MIAMI DISTRICT.

been found under Humboldt Hill, where there is approximately 1,000,000 tons of ore to the acre. No general average for the Miami ore zone is available, but a thickness of 410 feet is known under Inspiration Ridge, north of the Colorado shaft, and parts of the ore body in the Miami Copper Co.'s ground are as much as 500 feet thick. In the Live Oak and Keystone divisions of the Inspiration Consolidated Copper Co.'s ground the ore is generally thinner than under Inspiration Ridge.

RELATIONS OF THE ORE BODIES TO THE SURFACE.

The depth to ore, or the thickness of the overburden, varies widely from place to place. This is particularly true in the Miami district, where, on the Live Oak and Miami ground, the leached rock is itself in places overlain by dacite or Gila conglomerate.

In the Ray district the average thickness of the overburden on the ground of the Ray Consolidated Copper Co. lies between 200 and 250 feet. The thickness ranges from about 45 to 600 feet, although in very few places does the leached ground extend to depths greater than 500 feet. Drill hole 21 of the Arizona Hercules Copper Co., east of Mineral Creek, is reported to have gone down nearly 900 feet feet before reaching ore. Possibly other holes drilled on this ground during 1915 and 1916 by the Ray Hercules Copper Co. have also penetrated unusually thick overburden, but full particulars concerning the occurrence of ore in these holes are not available for publication.

In the Miami district chalcocite ore lay only about 500 feet below the surface near the Joe Bush shaft. On the other hand, some of the deep churn-drill holes on the Live Oak ground went through nearly 1,000 feet of rock before reaching the zone of chalcocite enrichment, and the Barney No. 1 hole, after penetrating 630 feet of Gila conglomerate, 430 feet of dacite, and 40 feet of doubtful material, passed through 200 feet of oxidized leached schist. In other words, at this place the schist is thoroughly oxidized at a depth of 1,300 feet.

Partly in order to study the relation of the ore in the Miami district to the present surface the records of 333 churn-drill holes, including nearly all the holes completed prior to 1917 on the Miami Copper Co.'s ground and all save the Keystone holes on the Inspiration Consolidated Copper Co.'s ground, have been plotted graphically as Plate LI. The records have been arranged from left to right in the order of descending altitude of the tops of the holes, without any regard to a real position. Inspection of the chart shows that the ore occurs at all depths within a range of about 1,100 feet and, except for this general limit, is not related in any regular way to the present topography. When holes in which the ore occurs at about the same elevation above sea level are grouped together it is found that the deepest and lowest ore occurs in the western part of the Live Oak ground, that there is a general rise to the northeast toward the Keystone ground, a drop eastward near the Colorado shaft of the Inspiration Co., and finally a descent toward the east in the Miami ground. These relations are more graphically brought out in the generalized longitudinal section shown in Plate L.

It will be observed that the lowest ore occurs in portions of the Miami district where the surface rocks consist in part of dacite and Gila conglomerate, a covering which it might be supposed would have tended to prevent the oxidation and enrichment of the underlying sulphides. This leads to the suggestion that the dacite and conglomerate were not present when most of the enrichment was effected, a suggestion which is supported by the fact that removal of these rocks would leave a surface according more nearly with the vertical distribution of the ore than the present surface. In other words, there is at least some indication that the principal enrichment took place before the eruption of the dacite. This hypothesis will be more fully discussed later.

RELATIONS OF THE GROUND WATER TO THE SURFACE AND TO THE ORE BODIES.

The general relations of the ground water to the present topographic surface and to the ore bodies in the Miami district are shown in Plate L.

In utilizing churn-drill records it should be remembered that the observations recorded were made by men primarily interested in the presence or absence of ore, and that not all of what to them were incidental observations are of the same degree of accuracy. Moreover, as regards water level, only those records are of any value which relate to parts of the district not previously drained by mining operations. In the Miami district most of the drill holes on the Live Oak and Inspiration divisions of the Inspiration Consolidated Copper Co.'s ground were put down in advance of deep mining in their vicinity, and their water records are believed to be fairly trustworthy. Most of the holes of the Miami Copper Co., on the other hand, were drilled after mining operations were well advanced and show abnormally low water levels. There are probably few of them in which the water has not been artificially lowered.

In view of the labor involved in the compilation of this chart for the Miami district and the rather unsatisfactory character of the water record in the Ray district, it has not seemed advisable to attempt a similar presentation for the latter district.

If the surface of the Miami district were a regular, unaccidented slope and the rocks were uniformly permeable, then the line of first water for each drill hole as represented in the chart should lie on a curve of slightly less slope than the curve drawn through the tops of the holes when arranged, as in the chart, in the order of decreasing altitude. Evidently this correspondence between land surface and ground-water surface does not exist. The divergences are in part due to the fact that the district has a rather minutely diversified surface, in consequence of which two drill holes near together, one on a ridge and one in a ravine, may reach water at nearly the same level above the sea but at depths differing by the height of the ridge above the bottom of the ravine. In part also they appear to be due to other causes, such as differences of permeability in the rocks. Two free-hand curves drawn to inclose all the levels of first water shown on the chart, except those suspected of having been artificially lowered, would represent what may be termed the zone of first water. This zone as a whole corresponds roughly with the ideal condition of an underground water level sloping generally with the land surface but standing at greater depth under high ground than under low ground. A few holes in which the water was found unusually near the surface, as Live Oak holes 85 and 86 (Nos. 171 and 268 on the chart), are situated in the bottoms of ravines that carry considerable water after rains. Others with high water level, such as Miami hole 73 (No. 330 on the chart), probably tapped some very local accumulation of water held up by an impervious rock layer or gouge seam.

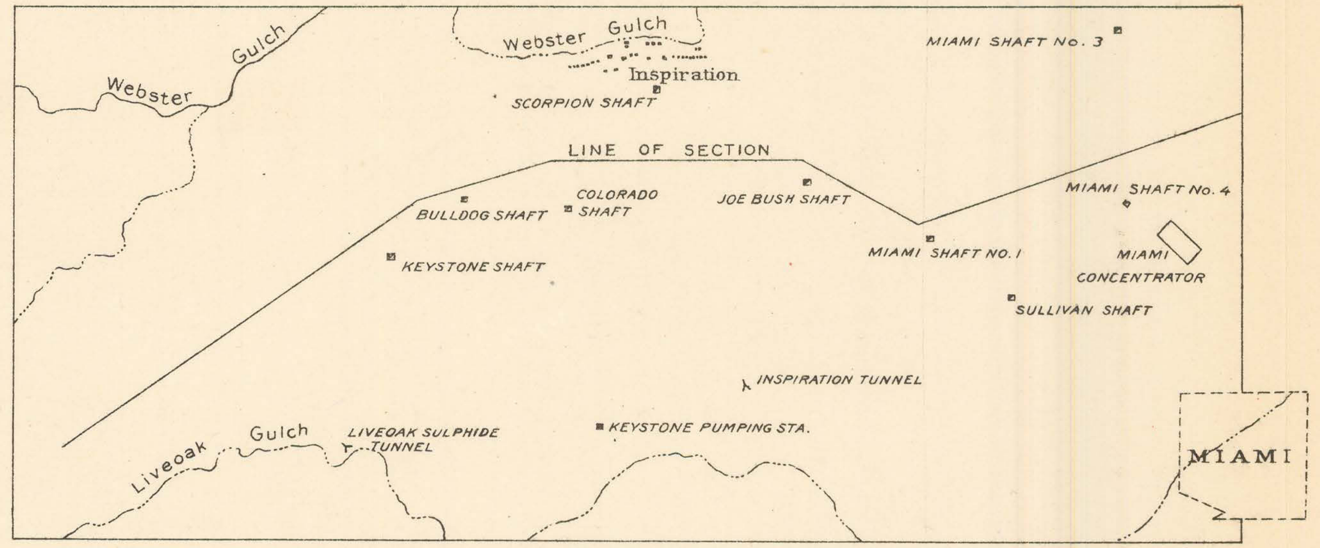
When the records are classified with reference to the elevation above sea level of the first water found, it appears that in general the water originally stood highest in the western part of the district and lowest in the eastern part. In other words, at the beginning of mining operations the underground water surface sloped eastward toward the broad gravel-filled valley of Pinal Creek. An attempt was made to prepare from the drill records a contour map of the underground water surface, but the irregularities in the records, if not in the surface itself, proved too great to admit of this mode of graphic presentation.

Reference to the chart (Pl. LI) shows that there is no regular relation between the ore bodies and the ground-water surface beyond the fact that the ore as a rule lies deeper to the west, whereas the water surface gets deeper to the east. Ore may occur high above the water level, as in Inspiration hole 1108 (235 on the chart), or hundreds of feet below it, as in Live Oak holes 46 (134 on the chart) and 44 (54 on the chart). This irregularity supports the suggestion offered on page 29 that the enrichment which produced the ore bodies was effected in the main before the development of the present topography.

In one drill hole in the Miami district, the Barney No. 1, artesian water was found. This hole, situated near the Barney shaft in the large area of Gila conglomerate in the western part of the district, went through 630 feet of conglomerate and then through 430 feet of dacite into about 40 feet of soft material, possibly dacite tuff. This is the water carrier, and the water was under sufficient head to flow out at the surface. The dacite flow in this locality apparently dips gently to the east, and the water was probably gathered in the higher country just west of the area shown in Plate XXXIX.

LOWER LIMIT OF OXIDATION.

It has been shown in the preceding sections that in the Miami district the lower limit of oxidation and the ground-water surface, as it was at the beginning of mining, were far



Sulphide ore

Protore ("primary ore") and sulphides with less than 1.5 per cent copper

Copper silicates and carbonates with, in places, some sulphides

Barren leached rock

Gila conglomerate

Pinal schist

Granite porphyry

Dacite

GENERALIZED LONGITUDINAL SECTION ACROSS THE MIAMI DISTRICT

Showing relation of the ore body to geologic formations

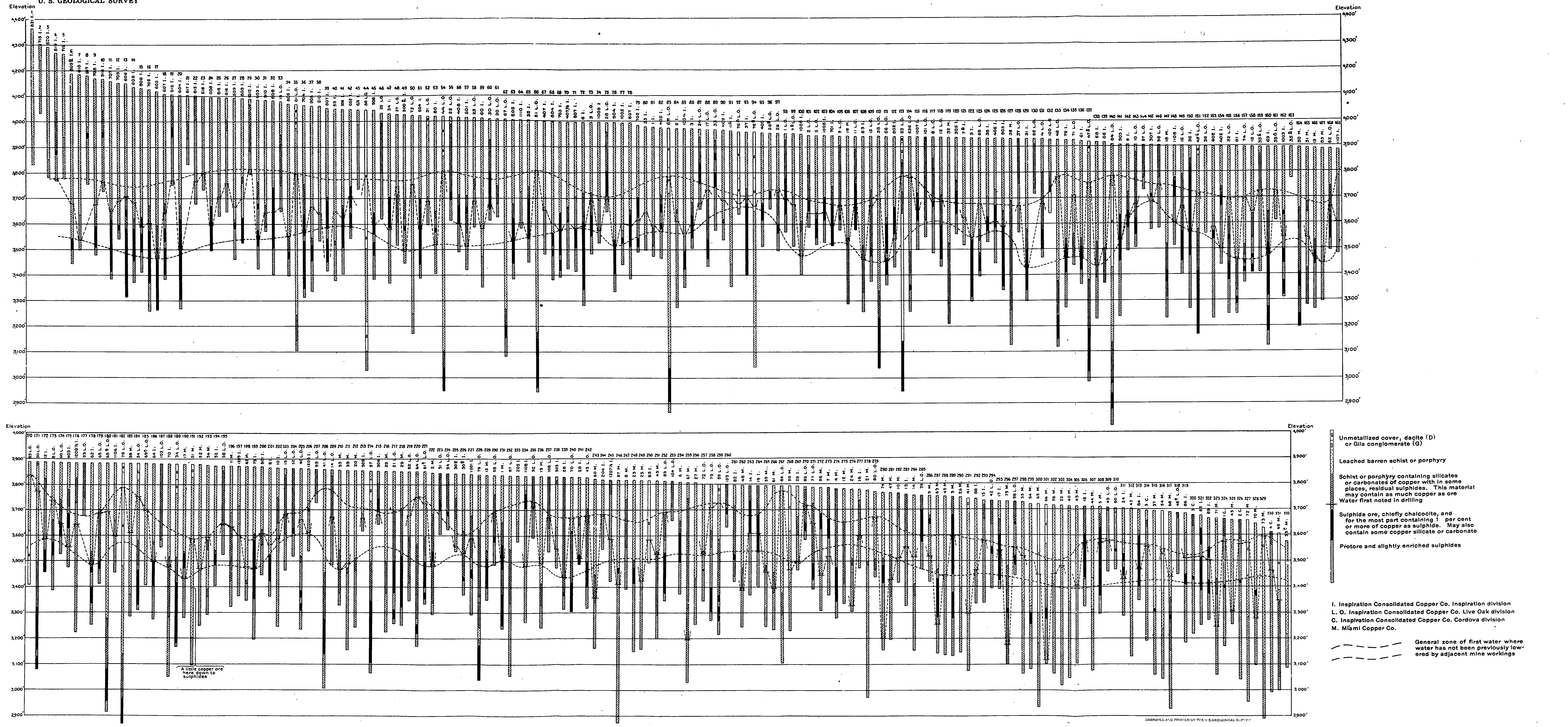
Scale $\frac{1}{6,000}$

0 $\frac{1}{8}$ $\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ Mile

1000 500 0 1000 2000 Feet

100 0 100 200 300 400 500 Meters

1919



DRILL-HOLE CHART OF THE MIAMI DISTRICT, ARIZONA from coincident. In the Ray district it is exceedingly difficult and perhaps impossible to get from the available ground-water data any definite conception of the ground-water surface when mining began; but apparently here also it was neither coincident with nor closely related to the bottom of the oxidized zone, although the divergence was less striking than at Miami. It has also been shown that in general the layer of oxidized material above the ore is from 45 to 600 feet in the Ray district, the average thickness as calculated by the engineers of the Ray Consolidated Copper Co. being 252 feet.[1] Not all of the overburden in the Miami district can be considered oxidized material, for, as has been shown, much of it in certain localities is dacite or Gila conglomerate, believed to have been laid down after most of the oxidation had been accomplished. Nevertheless, if these younger rocks were disregarded the range and average thickness of the oxidized zone at Miami would probably still be greater than those of the similar material at Ray.

In general, the bottom of the oxidized zone is a fairly definite but uneven and undulatory surface. If at any time in the history of the deposits this surface was coincident with a ground-water surface which stopped its gradual descent this coincidence is no longer evident. Oxidation appears to have been limited rather by the gradual exhaustion of oxygen from air and rain water as they penetrated downward through the rocks. Such being the case, oxidation would extend deeper along certain favorable channels than through the mass of the rock, and as such zones of easier penetration would rarely be vertical, there is little difficulty in accounting in this way for the occasional observed occurrence of oxidized material directly beneath protore or enriched sulphide ore. The most conspicuous example of such a relationship is that in the Miami mine, described on page 163.

RELATIONS TO KINDS OF COUNTRY ROCK.

The rocks intimately associated with the disseminated ores are, in the Miami district, the Pinal schist and the Schultze granite porphyry, and, in the Ray district, the same schist, the Granite Mountain variant of the quartz monzonite porphyry of the district, and diabase. By far the greater part of the ore in both districts is metallized schist, a relatively small part is metallized granite porphyry or quartz monzonite porphyry, and a very much smaller part, in the Ray district, none of which has yet been mined, appears from drill records to be in diabase.

Evidently the relations existing between the igneous rocks and the ore may be of two kinds. These rocks are not merely to be regarded, like the schist, as material that has been in part converted to ore, but must be considered also as possible active agents, through the consequences of their intrusion, in the process of metallization. In dealing with them it is necessary to take account not only of their more or less passive or directive function as country rock but of their possible energetic participation in ore deposition. In the present chapter attention will be confined chiefly to observed relations. Discussion of the extent to which the igneous rocks may have contributed to the origin of the ores will come later.

In the Miami district the ore in a general way occupies a marginal position with reference to the extreme northern lobe of the Schultze granite, the rock of this lobe, as described on page 108, being chiefly granite porphyry. It does not follow the contact closely, however, nor is it entirely in one rock.

The main Miami ore body is chiefly in schist, although a granite porphyry dike which cuts the schist has, like that rock, been converted into ore. The Captain ore body and nearly all of the main Inspiration ore body are in schist. The Keystone and Live Oak ore bodies are also in schist, but instead of lying near the margin of the granite porphyry they occur beneath an intrusive sheet of the porphyry, as described on page 110 and shown in Plate LI. Such comparatively thin and deep ore as has been found by drilling west and southwest of the Live Oak ground is in schist and is apparently not very closely related to the granite porphyry as exposed.

In the Ray district the association of the ore with the porphyry, here a quartz monzonite porphyry, is less close than at Miami. A considerable part of the ore in the No. 1 mine, chiefly in the northeast part of the workings, is in the mass of quartz monzonite porphyry that is exposed at the surface between the No. 1

[1] Ray Consolidated Copper Co. Third Ann. Rept., for the year ending Dec. 31, 1911, p. 10.

and No. 3 shafts. With the exception of some irregular porphyry dikes, mostly near Humboldt Hill, all of the ore body worked in the No. 2 mine is in schist, as is also most of the ore of the No. 3 mine. By far the greater part, probably over 90 per cent, of the known ore in the Ray district is in schist.

Exploration by drills of the Ray Hercules ground, however, shows that of the 3,000,000 to 9,000,000 tons of ore estimated to be present by Mr. Frank H. Probert[1] over 75 per cent, according to Mr. Probert, "occurs in diabase and granite porphyry, mostly in the former."

In both districts schist and porphyry have apparently been equally susceptible of metallization, and there is no essential difference between ore in schist and ore in porphyry. Closely spaced assays in drifts passing from schist into porphyry show no perceptible change at the contact. Where the contact is due to a fault, however, there may be an abrupt change in the character of the ore, just as there might be in passing across a fissure that is entirely in schist or entirely in porphyry. It is the fissuring, not the kind of rock, that is responsible for the difference.

It is a fair conclusion from the relations just outlined that the parts of the porphyry masses now visible in the vicinity of the ore bodies were not sources of metallization but, like the schist, were themselves acted upon by metallizing solutions which must have had some more distant origin than any mass of rock now to be seen in the districts.

In the Miami district diabase, so far as known, does not occur in close association with the disseminated ore. In the Ray district, on the other hand, while none of the ore of the Ray Consolidated Co.'s mines is known to occur in diabase, except possibly a very little close to the overlying schist, a considerable part of the ore in the No. 1 and No. 3 mines is underlain by diabase, and the ore just above that rock is as a rule of better grade than the average.

That the ore in the Ray district is, in certain places, limited on the west by diabase first became evident in the Ray Central (No. 3) mine. In that mine the diabase appeared on the second level from 200 to 350 feet west of the Madeline shaft or from 700 to 850 feet west of the No. 3 shaft. This diabase was afterward more extensively exposed in the No. 2 sublevel of the No. 1 mine, which was laid out to work the western and lower-grade part of the Ray Central ground and is an extension of the old second level of the Ray Central mine. The ore immediately above the diabase on this sublevel is above the average grade, although not as rich as that worked in the No. 3 mine. On the third level of the Ray Central mine the contact, here trending nearly northeast, was found to pass through the Madeline shaft. On the fourth level the contact, with nearly the same northeasterly trend, was found about halfway between the Madeline and No. 3 shafts. An east-west cross section through the Madeline shaft shows the diabase to have an apparent dip, in the plane of the section, of about 16° E. The strike of the contact on the fourth level is nearly N. 30° E., and the true dip on this level is approximately 4° more than the apparent dip in the east-west section, or 20°. Diabase also appeared in the eastern part of this mine, especially on the fourth and lower levels. At the time of my last visit the relations of this diabase to the ore-bearing schist were less clear than those of the diabase to the west, the contact to the east of the ore body having been less thoroughly explored. On the fourth level this contact appeared to dip west, but on the fifth level the dip is apparently to the east at 70° to 80°. Drill holes east of the No. 3 ore body show the top of the diabase to be from 1,703 to 1,905 feet above sea level, or to have a general elevation not very different from the top of the diabase just west of the No. 3 shaft. On the other hand, the deepest workings of the No. 3 mine show no diabase under the deepest part of the high-grade ore body, the ore on the sixth level grading downward into unenriched schist. These relations are shown in part in the section (fig. 29) along the 2 North line of the Ray Central coordinates, very kindly supplied by Mr. Thornton, chief engineer for the Ray Consolidated Copper Co. They suggest that the diabase sill shown in the figure as dipping gently east under the ore is faulted and that the deepest ore of the No. 3

[1] Personal letter of Sept. 7, 1912. Mr. Probert's statement is: "I figure that there are 3,200,000 tons of average grade 2.44 per cent actually proved by holes put down at the intersection of coordinates 200 feet apart; 3,800,000 tons of average grade 2.04 per cent as probable ore, and a further possibility to the south and east, not definitely proved, of approximately 2,000,000 tons averaging 1.9 per cent copper. This does not, of course, include any high-grade ore to be developed along the major faults crossing the claims."

mine lies in a nearly north-south trough formed by the dropping down of a fault block along the bottom of a gentle diabase syncline. On the west, it will be observed, the ore rests directly on the diabase. On the east, on the other hand, there is in most places about 50 feet of unenriched schist between the ore body and the diabase.

Comparatively recent work in the No. 1 mine south of the former Ray Central ground has shown that the diabase west of the ore body extends southward and limits on the west a considerable part of the ore body worked in the No. 1 mine. This diabase is cut in a number of places on the 1970 and second levels, and on the second level it is penetrated by the long drift that runs northwest toward the Pearl Handle shaft. It has been penetrated also on the third level, where the sheet has a dip of about 20° E. The second level goes through some 250 feet of diabase, and the third level through about 550 feet. The greater distance on the third level is apparently due chiefly to a lower dip on that level, although perhaps partly to a greater thickness of diabase. The average thickness of the sheet between the second and third levels appears to be about 125 feet.

The sheet of diabase has been described as limiting parts of the ore body on the west. This limitation, however, is local, for, as may be seen from Plate XXXVII, the ore in the vicinity of the Pearl Handle shaft lies west of the diabase. The diabase itself is practically barren, and so is the schist directly beneath it. As the diabase does not come to the surface and has been only partly explored underground, the shape and extent of the sheet are very imperfectly known. Apparently, however, its upper limit is somewhere east of the Pearl Handle shaft and it does not extend over the part of the ore body worked southwest of that shaft.

The chief function of the diabase in connection with the origin of the ore appears to have been the direction and retention of descending cupriferous solutions by the gouge seams commonly present at and near its upper surface. That the diabase probably performed this function is indicated by the fact that in the development of the Ray Central workings this contact proved a troublesome source of water. According to Mr. Probert streams as large as a man's arm issued in some places from the diabase and the overlying schist.

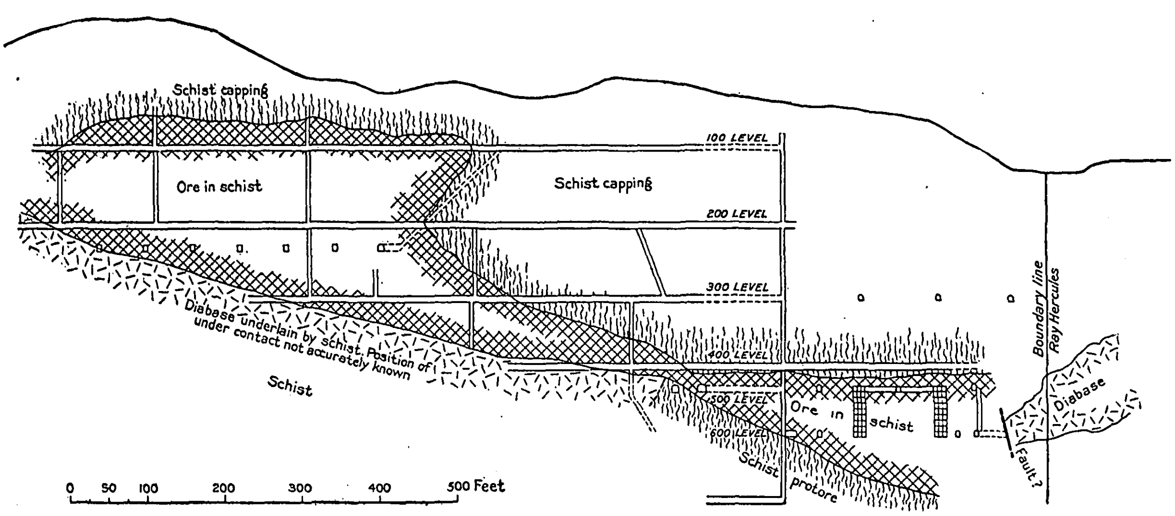


FIGURE 29.—Section on the 2 North line of the Ray Central coordinates of the Ray Consolidated Copper Co., showing relation of the diabase to the ore in the No. 3 mine.

STRUCTURAL EFFECTS OF FAULTING.

The generally uniform character of the rocks in which the ore occurs and the absence of beds or similar structural units of pronounced individuality that might by their evident dislocation register the amount of displacement along each fissure render it difficult to ascertain the extent to which faulting has determined the shapes of the ore masses. Fissures in the ore are numerous, and many of them contain sufficient gouge to suggest extensive displacement. Some of these, however, appear to have less persistence along their strike than would be expected were they coincident with faults of large displacement; and it is difficult to avoid the conclusion that gouge seams a foot or more in thickness may be the result of movements, probably not all in the same direction, whose net displacement may be less than 50 feet. Some of the more conspicuous fissures that have affected the ore bodies, particularly those cut in underground workings, will now be described.

FAULTS EXPOSED IN THE MIAMI MINE.

The Miami fault affects conspicuously the surface distribution of the rocks in the Miami district and has been fully described in the chapter on the local geology (pp. 112-114). As there shown, it definitely limits the Miami ore body on the southeast, although, as a rule, the ore instead of extending quite to the main gouge seam stops at one of the many subsidiary fissures in the footwall of the principal fissure.

A part of the movement along the Miami fault fissure—it is believed the greater part—has taken place since the major concentration of the ore by enrichment. Consequently it is highly desirable, in view of the probable existence of ore to the east of it, beneath the conglomerate and perhaps beneath dacite also, that the direction of movement along this fault, as well as its throw, should be known. Indeed, for practical purposes the direction is more important than the amount of throw, for after a drill hole has been put down through 2,000 feet or more of conglomerate, miscalculation as to the depth of the ore is less vital and more easily rectified than the mistake of boring in the wrong locality. Unfortunately no means have yet been discovered to determine whether the slip of the fault has been straight down the dip or whether there has been a large lateral movement to the northeast or southwest. The prospector is more or less in the dark whether to drill east of the fault, in the line of prolongation of the Miami-Inspiration ore bow, or whether to try his fortune a considerable distance north or south of that line.

Another fault or fault zone, not recognized on the surface, limits in part the ore body on its northeast side. This fault strikes about N. 48° W., and its source is thus nearly at right angles with that of the Miami fault. The fault can not be satisfactorily studied, for wherever drifts penetrate it the work as a rule is stopped, and masses of tough gouge soon fall into the drift and block access to the face, or, if the drift is carried through the fault zone, close lagging is necessary and inspection of the fault is thereby prevented. Such individual gouge seams as could be seen generally dip to the northeast, but the position of the fault on the different levels indicates that on the whole the zone of fissuring is nearly vertical. On the 345 and 370 levels this fault zone limits the ore sharply, the ground northeast of the fissure being rusty leached "capping." What appears to be the same fault zone is found also on the 420 level, but here some ore occurs northeast of it. This ore in turn is cut off by a nearly parallel fissure about 300 feet northeast of the first. Apparently in this part of the mine the barren leached material is stepped down to the northeast by two or more faults, very much as has been described on page 114, for the Miami fault. In consequence of this structure, a fault which on an upper level cuts off the ore and seems to have considerable structural and economic importance may on a lower level appear merely as an apparently insignificant fissure within the ore body.

A fissure containing abundant gouge, in places 4 feet thick and apparently rather more persistent than most fissures that traverse the ore body, is exposed at many places on the 345, 370, and 420 levels. It has a curved strike, concave to the northeast, and is shown just east of the No. 2 shaft in Plate XXXII. The displacement along this fissure has not been ascertained, and, so far as known, the fault has had little or no influence in determining the shape of the ore body.

There are a considerable number of fissures in the ground between the main Miami ore body and the Captain ore body. Most of them strike nearly northwest and dip northeast. In some places they separate ore in schist on the northeast from unenriched granite porphyry on the southwest. It has not proved practicable to trace individual fissures of this zone for great distances or to ascertain the displacement effected by any one of them. Along most of them the downthrow is apparently to the northeast, and they appear to belong to a northwesterly fault zone that has dropped the ore and overlying oxidized material of the Pinto and Miami ore bodies below the level of corresponding materials in the Captain ground. The fault zone appears from its position on the 320, 345, 370, and 420 levels to dip 40°–45° NE. The throw is probably from 250 to 300 feet but has not been accurately determined.

This fault is approximately in line with the Pinto fault, shown in Plate XXXIX, between schist and dacite just northeast of Inspiration, and may be identical with it. Probably also it coincides at the surface with the northeast contact of the strip of porphyry between the No. 1 and No. 2 shafts of the Miami mine shown as a fault on Plate XXXIX. Apparently the Pinto fault is offset by a younger fault north of the Joe Bush shaft, but the surface exposures do not afford altogether satisfactory proof of this relation.

The Captain ore body on the 80, 135, 190, 270, 345, and 370 levels is limited on its east side, at least in part, by a zone of fissuring which as a whole strikes nearly north but is curved with the concavity to the east. The individual fissures have considerable diversity of dip, but the general dip of the zone is west and appears to average from 70° to 75°. The dominant fissure of the zone at any particular place generally shows from a few inches to a foot of tough gray gouge. The direction and amount of throw on this fault zone are not known, but apparently the movement was normal, the country on the west of the fissure having gone down relatively to that on the east.

FAULTS EXPOSED IN THE INSPIRATION MINE.

In the Inspiration mine the only faults that are known to have been effective in determining the shape or extent of the ore body are the Joe Bush and Bulldog faults. These have been described on page 114. Numerous other fissures have been cut in the underground workings, some of which are locally conspicuous and contain thick seams of gouge. It has not proved practicable, however, to trace these for any great distance or to ascertain what effect they may have on the form or structural relations of the ore body.

Drifts in the Inspiration mine that extend west of a line drawn north from the Colorado shaft pass into ground that is greatly disturbed and is traversed by fissures containing much gouge. These gouge seams dip generally at rather low angles to the east and are probably a part of the Bulldog fault zone. If so, their position on these levels with reference to the outcrop of the fault zone indicates a general easterly dip of about 33° for the fault zone as a whole.

On Plate XXXIX is shown a fault that crosses Webster Gulch near Inspiration and drops dacite against schist. This fault, locally known as the Pinto fault, is thought by some to account for the greater depth of the ore in the Pinto lobe as compared with the main Inspiration ore body. This is possible, but so little underground work has yet been done on the Pinto ore body that the supposed effect lacks complete demonstration. As previously pointed out, the Pinto fault may be the same as the fault between the No. 1 and No. 2 shafts of the Miami mine.

FAULTS EXPOSED IN THE KEYSTONE MINE.

The Keystone exploratory workings as seen in 1912 showed few steeply inclined fissures but many nearly horizontal ones dipping in various directions. Most of those seen are of uneven undulatory character, and many contain thick seams of gouge. Similar low-angle, rolling fault fissures were noted in the Mercer and Woodson tunnels and appear to be particularly characteristic of the ground just west of or in the footwall of the Bulldog fault zone.

FAULTS EXPOSED IN THE LIVE OAK MINE.

The complex faulting as exposed at the surface near the Live Oak mine has been described on page 115. At the time of my last visit underground work in this mine had not progressed far enough to throw any additional light on this structure. It will probably be found that the shape of the ore body is modified considerably by faults, and possibly the ore, instead of dipping rather regularly to the southwest, as shown in sections constructed from drill records, is in reality stepped down by faulting.

AGE OF FAULTS IN THE MIAMI DISTRICT.

Probably along very few of the faults in this district has the total displacement been effected instantaneously or by a single continuous movement. Much more commonly the movement took place slowly and extended over a long period of time or proceeded by a series of jumps separated by intervals of rest. Between these two kinds of movement the faults, could we watch their development, would probably show a complete series of gradation. The movement along a fault fissure, moreover, may change in kind as well as in rate. At any one place it may take a new direction or even be reversed. Such being the conditions, striae are likely to record only the very latest movement, although of course large grooves or corrugations in the solid rock walls of a fissure may act as a sort of rifling and force subsequent movement into the initial direction. In view of these considerations, it can readily be seen that although it may be possible to show that some movement along a fault has taken place at a time determinable with reference to certain other geologic events, it is rarely possible to learn from a study of the fissure whether this movement corresponds to the whole of the displacement or to ascertain when faulting began.

No evidence has been found to indicate that any of the faults exposed in the Miami district are older than the original or hypogene metallization. Some of them may have been in existence before enrichment began; but this, if a fact, is exceedingly difficult to establish, for while it is believed, as is more fully set forth on page 173, that most of the supergene enrichment took place before the development of the existing topography, the process in all probability has been going on at a lessened rate to the present day. Consequently a fault may be earlier than some enrichment and yet be later than most of it. That most of the faults are later than the beginning of enrichment is indicated pretty clearly by the occurrence in their gouges of rounded fragments of chalcocitic ore and of crushed, oxidized material evidently derived from the leached rock that overlies the ore. The Miami fault and some of those near the Live Oak mine cut dacite and Gila conglomerate—rocks which, as elsewhere shown, are probably younger than most of the enrichment.

FAULTS EXPOSED IN THE RAY MINES.

The schist in the metallized area at Ray shows, at the surface, abundant small fault breccias, many of which are rusty and so well indurated as to be nearly as hard as the neighboring schist. Only two breccia zones, those of the Sun and Sharkey faults (see Pl. XLV), can be traced with confidence for any considerable distance.

In the mine workings gouge-filled fissures are fairly abundant, but no means have been discovered for determining the kind and amount of displacement along any one of them, and from a practical point of view any effect these fissures may have had in determining the present shape of the ore bodies appears to be negligible. Most of them are probably younger than at least the hypogene metallization, but may have had some influence in directing the course of the generally downward-moving solutions that effected the enrichment.

The Sharkey fault (Pl. XLV) crosses the area of metallized schist in a general northwesterly direction. It probably coincides with a zone of fissuring in the saddle of Emperor Hill but has not been definitely traced south of Copper Canyon, and is not well exposed on Emperor Hill save in the saddle mentioned. East of Humboldt Hill the fault is marked by a fairly strong outcrop of rusty breccia and hard gouge. The main fissuring appears to run through the saddle southwest of the Sharkey shaft, as shown in Plate XLV, and to continue on toward the Flux shaft. The schist in this vicinity, however, is so disturbed and altered and so cut by minor faults as to obscure the course of the main fissure. The dip of the fault is not evident at the surface, and the fissure zone has not been satisfactorily identified underground. From its apparent position on the 1925 level the fault fissure supposedly dips northeast at a somewhat greater angle than the Sun fault.

The gouge of the Sun fault is, as a rule, so well indurated as to form a fairly hard rock, specimens from which can be knocked off with the hammer and trimmed in the usual manner for rocks. In places it consists chiefly of fragments and fine detritus of schist. In other places the gouge material is chiefly crushed and decomposed granite porphyry. Some of it contains abundant small grains of pyrite superficially altered to chalcocite. These appear to have formed and to have been enriched in their present positions. In places the fault zone comprises a number of seams of this indurated gouge separated by slabs of schist. Similar nearly parallel seams of hard gouge also occur in the schist at considerable distances from the main zone.

The characteristics of the Sun fault zone indicate that it is older than the fissures containing soft gouge that are exposed in the No. 1 mine. It shows no signs of recent movement and probably antedates the major enrichment of the ore bodies and possibly also the hypogene metallization.

As a rule the ore in and near the Sun fault zone is a little richer in copper than the average ore of the mine, but the difference is not very marked and the fault does not appear to have had much influence in determining the shape of the ore body. The ore shows no particular tendency to extend out along the fault.

On the levels now opened in the No. 2 mine the Sharkey fault is chiefly in oxidized, leached ground, and little information concerning the relations to the ore of this fissure, or, more probably, zone of fissuring, could be obtained.

FAULTS IN THE RAY HERCULES GROUND.

The fault east of Ray, described on page 129, which brings diabase and dacite on its northeast side against schist and granite porphyry on its southwest side, apparently has dropped the part of the ore body lying east of it from 350 to 400 feet lower than the ore to the west. Too little, however, is as yet known of this ground to permit any detailed description of the relations below the surface. The displacement along this fault apparently took place after the period of principal enrichment, and such ore as may be present east of the fissure undoubtedly lies deep, as shown by the fact that most of the drill holes in that part of the area range from 700 to 1,150 feet in depth.

RELATION OF HYPOGENE METALLIZATION TO FAULTING.

In neither the Ray nor the Miami district does the hypogene metallization appear to have followed regular or systematic zones of fissuring. Some general disturbance and fracturing of the whole rock mass there undoubtedly was, and the many small irregular fissures that resulted were afterward filled with quartz and pyrite and, in much smaller amount, chalcopyrite and molybdenite. These fillings, however, are what are commonly referred to as stringers or veinlets rather than veins and have little individual persistency.

CHAPTER IX.—PROTORE, ORE, AND CAPPING.

DEFINITIONS.

That the ore bodies of the Ray and Miami districts were formed by a process of enrichment acting upon material that originally contained but very little copper is generally recognized. This material is commonly referred to as "primary ore," but of course it is not ore at all in the true sense of that word, nor is most of it likely to become ore by any improvements in mining and milling that can at present be foreseen. To designate this primitive ore stuff concisely and accurately, without using "ore" in an undesirably loose sense, apparently requires a new term, and the word "protore" (first or primitive ore) has been suggested [1] as likely to be a serviceable substitute for the unsatisfactory and periphrastic expressions that have hitherto been current.

Obviously, the derivation of this term momentarily ignores the distinction which is aimed at. This inconsistency, however, does not appear to be important so long as the result is a convenient word which suggests but can not be confounded with "ore." "Protore" by definition, then, is used in connection with ore bodies due to sulphide enrichment, to designate the metallized rock or vein substance which is too low in tenor to be classed as ore but which would have been converted into ore had the enriching process been carried far enough.[2] This frees the expression "primary ore" for its proper application to unenriched material that can be profitably mined. The term "protore" is intended to apply also to the material which has been converted into ore by enrichment and which therefore no longer exists. It might be objected that this material was perhaps different from the pyritized rock underneath the present ore bodies, containing possibly more chalcopyrite, and that it became ore because of that original difference. To some extent and in certain places this may be true, but refinement of terminology may be carried so far as to be a hindrance rather than a help in the communication of ideas, and such, it is believed, would be the result if a second new term were introduced to express this possible rather than demonstrable distinction.

It will be observed, moreover, that "protore" as here defined does not exclude material that may have undergone incipient enrichment. As a matter of fact, it has proved unexpectedly difficult in the mines at Ray and Miami to obtain samples of metallized rock that are entirely free from enrichment. Most of the so-called primary ore, when closely examined, shows the presence of some chalcocite, usually as thin films on crystals of pyrite. To distinguish by a separate name such material from the wholly unmodified protore into which it grades would probably also be an unnecessary refinement.

In practice it will be sufficiently accurate under present economic conditions to refer to rock carrying less than 1.3 per cent of copper as protore, while that containing 1.3 per cent or more of copper will be classed as ore. Such usage will class with the protore some considerably enriched material, but this will be a small quantity compared to the total bulk of the unenriched rock. The limit here set is not inconsistent with the fact that some material of lower grade goes to the mills, for in mining by a caving system ore is to some extent mixed with waste. The limit, moreover, is not the same in all mines, some calculations of tonnage being based on 1.5 per cent as the lower limit of ore—a figure which is used in many places in this report. It also shifts with changes in the price of copper when these exceed the ordinary fluctuations and maintain their departure from the normal over any considerable time.

The choice of the word "capping" to designate the leached, practically barren over-

[1] Ransome, F. L., Econ. Geology, vol. 8, p. 721, 1913.
[2] The use of the term is not necessarily restricted to rock that contains sulphides. See Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 68, 1917.

burden is simply an adoption of local usage. The term is not ideal, but it does not appear so objectionable as to make the coining of a new word necessary or desirable.

COPPER CONTENT OF PROTORE.

The average copper content of the wholly unenriched protore is susceptible only of a rough determination from the data available. The record of any drill hole that goes through an ore body into protore usually includes a statement of the lowest point at which chalcocite was found in the drill sludge. At or near this point there is, as a rule, a marked drop in the assays, which continue uniformly low to the bottom of the hole. When, however, the attempt is made to separate the assays representing protore from all others, uncertainties at once arise. The passage from ore to protore may be gradual, and assays showing more copper than is apparently normal for protore may continue for some distance below the recorded disappearance of chalcocite. The protore, moreover, is not uniform in tenor and in places contains enough chalcopyrite to make it nearly or quite of ore grade. Consequently, when in a drill record a few comparatively high assays appear in material that is chiefly protore, it is not always possible to determine from the record whether the high assays represent slight local enrichment or unusually high-grade protore. In many drill records the assays continue to show below the point where chalcocite is reported as having disappeared, a general decrease in copper downward to some point below which they remain fairly constant. This may mean slight enrichment below the last chalcocite recognized by the drill sampler, it may mean the carrying down of chalcocite from above in the sludge, or it may mean that the protore at this place originally graded downward from higher-grade into lower-grade material.

As a whole, the protore of the Miami district appears to be richer in copper than that of the Ray district, and the protore under the main ore body of the Miami mine contains decidedly more copper than most of the protore that has not been converted by enrichment into ore.

The average of 126 assays of diamond-drill cores from material under the Miami ore body, which according to the records of the Miami Copper Co. showed no chalcocite, is 1.18 per cent of copper. The average of 57 assays of what appeared to be typical protore under the Ray ore body gave 0.50 per cent, and of 34 assays of similar material under the Live Oak ore body 0.39 per cent. The average of 204 assays from drill records, chiefly of material under the Captain ore body of the Miami Co., is 0.58 per cent, and of 215 assays from the records of churn-drill holes on Miami property but for the most part outside of the area of the principal ore bodies, 0.69 per cent.

Owing to the fact that when a churn-drill hole is put down through ore into protore, more or less chalcocite is carried down as sludge from the ore above, the first few assays of the protore are likely to be a little high. Spurr and Cox, in their report to the Ray Consolidated Copper Co., basing their results on the data from nine drill records, give the average assay for protore as 0.32 per cent of copper. They deduct from this 10 per cent as an allowance for extraneous chalcocite from the upper parts of the holes, giving 0.29 per cent of copper as the true average for Ray protore. This probably is a little low. An examination of all the Ray Consolidated Co.'s drill records leads to the conclusion that below the point where the copper shows any progressive decrease, and presumably therefore below any natural or artificial enrichment, the protore averages from 0.4 to 0.5 per cent of copper. Unenriched diabase at Ray generally contains considerable visible chalcopyrite, and appears to be on the whole richer in copper than the schist protore. To test this apparent fact six samples of diabase showing no evidence of enrichment and taken from places in the No. 1 mine below the ore body were assayed by Mr. W. S. Osborn, the chemist of the Ray Consolidated Copper Co., with the results shown below:

Assays of diabase protore at Ray.

Locality in No. 1 mine.	Per cent of copper.
1970 west level, N. 11 W.	0.9
1970 west level, N. 12 W.	.9
Second (1917.7) level, main drift, 10 W.	.7
Second (1917.7) level, main drift, 12½ W.	.6
Second (1917.7) level, main drift, 1¼ S. 500 W.	.8
Third (1773) level, 3½ N. 5 W.	1.0
Average	.8

There seems to be no reason why such material, if favorably situated with respect to descending solutions, should not be enriched and converted into excellent ore. That it has not been changed to ore in the ground opened by the No. 1 and No. 3 mines appears to be due to its position with reference to the surface and to the presence of gouge at its upper contact with the schist, which prevented free descent of copper-bearing waters.

The protore at both Ray and Miami may be metallized schist or metallized granite porphyry, but in both districts the metallized schist is by far the more abundant variety and will be first described.

SCHIST PROTORE.

The metallized schist does not differ conspicuously in appearance from the normal Pinal schist. On the whole it is perhaps a little lighter in color, and none of it has the bluish tint that is exhibited by some varieties of this rock at a distance from the ore bodies. The features that especially distinguish it are the innumerable veinlets, carrying quartz and pyrite, that traverse the rock in all directions, the presence of pyrite disseminated rather generally through the mass of the schist, and consequently a prevalent rusty hue on weathered surfaces. A few of the quartz-pyrite stringers attain a width of 6 inches or more, but as a rule they are smaller and range from mere films, scarcely visible to the unaided eye, up to little veinlets a quarter of an inch wide. These veinlets have no regularity of arrangement but run in all directions with little or no regard to the planes of schistosity.

Pyrite is by far the most abundant and widespread sulphide of the protore but is generally accompanied by a little chalcopyrite and in some places by molybdenite.

In many samples microscopic examination of the concentrates panned from the crushed material shows more or less chalcocite, usually in very thin dark films on the pyrite. That the black material is chalcocite may be clearly shown by making use of the reaction between that mineral and a dilute solution of silver sulphate described by Palmer and Bastin.[1] If a particle of pyrite showing some of the black coating is placed under the microscope and covered by a drop of the silver solution, metallic silver is reduced at once and delicate feathery crystals of silver may be seen sprouting out from the chalcocite surface, while the solution becomes tinted with copper sulphate.

The chalcopyrite is important, for from the destruction of this mineral probably came nearly all the copper in the present ore bodies, although doubtless some was derived from apparently homogeneous pyrite. As a rule, however, chalcopyrite is present in surprisingly small quantity, and in much of the protore chalcocite is the only cupriferous mineral recognizable. It becomes necessary to conclude that much of the protore, before any enrichment whatever took place, contained exceedingly little copper, certainly less than has been sometimes supposed. The molybdenite is rarely visible in the schist protore but has been identified at a few places and is probably distributed widely through it in small quantity. It is more abundant in the porphyry protore.

The pyrite, chalcopyrite, and molybdenite have been deposited mainly with the quartz in the small fissures, but there is considerable pyrite, generally in very small crystals, disseminated through the substance of the schist. On the whole, however, the commonly applied name "disseminated ore" is likely to be a little misleading unless it is understood that the dissemination is due to the minute and dispersive character of the fissuring and veining much more than to the development of sulphides in isolated grains throughout the rock mass.

Under the microscope in thin section the protore appears of simple mineral composition. The dominant constituents are quartz and sericite in fine-grained aggregation, and the schistose structure consists of an alternation of layers in which sericite predominates with those in which quartz is the more abundant mineral. These two minerals and the sulphides previously mentioned are generally accompanied by a little biotite and chlorite, a few rounded crystals of zircon, and sparse minute granules of epidote.

The chemical composition of typical schist protore is shown by five analyses in the following table. With them are placed for comparison four analyses of unmetallized Pinal schist. All the analyses were made in the chemical laboratory of the United States Geological Survey.

[1] Palmer, Chase, and Bastin, E. S., Metallic minerals as precipitants of silver and gold: Econ. Geology, vol. 8, p. 146, 1913.

Analyses of schist, protore, and ore.

	Schist.				Protore.					Ore.			
	1	2	3	4	5	6[a]	7[b]	8	9	10[c]	11[d]	12	13
SiO_2	65.58	66.84	72.87	61.62	78.91	71.28	68.20	66.92	63.70	69.35	68.52	70.63	63.04
Al_2O_3	16.47	17.46	12.89	19.98	10.76	13.53	16.61	19.23	19.53	12.96	15.35	14.02	17.82
Fe_2O_3	4.19	4.88	2.40	3.46	.81	.61	1.26	.54	3.49	.22	1.02	2.47	2.36
FeO	2.25	.74	1.76	2.57	1.64	1.00	1.27	.99	1.24	.90	.67	.95	.89
FeS_2					.20	4.86	1.26	1.40	.39	4.98	2.03	.52	.99
Cu_2S					.05	.97	.80	.79	.15	2.85	3.18	2.56	3.15
MgO	1.29	1.14	.82	1.24	1.66	.41	1.04	.97	1.60	.34	.21	.70	.58
CaO	1.29	.37	1.90	.62	.25	.17	.27	.27	.41	.18	.07	.13	.13
Na_2O	1.42	.53	3.01	1.78	.16	.31	.73	.39	.46	.80	.41	.41	.62
K_2O	4.58	4.65	3.03	5.35	3.44	3.81	5.39	5.61	5.08	5.02	5.74	4.93	6.58
H_2O below 110°	.22	.17	.26	.21	.20	.31	.64	.24	.19	.13	.24	.14	.20
H_2O above 110°	2.27	2.61	.24	2.23	1.94	1.90	2.37	2.45	3.43	2.25	2.03	2.41	2.37
TiO	.83	.67	.66	.56	.27	.47	.51	.58	.65	.43	.54	.61	.85
ZrO_2					.04	.01	None.			None.	.02		
CO_2					Tr.		None.						
P_2O_5	.06	.03	.13		.14	.09	.11	.08	.08	.13	.06	.13	.11
SO_3						Tr.	None.			Tr.	None.		
NiO					None.								
MnO	.06	.02	.07		.04	None.	.01	Tr.	.01	None.	None.	.01	.01
BaO						.07	.16			None.	.05		
Li_2O				Tr.	Tr.								
	100.51	100.11	100.44	99.62	100.51	99.80	100.63	100.46	100.41	100.54	100.14	100.62	99.60

[a] Sample contained about 0.32 per cent of metallic iron, probably introduced in sampling and excluded from analysis as calculated.
[b] Sample contained about 0.29 per cent of metallic iron, probably introduced in sampling and excluded from analysis as calculated.
[c] Sample contained about 0.56 per cent of metallic iron, introduced in sampling and excluded from analysis as calculated.
[d] Sample contained about 0.09 per cent of metallic iron, probably introduced in sampling and excluded from analysis as calculated.

1. Pinal schist (Ry. 332). South slope of the Red Hills, Ray district. George Steiger, analyst.
2. Pinal schist (M. 3). North side of Webster Gulch, 1,500 feet west of the Warrior mine, Miami district. George Steiger, analyst.
3. Pinal schist (Ry. 345). Probably metamorphosed rhyolite. Three-quarters of a mile north of summit of Granite Mountain, Ray district. George Steiger, analyst.
4. Pinal schist (Ry. 348). One mile west of Sonora, Ray district. Close to granite porphyry contact. R. C. Wells, analyst.
5. Metallized schist or protore (Ry. 361). No. 1 mine, 1912 (second) level, west of ore body, Ray district. R. C. Wells, analyst.
6. Metallized schist or protore. No. 2 mine, 2,190 level, at 54 west and 4½ north (mine coordinates), Ray district. R. C. Wells, analyst. Sample furnished by Ray Consolidated Copper Co. Mine assay gave 1 per cent of copper.
7. Metallized schist or protore. No. 1 mine, 2,075 or adit level, at 4½ south and 1½ west, Ray district. R. C. Wells, analyst. Sample furnished by Ray Consolidated Copper Co. Mine assay gave 0.8 per cent of copper.
8. Metallized schist or protore. Inspiration mine, Joe Bush shaft, 3350 station, Miami district. Chase Palmer, analyst. Sample furnished by Inspiration Consolidated Copper Co.
9. Metallized schist or protore. Inspiration mine, Scorpion shaft, 3480 station, Miami district. Chase Palmer, analyst. Sample furnished by Inspiration Consolidated Copper Co.
10. Ore. No. 2 mine, 1925 sublevel, 12½ north and 46½ west, Ray district. R. C. Wells, analyst. Sample furnished by Ray Consolidated Copper Co. Mine assay gave 1.81 per cent of copper.
11. Ore. No. 1 mine, 1940 level, 5½ south and 9½ west, Ray district. R. C. Wells, analyst. Sample furnished by Ray Consolidated Copper Co. Mine assay gave 2.65 per cent of copper.
12. Ore. Miami mine, 420 level. Chase Palmer, analyst. Sample furnished by Miami Copper Co.
13. Ore. Miami mine, 570 level. Chase Palmer, analyst. Sample furnished by Miami Copper Co.

NOTE.—The sulphides present in the protore are pyrite, chalcopyrite, and chalcocite in various proportions. Theoretically there should be no chalcocite in the protore, but it has been found that even material containing so little copper as that of analysis 7 contains a little secondary chalcocite as films on pyrite. It has proved unexpectedly difficult to obtain protore entirely unaffected by enrichment. As it is impracticable to determine in every sample how much of the contained copper is present in chalcopyrite and how much in chalcocite, some assumption is necessary to secure uniformity in the statement of the analyses. The present analyses are brought into form for comparison by calculating all the copper as chalcocite and deducting sufficient iron from that determined as Fe_2O_3 to combine with the remainder of the sulphur as pyrite. In analyses 10 to 13 this statement probably accords very closely with fact, while in the samples represented by analyses 5 to 9 there is probably more or less chalcopyrite present with the chalcocite. For reasons explained in the text, not much reliance can be placed on the state of oxidation of the iron as presented in the analyses.

Analyses 1 and 2 were made on as nearly typical unmetallized schist as could be obtained in the two districts. The rock corresponding to analysis 3 is an exceptional variety of the schist, probably an altered rhyolite, and that corresponding to analysis 4 has been affected mineralogically by the intrusion of the quartz monzonite porphyry of Granite Mountain. Analysis 5 was made on a fragment collected mainly to show the general character of the metallized schist, and analyses 6 to 9 were made on large samples of supposedly "primary ore" carefully collected for that purpose by the mine samplers. The samples were crushed and a small portion cut out for the analyst in the usual way. These analyses are thus probably more representative of the protore as a whole, including the veinlets, than analysis 5. The samples on which analyses, 6, 7, 10, and 11 were made all contained a little metallic iron in minute shredlike particles. This iron or steel probably came from the tools used in sampling or grinding. It was extracted from the powder with a magnet, its proportion to the whole sample determined, and allowance made for it in the final calculation of the analyses.

The accurate determination of the state of oxidation of the remaining or combined iron in the samples presented insurmountable difficulties. In the first place, some of the ferrous iron was oxidized in the grinding of the samples and during the time that elapsed between grinding and analysis. In the second place, the sulphides present, particularly chalcocite, exercise a marked reducing action on the potassium permanganate solution used in titrating for ferrous iron. As it has not proved practicable to determine for each sample the relative proportions of pyrite, chalcopyrite, and chalcocite present, the corrections made for the reducing action of the sulphides have necessarily been only approximations. Consequently the relative proportions of ferric and ferrous oxide as given in the analyses of the sulphide-bearing rocks can not be implicitly relied on.

Another difficulty in presenting the analytic results springs from the probable presence, in most of the samples, of chalcopyrite together with chalcocite. If it were possible to determine for each sample exactly how much of the copper is present as chalcopyrite and how much as chalcocite then the iron, copper, and sulphur, as determined by the analyst, might be properly proportioned between ferric oxide, pyrite, chalcopyrite, and chalcocite and so stated in the analysis. But this has not proved to be practicable. It might at first glance be supposed to be a simple matter to express the analyses in terms of ferric and ferrous iron, metallic copper, and sulphur, subtracting from the total the oxygen equivalent of the sulphur, but here again the quantity of oxygen to be subtracted depends upon a knowledge of the quantity of chalcopyrite present. In view of these facts it has seemed best to state the analyses uniformly by calculating all the copper as chalcocite and by deducting sufficient iron from that determined as ferric oxide to combine with the remainder of the sulphur as pyrite. In analyses 10 to 13 this form of statement probably accords closely with fact, but analyses 5 to 9 presumably should show some chalcopyrite present with the chalcocite.

The most noticeable feature in these analyses is the slightness of the difference in chemical composition between schist, protore, and ore. The metallized schist is distinctly lower in soda than the unmetallized schist. It averages a little higher in potassa—4.66 per cent, as against 4.40 per cent—but this difference is too small to be accepted as significant in view of the fact that some analyses of protore show considerably less potassa than some analyses of schist. The protore and ore, of course, have had copper and sulphur added, but it is difficult to detect any other important difference. When the iron, given as oxides and sulphide in the analyses, is, for the sake of comparison, all calculated as metallic iron, the results are as follows:

	Iron (Fe).	
Analysis 1	4.68	Schist, average 4.03.
2	3.98	
3	3.04	
4	4.42	
5	1.93	Protore, average 2.65.
6	3.48	
7	2.46	
8	1.80	
9	3.61	
10	3.17	Ore, average 2.69.
11	2.18	
12	2.71	
13	2.73	

So far as they go, these analyses show that metallization in copper is accompanied by loss in iron—a rather surprising result. Of course, such a comparison, to be reliable, should be based on a large number of analyses of carefully collected material. All that can be safely concluded from the few analyses given is that the quantity of iron added in the process of metallization was probably not large, the pyrite having been formed chiefly from iron previously present in the rock as magnetite and ferriferous silicates. The analyses of protore are fairly representative, although in analyses 4, 5, and 6 the copper is rather high, and the samples may have contained a little chalcocite. That there should be more iron in the ore analyzed than in the protore is also an unexpected result, as presumably in the enrichment to ore some of the iron is removed as chalcocite is deposited.

PORPHYRY PROTORE.

Like the schist variety, the porphyry protore is traversed by countless small irregular veinlets running in all directions and intersecting at all angles. The walls of these stringers may be fairly sharp, but commonly the adjacent rock is silicified, so that of the once angular fragments into which the porphyry was divided by the fissuring only rounded kernels of comparatively unaltered rock remain. Although these kernels are spoken of as comparatively unaltered, they are by no means fresh. They retain the general porphyry texture and they are speckled with sparkling and apparently fresh biotite, but the feldspars are dull and decomposed and the whole kernel is soft and friable. As in the schist protore, the quartz stringers carry pyrite, chalcopyrite, and molybdenite, but the exposures available indicate that both chalcopyrite and molybdenite are more abundant in the porphyry than in the schist. This suggests that, although the bulk of the ore is now in schist, the metallized porphyry was excellent raw material for the enriching process to work upon and in places probably contributed a large quantity of copper to the ore bodies now in the schist. The silicification of the porphyry was accompanied by the development of much sericite and by the dissemination of pyrite and, to a less extent, chalcopyrite and molybdenite through the substance of the altered rock.

The microscope shows that the formation of the sulphides in the granite porphyry has been accompanied by the general conversion of the rock to an aggregate consisting almost exclusively of quartz and sericite. The process has involved considerable recrystallization, and as a rule in rock where the biotite has disappeared the porphyritic quartz and an occasional small zircon are all that remain of the original constituents. Even the quartz phenocrysts have been attacked and partly replaced, some by sericite and some by secondary quartz. Such alteration apparently has required the addition of silica, sulphur, copper, and molybdenum and the subtraction of magnesia, lime, and soda. It suggests also the addition of potassa and iron, but the comparison of the analyses of schist tabulated on page 159 has rendered this supposition doubtful.

Where the biotite has not disappeared much of the altered rock is so fragile that satisfactory thin sections can not be cut from it. Here sericite and in some facies kaolinite are much more abundant than in the harder and more siliceous varieties.

In both districts considerable parts of some of the granite porphyry masses are fractured and veined with quartz, and their feldspars are altered to sericite or kaolinite or aggregates of these two minerals, but sulphides are lacking and apparently were never deposited. Where, as in these rocks and in the protore, kaolinite occurs in association with sericite, it is the older mineral and has been metasomatically attacked by the sericite. (See p. 138.)

ORE.

GENERAL CHARACTER OF THE SULPHIDE ORE.

The sulphide ore very closely resembles the protore, being in general a pale rock that, were it not for the speckling and veining by chalcocite would be almost white (Pl. LII). In texture and structure it is so nearly identical with protore that the description given for that material can be applied to it without change and need not be here repeated.

The essential mineralogic and chemical change effected by the process of enrichment is the more or less thorough substitution of dark-gray chalcocite for yellow pyrite and chalcopyrite, this bringing about some difference in the general tint and appearance of the rock. The body or gangue, if it may be so termed, of the protore, having already been converted into quartz and sericite, a chemically stable aggregate, does not suffer much change in the alteration of protore to ore by the descending cupriferous solutions. Certain specimens of porphyry ore from the Miami mine show fresh original orthoclase, and some of the schist ore from the 900-foot level of the Live Oak mine contains green biotite. That these minerals should have persisted unchanged through the original metallization which formed the protore and through the subsequent enrichment is rather remarkable. Apparently the enrichment was effected by solutions that were neither strongly acid nor of great chemical activity.

The chalcocite, because of its dark color, brings out more conspicuously than the original pyrite the dependence of the metallization upon small fractures. Most specimens of the ore are traversed by numerous little nearly black veinlets of this mineral, intersecting at various angles, commonly without any appreciable faulting, and ranging in width from mere films to veinlets 5 or 6 inches across. Veinlets over half an inch in width, however, are exceptional. Inspection of any fragment of ore shows that the separate particles of chalcocite are not disseminated evenly through the rock but to a large extent lie in the minute cracks or joints. (See Pls. LII and LIII.) The ore tends to break along these joints, so that fracture surfaces may show more abundant chalcocite than would appear on the surfaces produced by a saw cut straight through the rock. There are also many particles of chalcocite that are not visibly associated with joints or cracks, but these probably constitute a minor proportion of the whole. Thus the term "disseminated," now almost universally applied to these ores, is not strictly or etymologically appropriate. It is, however, very convenient, and its use in this connection is probably not seriously objectionable if the fact is kept in mind that the chalcocite, while in a general sense dispersed through the substance of the rock, is not entirely scattered through it in isolated seedlike particles.

From the best sulphide ore there are gradations on the one hand to protore and on the other hand to oxidized material. In the richer ore there may be little or no pyrite, all having been replaced by chalcocite. Other kinds when cut and polished show the chalcocite to contain residual kernels of pyrite (Pl. LIII, *B* and *C*), and still others, for the most part classed as protore, show only a mere film of chalcocite on the pyrite. In the other direction the passage from sulphide ore to leached barren material is bridged by ores containing chalcocite, malachite, and chrysocolla in various proportions. A considerable part of the ore mined in the Miami district is of this mixed character.

As studied in polished surfaces by reflected light, under the microscope, the chalcocite, chalcopyrite, and pyrite show the usual relations between these minerals in ores of this general character.

As a rule whatever chalcopyrite may have been present in the protore has disappeared in the ore, having been completely altered to chalcocite. Here and there, however, a veinlet may be found in which both sulphides are associated. A polished section of such ore shows the chalcopyrite to be traversed by an extraordinarily intricate network of chalcocite veinlets, which, notwithstanding its lacelike intricacy of mesh, is more regular than the pattern resulting from the replacement of pyrite by chalcocite.

The pyrite invariably shows the minute irregular fissuring or angular granulation characteristic of that mineral. It is along these little irregular cracks, as well as peripherally, that chalcocitization begins, and all stages may be found between such beginnings and complete replacement. As a rule the residual grains of pyrite, even if much reduced in size, retain to a surprising degree their original form and angularity.

Of the characteristic shatter structure of pyrite, to which Graton and Murdoch have applied the name "exploding bomb" structure, they remark: [1]

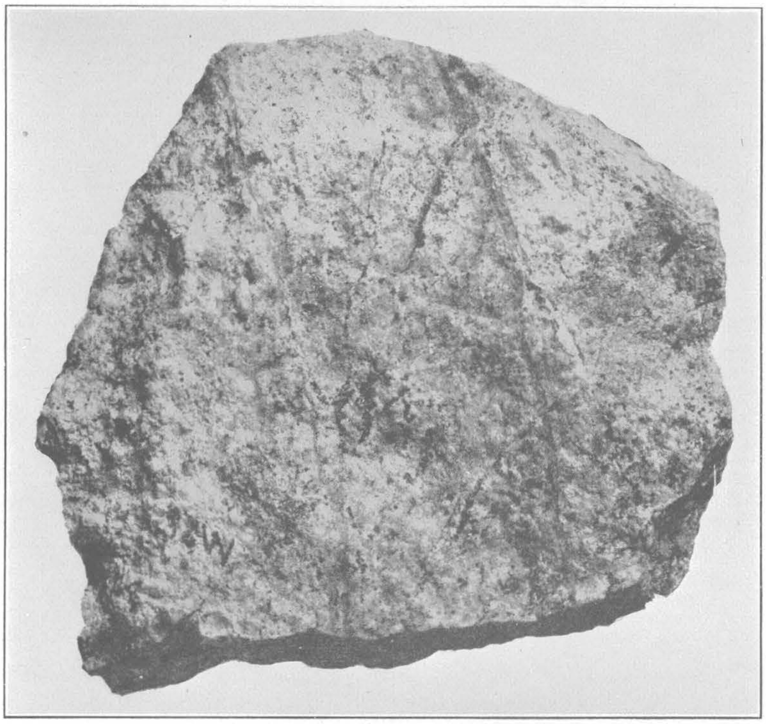
> The cause of this crushing and distortion is not yet clear, but it is plain that it took place in an early stage of crystallization of the ore, because no trace of such a thing is commonly to be found in the later sulphides or in the gangue, in the latter of which it would be expected that crushing or at least strain shadows would be seen in thin section if these materials had been subjected to stress.

In the same paper[2] they state:

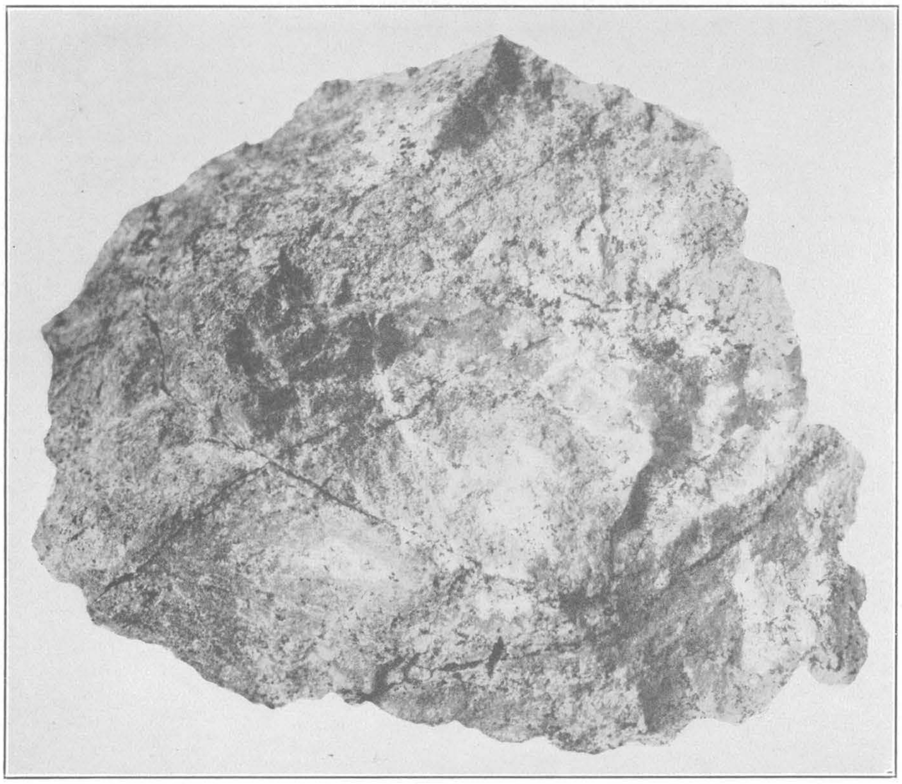
> In the average primary copper ore containing pyrite this mineral is commonly cracked and crushed and in many instances disarranged. Whatever the cause of this may be, it is not the result of external deformation after the deposition of the ore.

This conclusion is not only inherently difficult of acceptance but does not appear to be borne out by the observable relations of the pyrite to the gangue minerals in the Ray and Miami district. In most of the specimens studied the quartz near the pyrite, when examined in incident light falling at the proper angle on a polished surface, is seen to be nearly or quite as full of minute fractures as the pyrite, and many of the cracks can be followed from one mineral into the other. In

[1] Graton, L. C., and Murdoch, Joseph, The sulphide ores of copper; some results of microscopic study: Am. Inst. Min. Eng. Trans., vol. 45, pp. 26-93, 529-530, 1914.
[2] Idem, p. 67.



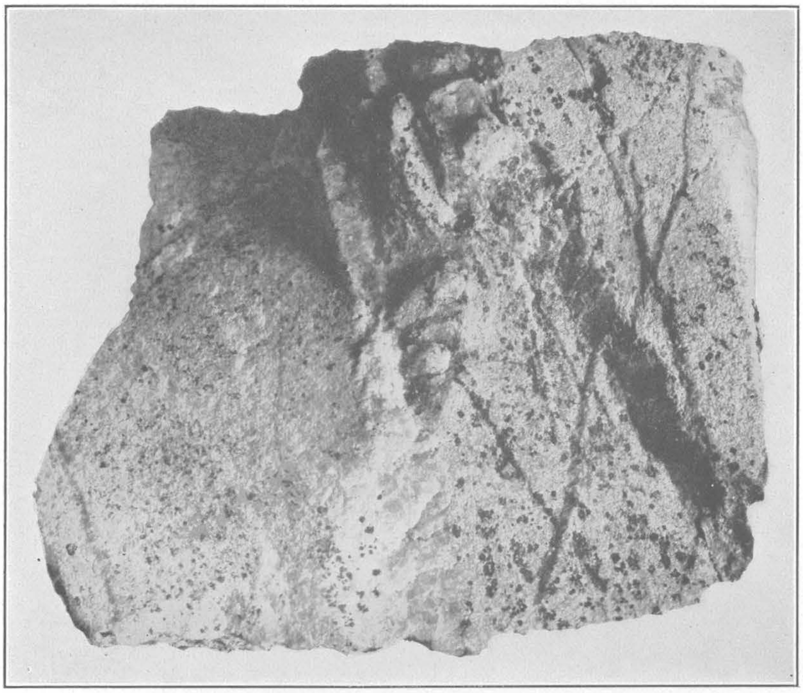
A. PORPHYRY ORE.



B. SCHIST ORE.

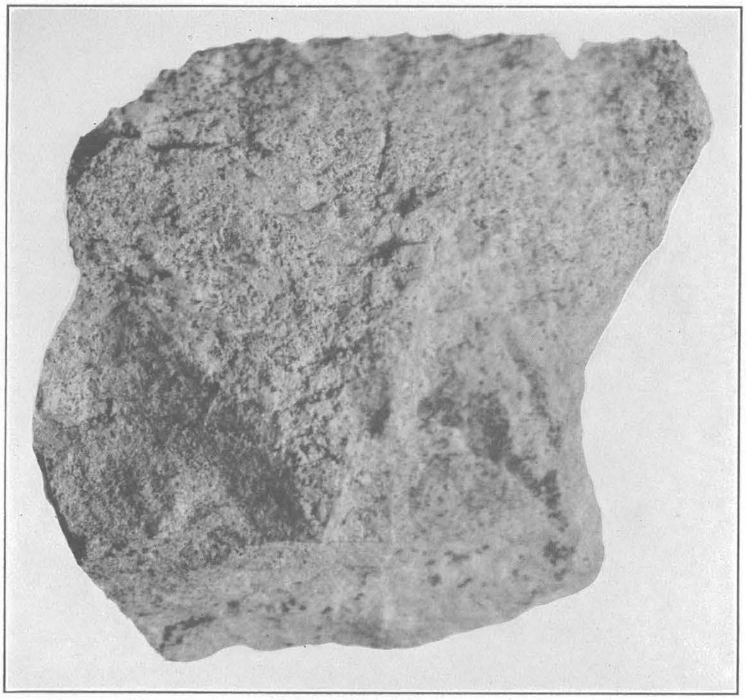
The black specks and veinlets are chiefly chalcocite.

DISSEMINATED COPPER ORE FROM 420 LEVEL OF MIAMI MINE.



A. ORE CARRYING ABOUT 2 PER CENT OF COPPER, FROM THE SECOND LEVEL OF THE NO. 1 MINE AT RAY.

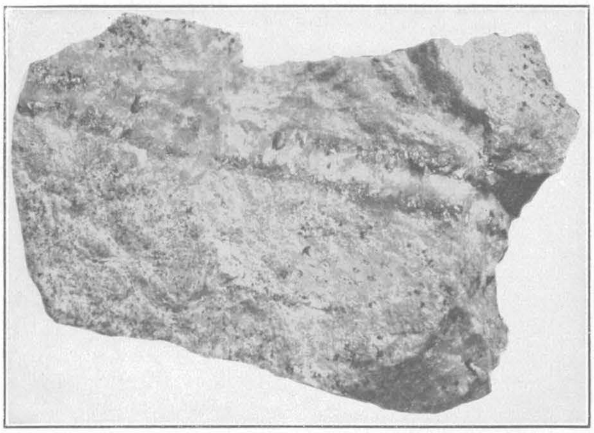
The chalcocite is rather evenly distributed in small particles through the altered schist, although some veinlets can be seen.



B. RELATIVELY HIGH-GRADE ORE, FROM THE FOURTH LEVEL OF THE NO. 3 MINE AT RAY.

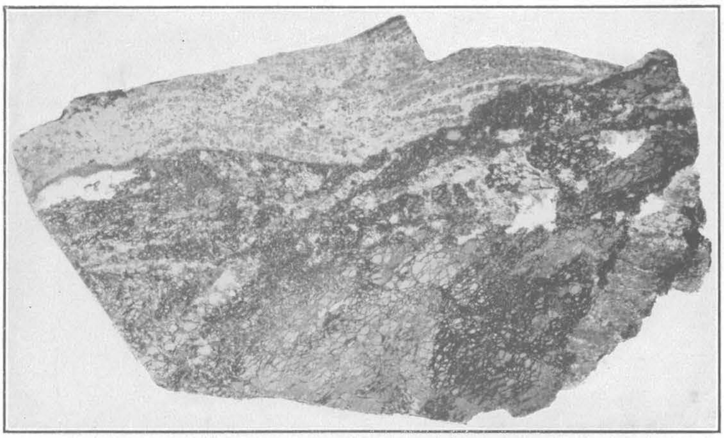
Note the veinlet of quartz, which carries a little native copper, and numerous black veinlets of chalcocite. The rock is schist.

DISSEMINATED COPPER ORE OF THE RAY DISTRICT.



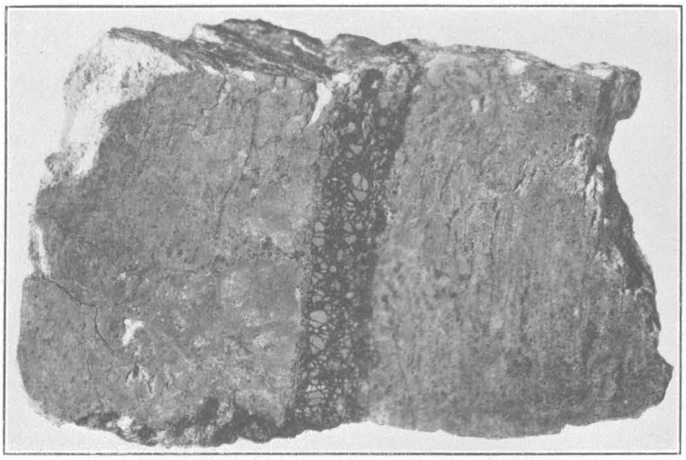
A. ORE SHOWING VEINLET OF QUARTZ WITH MOLYBDENITE ALONG ITS SIDES. FROM THE MIAMI MINE.

The scattered black specks are chalcocite in altered schist.



B. IRREGULAR MASS OF PYRITE IN ALTERED SCHIST, FROM THE NO. 1 MINE AT RAY.

Showing characteristic shatter-structure and partial replacement by chalcocite (black).



C. GOOD SCHIST ORE, FROM THE FOURTH LEVEL OF THE INSPIRATION MINE.

Showing veinlet of pyrite more than half replaced by chalcocite. Residual kernels of pyrite show light against the dark chalcocite.

partly chalcocitized protore, however, the fractures in the brittle nonmetallic minerals are much less conspicuous than those in the pyrite, the latter having been enlarged and filled by the deposition of chalcocite, which, by its contrast with the pyrite, greatly accentuates the structure. Nothing was seen in any of the specimens examined to suggest that the so-called exploding bomb structure in the pyrite is anything else than a result of stresses that have affected the whole rock.

Molybdenite, described on page 133 as a minor constituent of the protore, especially of the porphyry protore, remains unaffected, so far as can be seen, by the process of enrichment. (See Pl. LIV, *A*.)

Chemical analyses of the ore are given on page 159, where they are compared with analyses of protore and schist.

GENERAL CHARACTER OF THE PARTLY OXIDIZED ORE.

The partly oxidized ore is readily recognized by its greenish color, resulting from the change of part of the chalcocite to chrysocolla and malachite. This change may be very superficial, giving rise to little more than a brilliant stain, or it may have involved most of the chalcocite, leaving out only small residual kernels of the sulphide. In part, the malachite and chrysocolla directly replace the chalcocite, but in the process of oxidation a good deal of local migration of copper takes place, and both malachite and chrysocolla with some quartz are deposited in cracks and other small openings in the rock. The veins of chrysocolla formerly worked in the Keystone and Live Oak ground illustrate this migration on a rather extensive scale, for the fissures they occupy appear to have been filled originally with chrysocolla, not with sulphides. On the other hand, the carbonate-silicate ore of the Miami mine, which extends to a depth of about 1,000 feet under the western part of the main ore body, does not, as has been suggested,[1] indicate extensive migration of copper in solution as carbonate or silicate, for inspection of this ore shows residual chalcocite. The malachite and chrysocolla have resulted from the oxidation of the sulphide. In part these minerals have directly replaced the chalcocite (see Pl. XLVI, *C*), and in part they have been deposited in immediately adjacent openings. As a rule this oxidation was accompanied by the solution and redeposition of quartz. In some places little vugs are lined with chrysocolla, then with quartz, and finally filled with malachite. In other specimens chrysocolla, quartz, and chalcedony, intimately interlayered, have been broken and cemented by fresh quartz containing radial clusters of malachite. In still others both chrysocolla and malachite are covered by beautiful drusy layers of quartz or of quartz and chalcedony, through the translucent substance of which gleam the colors of the underlying copper minerals. The deposition of quartz was certainly not confined to a single period in the oxidation, but the malachite appears to be generally though perhaps not entirely younger than the chrysocolla with which it is associated.

[1] Tolman, C. F., jr., Secondary sulphide enrichment of ores: Min. and Sci. Press, vol. 106, p. 143, 1913.

TENOR OF THE ORE.

In tenor the ore ranges from any lower limit that may be set, usually some figure between 1 and 1.6 per cent of copper, up to about 10 per cent. Occasional assays show ore as high as 12 per cent, but there is no large body of ore of such richness. The general average of all the ore reserves of the Ray Consolidated Copper Co., estimated in the company's report for 1916 at 93,373,226 tons, is given as 2.03 per cent. From the beginning of operations to January, 1917, the company had mined 13,293,854 tons averaging 1.70 per cent of copper. The highest grade of disseminated ore mined at Ray is that of the No. 3 mine, of which it was estimated in 1914 that there was in the ground approximately 540,000 tons of an average tenor slightly above 5 per cent of copper.

In the Miami mine the samples as regularly taken by the company's samplers rarely carry more than 4.5 per cent of copper, although a general inspection of the assay plans and sections will show here and there assays between 4.5 and 6 per cent. The company's annual report for 1915 gave the ore reserves on January 1, 1916, as 18,140,000 tons averaging 2.40 per cent of copper and 17,000,000 tons averaging 1.21 per cent, or a total of

35,140,000 tons averaging 1.82 per cent. The ore sent to the mill in 1915 averaged 2.17 per cent of copper. The report for 1916 gave the following:

High-grade sulphide ore, 16,400,000 tons at 2.40 per cent copper.

Low-grade sulphide ore, 28,000,000 tons at 1.06 per cent copper.

Mixed sulphide and oxide ore, 6,000,000 tons at 2 per cent copper.

It may be questioned whether the 1.06 per cent material can properly be termed ore under present conditions, even with copper at its current high price. The ore mined in 1916 averaged 2.07 per cent.

Inspection of the assay plans of the Inspiration mines shows a similar though slightly lower range of variation. The company's annual report for 1915 gives the following statement of ore reserves:

	Tons.	Per cent.
Sulphide ore	46, 252, 000	2. 01
Low sulphide material	28, 698, 000	1. 26
Oxidized material	17, 460, 300	1. 31
Mixed carbonate and sulphide material	4, 732, 700	1. 31
	97, 143, 000	1. 63

The ore sent to the mill in 1915 averaged 1.702 per cent of copper, which, it may be observed, is practically the same as the average for all ore milled from the Ray mines in that year. In 1916 the ore milled by the Inspiration Co. averaged 1.548 per cent of copper, of which 1.213 per cent was in the form of sulphides and 0.335 per cent in oxygen compounds.

OXIDIZED AND LEACHED ROCK.

From the complete oxidation of the protore and ore two general kinds of material result. One is a rock brilliantly colored with malachite and chrysocolla containing approximately as much copper as the ore but in a form not susceptible of satisfactory concentration by the processes applied to the sulphides. In a few places it has been rich enough to mine in a small way and ship to the smelters.

Such copper-stained rock, traversed generally by many little veinlets of chrysocolla, is abundant in the Miami district, generally in or close to the granite porphyry, and was what first attracted attention to the economic possibilities of the district. It is a conspicuous feature at the surface near the No. 1 or Captain shaft of the Miami mine and near the Keystone shaft. As a rule the best ore bodies do not occur beneath rock of this character. Such brilliant coloring indicates that much of the copper, instead of migrating downward to form chalcocite, has been fixed near the surface as silicate and carbonate in a form that under present economic conditions and current metallurgic practice is not yet available as ore, although much of it will in time be utilized. It indicates also, as will be more fully shown later, that the material oxidized at the place where the silicate and carbonate of copper abound was not pyritic but had previously undergone chalcocitization—in other words, that erosion had overtaken and encroached upon downward enrichment.

The other class of material consists of the leached rock or capping. This in its typical development is in strong contrast with the copper-bearing rock just described, although the materials of the two kinds grade into each other. Its prevalent characteristics are a more or less rustiness of tint and a practical absence of copper. It contains enough iron oxide to give a reddish color to churn-drill sludge, whereas the unoxidized schist and ore give a gray sludge and the material containing much chrysocolla and malachite a greenish-gray sludge.

Close inspection shows that the rusty pigment is not evenly distributed through the rock but occurs with quartz along cracks or joints, as little specks in the body of the rock, and as a superficial wash over weathered fragments or outcrops. The specks are seen to be little pores lined or filled with spongy oxide, and similar material occurs in the quartz veinlets. It is clearly the residue left after the oxidation of the pyrite and chalcopyrite and the removal of part of the iron and virtually all the copper. The substance of the rock itself is as a rule nearly white.

One result of these changes, especially the deposition of quartz and iron oxide, often in very intimate association, is a more or less superficial induration, the weathered oxidized material, although brittle and fractured, being as a rule harder than the sulphide ore beneath it. This difference is apparently not due to any notable addition of silica but probably to the setting free and redeposition of silica from feldspars and other silicates and to the combination into hard aggregates of quartz with iron oxides derived from pyrite.

It might be supposed that the oxidation of the sulphides, with the consequent formation of metallic sulphates, would be accompanied by other conspicuous mineralogic changes in the rock. This, however, is not the case. Were it not for the removal of the sulphides it would be impossible to distinguish with certainty under the microscope a thin section of leached capping from a thin section of ore. Both are composed essentially of quartz and sericite, and their microstructures are identical.

If it were possible to recognize with certainty a particular variety of cap rock as indicative of ore beneath it, much expensive drilling might be dispensed with, but at present no great reliance can be placed upon visible surface criteria. It may be said, however, that a deep and conspicuous redness of the surface is less propitious than a rather subdued tint of rustiness. The excessive ruddiness generally indicates that the chalcocite zone is thin and that protore will be reached comparatively near the surface. On the other hand, abundant chrysocolla near the surface suggests that erosion may have overtaken the chalcocite zone in its downward progression and have removed some of the ore body. As a rule, the cap rock above an ore body contains abundant small quartz stringers which show, by minute rusty cavities, the former presence of iron sulphide.

In order to ascertain the general chemical composition of typical cap rock, a good-sized sample was collected on the 370-foot level of the Miami mine and was analyzed in the chemical laboratory of the Survey. The analysis is given below, and with it, for comparison, is placed the mean of the two analyses of Miami ore given on page 159:

Chemical composition of cap rock.

	1	2
SiO_2	68.30	66.83
Al_2O_3	17.41	15.92
Fe_2O_3	3.80	2.36
FeO	.15	.92
FeS_2		.75
Cu_2S		2.85
MgO	.83	.64
CaO	.04	.13
Na_2O	.53	.51
K_2O	5.71	5.75
H_2O below 110° C	.15	.17
H_2O above 110° C	2.44	2.39
TiO_2	.66	.73
P_2O_5	.47	.12
MnO	.01	Trace.
	100.50	100.07

1. Cap rock from the 370-foot level of the Miami mine. Chase Palmer, analyst.
2. Mean of two analyses of Miami ore (10 and 11 in table on p. 159.)

The above comparison shows how little alteration beyond the abstraction of copper and sulphur, the change of the iron to ferric oxide, and the rearrangement of the silica is effected in the metallized schist by natural leaching. A similar comparison of porphyry ore and porphyry capping might show a slightly greater difference, but it did not seem worth while to have additional analyses made to determine this point.

The copper tenor of typical leached capping is extremely low, and such material rarely shows any visible trace of the presence of copper-bearing minerals. Assays of capping usually range from a mere trace to about 0.2 per cent of copper, higher results generally being indicative of the presence of a little visible silicate or carbonate of copper—in other words, of material intermediate between typical leached capping and oxidized but unleached ore.

CHAPTER X.—ORIGIN OF THE COPPER DEPOSITS.

GENERAL STATEMENT OF THE PROBLEM.

The preceding descriptive chapters should have made it evident that two general processes of distinctively different character have contributed to the origin of the ores. The first was ascensional, or hypogene, and produced the protore; the second was descensional, or supergene, and converted protore to ore. How came certain kinds of rock in certain parts of each district to be filled with disseminated sulphides, chiefly pyrite, and how came this protore to be enriched to ore? As will appear in the following pages, these questions can be answered only in part, for of what is sometimes referred to as our "knowledge" of ore deposition a much larger proportion than some geologists seem willing to admit is more safely to be regarded as speculation than as established truth.

DEPOSITION OF THE PROTORE.

INFLUENCE OF IGNEOUS ACTIVITY.

Had no previous study been made of the copper deposits of the western United States and were observation restricted to one only of the two districts here described, the observer might well inquire whether the association of the ores with granitic or monzonitic porphyry is merely accidental or is an illustration of cause and effect. The present state of our information, however, leaves little room for this doubt. Not only at Ray and Miami but at Clifton, Bisbee, and Ajo in Arizona, at Ely in Nevada, at Santa Rita in New Mexico, and at Bingham in Utah, not to mention occurrences outside of this country, copper ores generally similar to those of Ray and Miami are closely associated with monzonite porphyry or with porphyry intermediate in character between monzonite porphyry and granite porphyry. In some of these districts the evidence for an essential genetic relationship between ore and porphyry is plain; in others it is more or less equivocal to anyone who permits himself to realize that some ores, even ores of copper, may occur in localities where there is nothing to suggest any connection between them and igneous activity. Taken collectively, however, the disseminated copper deposits of the southwestern United States present convincing evidence that the monzonitic porphyries, by which they are invariably accompanied, had something to do with their origin.

It is not to be supposed, however, that the now visible parts of these bodies of porphyry contributed in any active way to ore deposition. They, like the neighboring schist, have themselves been altered by the ore-bearing solutions, and, where favorably situated, have been changed into protore just as the schist was changed under similar circumstances. Their significance lies in their testimony to the probable presence of much larger masses of similar igneous material below any depths likely to be reached in mining, and it is from these larger and deeper masses, which must have taken far longer to solidify and cool than the bodies now exposed by natural erosion and in the mines, that most of the energy and at least a part of the materials were derived to form the protore.

CHARACTER OF THE DEPOSITING SOLUTIONS.

The probable character of the hypogene solutions that deposited a given ore body is ascertainable in part from the observed effects of the solutions on the rocks which they traversed, in part from the study of present-day spring waters, in part from experimental work, and in part from general chemical considerations. On the basis of evidence drawn from the various sources mentioned, fairly general acceptance is given to the view that deposits such as the protore of Ray and Miami are the work of thermal alkali sulphide waters probably carrying some carbon dioxide. It can not be said that these particular deposits very definitely confirm or modify this commonly held view.

Owing to the lack of original uniformity of composition the rocks in which the ore occurs at Ray and Miami are not favorable to the accurate chemical comparison of altered with unaltered rock, and it is not possible to determine satisfactorily the increases and decreases in the rock mass that accompanied protore deposition. Two elements that the depositing water brought up from below were sulphur and copper. Probably, also, molybdenum and silicon should be added to these, for it does not seem likely that molybdenite was originally present in the schist, and the direct comparison of analyses of schist and protore, which it is to be remembered is a comparison not of equal volumes but of equal weights of the two rocks, appears to indicate some silicification. On the other hand, although the abundance of pyrite in the protore suggests the addition of iron, the analyses indicate rather that the iron already present in the silicates of the schist and porphyry and as magnetite was more than sufficient to form the sulphide now in the rock. There is no development of carbonates at Ray or Miami and therefore nothing directly indicative of the presence of carbon dioxide in the hypogene solutions. The abstraction of soda and the lack of any notable increase of potassa in the protore as compared with the original schist and porphyry do not, moreover, indicate high alkalinity of these solutions.

In the Ely district, inasmuch as the orthoclase phenocrysts of the porphyry were not attacked by the ore-bearing solutions, Spencer[1] concluded that these solutions were saturated with respect to that mineral and therefore, by inference, comparatively rich in potassium. At Ray and Miami none of the common silicate minerals of the schist or porphyry have been entirely immune from attack, although in places the biotite of the porphyry has remained remarkably fresh, even after enrichment, although, as is well known, the mineral is completely decomposable in the laboratory by sulphuric acid. This, so far as it goes, might be taken to indicate that the hypogene solutions were rich in potassium and iron, a result not in accord, however, with other effects produced.

On the whole, the hypogene solutions appear to have been of rather feeble chemical activity, and although the quantity of copper which they transported was large in the aggregate, it was small when measured in percentage of the metallized rock mass.

[1] Spencer, A. C., The geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, p. 65, 1916.

INFLUENCE OF STRUCTURE.

No clear relation has been made out between primary metallization and rock structure. It may be said that such metallization has taken place at or in the vicinity of the contact between schist and granite porphyry, but this is true only in a general way. Typical protore may be found more than 1,000 feet from any known porphyry mass of considerable size. Moreover, it is only along certain parts of the contact region that any deposition has taken place. In the Ray district, for example, the schists near the granite porphyry on Granite Mountain, although showing contact metamorphism, are not noticeably sulphidized, and in the Miami district it is only along the northern border of the north lobe of the Schultze granite that the schists contain much disseminated pyrite and chalcopyrite.

The conditions that determined the ascent of metallizing solutions at any particular place were doubtless complex. Essential ones must have been permeability of the rocks affected and an abundant supply of the active solutions.

Permeability, as shown by a study of the protore, was due in large measure to minute irregular fissuring. This fissuring perhaps accompanied the formation of larger fissures along which faulting took place. These larger fissures, however, are not easily recognized. Most of the faults mapped in the Miami district (Pl. XXXIX) are believed to be younger than the deposition of the protore, but the observable facts upon which this conclusion rests are such as may have succeeded and obliterated evidence of older movement along the same fissures. It may often be shown that a certain movement along a fault took place after certain other geologic events in the history of a district, but it can rarely be demonstrated that this particular displacement was the first manifestation of faulting along the fissure.

In the Ray district the Sun and Sharkey faults and other less conspicuous fissures not mapped appear to be of considerable antiquity and may have contributed to the permeability of the schist at the time the protore was formed.

Permeability, it is believed, was favored also by irregularity of the intrusive contact and by the presence of little tongues and dikes of porphyry extending out into the schist. The act of intrusion must have caused some disturbance of the schist, and the presence of such tongues and dikes, by introducing heterogeneity into the rock mass, probably made for further fissuring and to that extent provided communicating channels between the deep-lying igneous material and the zone of sulphide deposition. Some probability is given to this suggestion by the fact, as may be seen from Plates XXXIX and XLV, that small dikes and irregular protrusions of porphyry are abundant in the metallized ground, both at Ray and at Miami. This is particularly noticeable about Humboldt Hill, in the Ray district, where the ore body attains its greatest thickness. That thickness, however, it should be remembered, is probably due more to enrichment than to protore deposition.

The quantity of mineralizing solutions available at any place in the contact zone probably depended to a large extent also on the shape of the deep-seated mass of magma from which they rose. This mass, however, is entirely beyond our ken, and its form must remain, for the present at least, unknown.

INFLUENCE OF VARIATIONS IN COUNTRY ROCK.

There appears to be no regular or significant difference between schist protore and porphyry protore as regards tenor in copper. Chalcopyrite, however, if not more abundant, is in places a more conspicuous constituent of the porphyry protore than of the schist protore. Molybdenite also seems to be more abundant in porphyry than in schist. Diabase does not occur in close association with the protore at Miami, but, as described on page 124, does have to be taken into account in the Ray district. At Ray the mineralized diabase, as a rule, appears to carry more pyrite and chalcopyrite and to assay rather higher in copper than the average schist or porphyry protore. (See p. 157.) This is not surprising when it is remembered that the diabase contains a much larger quantity of iron originally present as oxide and silicate than the other rocks and also, as has been shown in a previous publication,[1] contains originally a little copper. Practically no enriched disseminated ore has yet been mined in diabase in the Ray district, but there appears to be no reason why, under suitable conditions, enrichment of the mineralized diabase should not have taken place, and consequently it would not be surprising if bodies of ore were found in that rock east of Mineral Creek.

The association of some of the ore in the Ray district with diabase and the common occurrence of copper ore with the same rock in other parts of the Globe-Ray region offer a strong temptation for regarding this rock as having some genetic connection with the ore. The fact, however, that a large part of the ore in the Ray district and practically all of that at Miami has no close connection with diabase, so far as known, makes it fairly certain that its presence was not an essential factor in the deposition of the protore.

RELATION TO THE SURFACE EXISTENT AT THE TIME OF DEPOSITION.

Since the deposition of the protore the region has undergone too many vicissitudes to permit the mental restoration of the topographic features then existent. Attempts have been made to estimate the thickness of rock that was removed by erosion during the progress of enrichment. J. E. Spurr, for example, in the report by Spurr and Cox to the Ray Consolidated Copper Co. (unpublished), estimated that in one place 467 feet of rock had been leached and removed from above the present ore bodies. Another estimate made by the same geologist in the same report, based probably on slightly different data, gave 575 feet. These figures, it may be noted, agree fairly well with the 500 feet estimated by Spencer[2] as a minimum for the Ely district, Nev.

These estimates are based on the assumption that the process of enrichment has been continuous and that all the copper has been carried down and redeposited. As will be shown later, the process is probably cyclic, and, if the deposits have been subjected to erosion long enough to permit the completion of one or more cycles, a large part of the copper may have been carried away and lost. Even where the complete cycle is not developed, probably considerable copper is shifted laterally in solution and is not added to the ore body. Conse-

[1] U. S. Geol. Survey Prof. Paper 12, p. 12, 1903.

[2] Spencer, A. C., The geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, p. 80, 1916.

quently the estimates given, on the supposition that the average tenor of the protore, another uncertain factor, has been correctly estimated, are likely to be under rather than above the truth.

It is probable that at the time the protore was deposited at least 500 feet of rock lay above the present surface, and it is not at all unlikely that the thickness was several times the figure mentioned. The crystallinity of the granite porphyry and the character of the metamorphism that accompanied or followed the intrusion are both indicative of the solidification of the magma under a fairly thick cover. In the Miami district the granite porphyry itself, at the present day, is in places fully 750 feet thick above the ore.

POSSIBLE FUNCTION OF ADSORPTION.

Adsorption is the property possessed by some substances, especially those in a fine state of division, of precipitating solids from solution through the operation of the principle of surface concentration. Solutions are more concentrated at their surfaces than in the body of the liquid, and any conditions that tend to increase the surface of a solution tend also to local concentration of the solute and consequently to precipitation.

If the hypogene solutions found access to the zone of deposition through comparatively few and relatively large channels or fissures, then upon reaching the mesh of tiny fissures in the schist and porphyry within the region of deposition their surface area must have been enormously extended, with a consequent increase in local concentration and a tendency toward precipitation or greater chemical activity. It is not known whether such physical conditions actually existed, but it is perhaps well to bear in mind the possibility of adsorption having a part in the deposition of ore in porous or minutely fissured rocks.

GEOLOGIC AGE.

The deposition of the protore probably followed closely the intrusion of the granite porphyry, but no facts are known that might serve to fix this event definitely in geologic time. The granite porphyry is younger than the diabase, whose intrusion, on general grounds rather than from any definite evidence, is supposed to have taken place at the end of the Mesozoic era. It appears reasonable to regard the intrusion of the granitic porphyries as an early Tertiary event, but it must be admitted that this is little more than conjecture. The deposition of the protore certainly took place after the laying down of the Tornado (Mississippian and Pennsylvanian) limestone and before the eruption of the dacite.

ENRICHMENT.

GENERAL CHARACTER OF THE PROCESS.

The general progress of enrichment in disseminated copper deposits, with special reference to those in porphyry, has been admirably outlined by Spencer [1] as follows:

> The chemistry of downward chalcocite enrichment may be treated by following in imagination the incidents of the journey made by rain water, which falls on the surface, soaks into the ground, and penetrates an existing ore body. The subject is here considered with special reference to the porphyry ores of the Ely district.
>
> Rain water carries in solution the gases of the atmosphere, including oxygen and carbon dioxide. In arid and semiarid regions it contains also noteworthy amounts of common salt, which may be regarded as of wind-blown origin. As these waters pass into the soil and into the porous weathered capping that lies above the ore mass they come into contact with orthoclase and mica and with oxidic compounds of iron and copper (including limonite and its congeners), basic sulphates carrying iron or copper, and basic carbonates of copper. Metallic copper and the red oxide, cuprite, are also fairly common in the overburden. The silicate minerals in the capping tend to make the water alkaline,[2] but as they are only slightly attacked this tendency is likewise slight. Of the metallic minerals in the capping, those containing sulphate decompose, being somewhat soluble, the result being to produce and to leave in place limonite and copper carbonates and to furnish small amounts of iron and potassium sulphates to the solution. That the copper carbonates, though relatively stable, yield gradually to solution is shown by the much smaller amount of copper in the upper part of the capping than in the lower part. Thus far the dissolved oxygen does not enter largely into the reaction, because most of the minerals of the capping are already fully oxidized. The only exceptions to be noted are cuprite and native copper. Also, the carbonic dioxide has been by no means exhausted.
>
> Everywhere the capping, which is colored characteristically red by ferric-iron compounds, gives place by a short transition to gray or bluish ore. Just beneath the capping the solution encounters material rich in sulphide minerals that are subject to ready oxidation. Here, then, chemical action between the oxygenated waters and the sulphide minerals ensues, a series of reactions being

[1] Spencer, A. C., Geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, pp. 76–77, 1916.

[2] Cameron, F. K., and Bell, J. M., U. S. Dept. Agr. Bur. Soils Bull. 30, pp. 12 et seq., 1905. Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 478–483, 1916.

initiated, of which the culminating reaction involves the deposition of chalcocite. At first the waters contain free sulphuric acid, furnished by the decomposition of pyrite, but gradually the acid becomes neutralized by bases furnished by the gangue minerals, and at sufficient depth the solutions become alkaline. If the decomposing minerals are considered the reactions that occur beneath the capping present a succession of oxidations, whereas if considered with respect to the active solution, the changes are, of course, in the direction of reduction. The reactions of the series may be considered in three groups, assignable in a general way to higher, intermediate, and lower positions in the body of sulphide-containing material. In the upper part of a sulphide ore body atmospheric oxygen is the oxidizing agent; somewhat lower down, where free oxygen has been exhausted, ferric sulphate becomes active; and after the oxygen made available by this carrier has been utilized cupric sulphate furnishes oxygen. The action of cupric sulphate on pyrite and chalcopyrite results in the deposition of chalcocite and the consequent enrichment of material carrying the primary sulphides. The formation of secondary chalcocite probably involves a series of transitions or stages, as pyrite—chalcopyrite—bornite—covellite—chalcocite.

The following discussion is incomplete in that the chemistry of the copper minerals that are characteristic of the capping is not considered. Though oxidation in the portion cf an ore body that lies just beneath the capping results in the compounding of cupriferous solutions, the fact must not be neglected that here also are formed the relatively stable basic carbonates and sulphates and the even more stable minerals, cuprite and metallic copper.

Although the chemistry of enrichment in its broad outlines is fairly well understood, many details and special problems remain to be worked out. These are being attacked in a joint study under the auspices of American copper companies, the Harvard Mining School, and the Geophysical Laboratory of the Carnegie Institution of Washington. In view of the geologic and chemical ability thus focused on the subject of enrichment and the progress already made, it is scarcely to be expected that a geologic report on only two districts wherein the operation of the process is similarly displayed should go very deeply into the chemical discussion of enrichment. All that will here be attempted will be a general account of the process as locally exemplified and the presentation of such suggestions as may have sprung from observations in the districts described.

The foregoing quotation from Spencer gives a clear picture of the process in operation, but it is incomplete, as it takes no account of conditions before the formation of some oxidized capping and omits to describe important changes that it is believed may take place after a certain stage in enrichment has been reached. In other words, it pictures a continuous rather than a cyclic process. In some, possibly in most, deposits the cyclic character is not obvious and the enrichment seems to have been continuous and progressive. It is necessary, however, to inquire how far this apparent continuity may be due to the fact that enrichment in such deposits is still in a comparatively early stage of development.

THE ENRICHMENT CYCLE.

The imagination does not easily picture the beginning of the enrichment of any deposit of the general kind here described. The characteristic capping which now covers the ore and through which rain water must percolate in the manner so well described by Spencer is a product of the weathering of protore or ore and hence marks a process well advanced. There must have been a stage when there was no capping, in the sense in which the word is used by the copper miners—a time when percolating rain water, without previously passing through material that had once contained pyrite and other sulphides, began its attack on the protore. On the other hand, only under exceptional geologic conditions could a large mass of pyritized rock be suddenly exposed to weathering. Normally rock of that kind would be brought within reach of atmospheric attack only by the slow removal of overlying rock by erosion, in the course of which pyrite might never appear at the surface, and the weathering of the protore would begin gradually. The sulphides first reached would perhaps be sparsely disseminated, and oxidation of them would proceed only here and there where conditions were especially favorable for the descent of oxidizing water. As successively deeper-lying portions of the pyritized rock were encroached upon by the zone of oxidation chemical activity would increase and the process of downward concentration of the copper by the reduction of sulphate solutions would attain full swing.

At first the oxidizing solutions worked on pyrite and chalcopyrite. But as the process went on, increasing quantities of chalcocite were deposited lower down at the expense of the pyrite and chalcopyrite, and this chalcocite gradually, as erosion progressed, came into the zone of oxidation. Finally a stage must have been reached in which chalcocite, not pyrite, became the chief sulphide under the attack of the atmosphere and of descending water.

Various steps in the oxidation of pyrite may be indicated by the following equations:

$FeS_2 + 4O = FeSO_4 + S$ .... (1)
$FeS_2 + 6O = FeSO_4 + SO_2$ .... (2)
$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$ ...... (3)
$2FeS_2 + 15O + H_2O = Fe_2(SO_4)_3 + H_2SO_4$ ... (4)

The products are ferrous and ferric sulphate, sulphur dioxide, and sulphur.

The oxidation of chalcocite by atmospheric oxygen may be represented as follows:

$2Cu_2S + O = 2CuS + Cu_2O$ .... (5)
$CuS + 4O = CuSO_4$ .... (6)

Here the products are cuprite and cupric sulphate. In the absence of pyrite, there is no ferrous or ferric sulphate and no free sulphuric acid.

The significance, as regards enrichment, of the difference between the oxidation of cupriferous pyritic material and the oxidation of chalcocite alone does not appear to have received much investigation from the chemical side, but observation in the Miami district strongly suggests that the process of enrichment is far more active when the material undergoing oxidation contains abundant pyrite than when it is chiefly chalcocite. The presence of free sulphuric acid in the one case and its absence in the other might be taken as an indication that acidity favors enrichment. Spencer,[1] however, reached the conclusion that "under natural conditions chalcocite will not replace primary sulphides when the acidity of the cupriferous solutions exceeds some rather small minimum," and Zies, Allen, and Merwin[2] found that, in laboratory experiments, sulphuric acid retards but does not change the nature of the reaction between pyrite and cupric sulphate.

The laboratory work, however, though essential and illuminating in helping to explain the process of enrichment, is necessarily carried out under conditions far simpler than those existing in nature, and this fact should never be lost sight of when the results of the laboratory are applied to the facts in the field. Thus although in a system of pure pyrite and cupric sulphate free sulphuric acid may retard the deposition of chalcocite on the pyrite, other reagents also come into play in a natural deposit, and these may modify the conclusions drawn from experimental work.

The effective constituent in a cupriferous enriching solution is cupric sulphate, with, when suitable reducing agents are present, the still more efficacious cuprous sulphate.

Inasmuch as the oxidation of chalcocite alone yields cupric sulphate, and as this highly soluble salt is an effective enriching agent, it is not immediately apparent why, when chalcocite is the only sulphide exposed to weathering, enrichment should not proceed as rapidly as when pyrite is abundant in the zone of atmospheric attack. It is a matter of observation, however, that when chalcocite weathers, especially in feldspathic rocks, part of the copper is not carried away as sulphate but is converted into carbonate or silicate and remains near the surface. This conversion of the copper from a highly soluble to less soluble forms could not take place especially as regards the carbonates, if free sulphuric acid were abundant, and here probably is an illustration of a way in which sulphuric acid, notwithstanding its retarding influence as shown by laboratory studies of enrichment, may, under natural conditions, facilitate rather than check that process.

Whatever may be the effect of the sulphuric acid set free when pyrite oxidizes, a considerable part of the greater activity in enrichment when this mineral is present must be ascribed to the formation of ferric sulphate, which is an active solvent for copper sulphates.[3] It reacts rapidly with chalcocite in accordance with the equation

$$Fe_2(SO_4)_3 + Cu_2S = CuSO_4 + 2FeSO_4 + CuS.$$

The resulting covellite is more slowly attacked as follows:

$$Fe_2(SO_4)_3 + CuS + 3O + H_2O = CuSO_4 + 2FeSO_4 + H_2SO_4$$

Thus, so long as pyrite is present, the copper is being taken into solution and being redeposited by reaction with sulphides at lower levels.

Of course malachite and chrysocolla, although far less soluble than cupric or cuprous sulphate, are not immune from solution. The occurrence of the hydrous copper silicate now being deposited in some of the mines, as described on page 140, shows clearly that the copper can migrate in the form of silicate. The chrysocolla veins formerly worked in the Keystone and Live Oak

[1] Spencer, A. C., Chalcocite enrichment: Econ. Geology, vol. 8, pp. 647-648, 1913.

[2] Zies, E. G., Allen, E. T., and Merwin, H. E., Some reactions involved in secondary copper sulphide enrichment: Econ. Geology, vol. 11, p. 444, 1916.

[3] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 159, 1917.

ground at Miami and the chrysocolla ore at the base of the dacite in the Warrior mine in the Miami district and at other places in both the Miami and Ray districts are believed to be the work of solutions that were derived from the oxidation of the disseminated sulphides and that carried the copper as silicate. No evidence has been found, however, to show that silicate or carbonate solutions of copper have anywhere been active in enriching sulphides. The occurrence of chrysocolla and malachite at considerable depth in the Miami mine, as described on page 136, has clearly resulted from the oxidation of chalcocite in place. The solutions that effected this oxidation do not appear to have added any notable quantity of copper to the amount already present in the rock but to have contributed only the carbonate and silicate radicles. In other words, this so-called oxidized ore, which was once chalcocitic ore, supposedly of about the same general grade as the rest of the deposit, now contains less rather than more copper than the unoxidized ore in its vicinity.

That the copper goes less readily into solution in deposits of chrysocolla and malachite than in pyritic sulphide deposits is a matter of direct observation. In the Miami district mine dumps in which the copper is present chiefly as silicate or carbonate show little change in color or character after several years' exposure to the weather. In the pyritic dumps, on the other hand, there is rapid oxidation, both copper and iron going into solution as sulphates which are partly and temporarily redeposited as efflorescent coatings. In some places also active chemical change is shown by a perceptible odor of sulphur dioxide.

The conclusion is reached that when enrichment has progressed so far that the sulphides immediately beneath the capping have been converted almost wholly to the relatively stable chalcocite the process slows, the chalcocite becomes gradually converted to malachite and chrysocolla, and if erosion proceeds at its original rate or is accelerated by faulting or other diastrophic movements it may overtake enrichment and attack the rock containing copper carbonate and silicate. This appears to be essentially the condition at the New Keystone mine in the Miami district.

This conclusion is regarded as probable rather than actually demonstrated. If it is correct, then a deposit that has resulted from prolonged erosion and enrichment may have passed through one or more stages, during which much of the copper collected by downward enrichment was swept away as sedimentary detritus and in solution in surface waters.

With the disappearance of the protecting chalcocite and the continued lowering of the surface by erosion pyritic protore would again be exposed to the action of air and downward-seeping oxidizing water, and a second cycle of enrichment would begin.

Between the intrusion of the granite porphyries associated with the ores and the eruption of the dacite the region was deeply eroded, as shown by the fact that in that period the porphyries, which must have solidified under considerable cover, were exposed and contributed detritus to the Whitetail.

Direct evidence of the superposition of the Whitetail formation or the dacite on the eroded granite and granite porphyries is scanty. In the western part of the Miami district the porphyry and dacite are in contact at a number of places, but the two rocks appear to have been brought together by faulting. Just north of Hutton Peak, in the western part of the Globe quadrangle, on a weathered surface of the Schultze granite, dipping about 30° S., is a layer, a foot or two thick, of soft gray clayey material containing some pebbles. Above the clay is a bed, at least 20 feet thick, of breccia composed chiefly of schist fragments and interpreted as representative of the Whitetail formation, which is highly variable in thickness and constitution. Above the breccia lies the dacite, apparently as originally poured out, although the contact between breccia and dacite is not exposed. The gray clay might possibly be interpreted as a fault gouge, but it probably is a bedded deposit. Northwest of the Pinal ranch the dacite as seen in a reconnaissance trip appears to lie on an erosion surface of Schultze granite and Pinal schist, and is thus younger than the granite and than the porphyry with which the ores at Miami are connected.

Although it is believed that the process of enrichment has potentially a cyclic character, it may well be doubted whether this character is often manifested in the simple, definite order of changes just outlined. There are many complicating factors, such as rate of erosion, depth to underground water level, climate, topography, and country rock, that must be taken into account. For example, it is conceivable that erosion might be so slow, the climate so arid, and drainage so feeble that the copper in the exposed chalcocite zone would, after oxidation, continue to be carried down and redeposited by enrichment of protore. Or, to put the matter somewhat differently, the appearance or absence of typical cyclic character might depend upon the relative speeds of denudation on the one hand and of the chemical changes contributory to enrichment on the other. Again, climate, by determining the physical condition of the soil, the nature of the vegetation, and the character of the rainfall, might be the dominant factor in deciding whether loose particles of malachite or chrysocolla are to be dissolved and the copper carried down into the earth, or are to be swept like other detrital grains into the nearest stream.

CHRONOLOGIC RELATION OF ENRICHMENT TO OTHER GEOLOGIC EVENTS.

The greater part of the enrichment in both the Ray and Miami districts is believed to have taken place before the deposition of the Whitetail formation, which is a land or continental accumulation of coarse detritus that underlies the dacite. The evidence upon which this conclusion rests will now be briefly summarized.

In the Ray district the nearly horizontal base of the Whitetail formation on Teapot Mountain is at least 800 feet lower than the highest granite porphyry exposed on Granite Mountain within the area mapped on Plate XLV. The two localities are only a mile and a half apart, and the observed relation could scarcely exist had not the granite porphyry been exposed by erosion before the deposition of the Whitetail.

Finally, the Whitetail formation on Teapot Mountain contains fragments of granite porphyry identical with what was described on page 62 as the Teapot Mountain porphyry.

It thus appears fairly certain that the region was profoundly eroded after the intrusion of the granite porphyries associated with the ore and before the deposition of the Whitetail formation, or at least before the eruption of the dacite. The deposition of the protore, without much question, closely followed the intrusion of the porphyries. Consequently it must be concluded that it also must have been eroded, at least in part; and if so, enrichment probably took place.

Spurr has estimated that from 467 to 575 feet of rock must have been leached and removed to supply the copper in the Ray ore body. It has been shown that this estimate is more likely to be under than above the truth. Now, there can not be much question that the Whitetail formation once covered part if not all of the ore-bearing area of the Ray district. (See Pl. XLIII, *B*.) The present base of this formation on the side of Teapot Mountain nearest to the ore body is from 2,700 to 3,000 feet above sea level. Humboldt Hill, under which is the thickest ore known in the district, stood, before it was undermined by stoping, at 2,616 feet. Thus, should it be maintained that enrichment has taken place chiefly during the present erosion cycle, it would be difficult to show how sufficient rock could have been removed to yield the necessary copper.

As already shown, the relation of the upper surface of the ore body to the present topography, while not so close as to suggest that enrichment and the development of that topography went hand in hand, is not such as to indicate in any very striking way that the two surfaces were independently developed. The result, in fact, is what might be expected if the principal enrichment took place before the deposition of the Whitetail formation, and if, since the stripping away of that formation, the process has been renewed and has made progress commensurate with the comparatively small thickness of rock that has been eroded since the pre-Whitetail surface was uncovered.

In the Miami district, on the other hand, the lack of parallelism between the top of the ore and the present surface is more striking. (See pp. 147–148.) The deepest ore in that district occurs where the surface is covered by dacite and Gila conglomerate, with possibly some of the Whitetail formation, which has a wide range in thickness and is not everywhere present between the dacite and the older rocks. Most of such ore, moreover, is below the present level of underground water. These facts indicate not only that the enrichment took place before the dacite was poured out over the surface, but that the faulting and tilting that have very plainly affected the dacite and Gila conglomerate have greatly modified the formerly existing relation between the zone of enrichment and the level of underground water. It is difficult to see how the deep ore of the Live Oak mine, buried under hundreds of feet of dacite and conglomerate and far below the present surface of the ground water, could have been enriched in its present situation. It should be pointed out, however, in this connection that not all the deep ore of the Live Oak ground is under dacite and Gila conglomerate. As shown in figure 19 (p. 116), some of the ore covered only by porphyry and schist is nearly 1,000 feet deep, so that the possibility of enrichment to at least that depth must be admitted, and this weakens the argument that, because other parts of the ore body now beneath dacite and Gila conglomerate are very deep, the enrichment must have antedated the dacitic eruption. Nevertheless, it is not probable that the Live Oak enrichment could have taken place under the present conditions of topography and drainage.

Recent drilling in the part of the Ray district east of Mineral Creek has shown the existence of conditions there somewhat similar to those in the Live Oak area, but detailed information concerning this exploration is not available.

Additional evidence that the enrichment probably took place before the eruption of the dacite is furnished by the occurrence, under the dacite, of oxidized and enriched ores to a depth of at least 1,600 feet in the western part of the Old Dominion mine, near Globe.

Although it is believed that there is sufficient evidence to demonstrate that most of the enrichment was effected before the eruption of the dacite, the process doubtless did not cease permanently with the lava outflow. A later period of active erosion, tentatively assigned to the early Quaternary, is recorded by the Gila conglomerate. In places, as shown by outliers of the conglomerate on granite porphyry and schist in the Miami district (see Pl. XXXIX), the older rocks in part of the area occupied by the ore bodies appear again to have been exposed to erosion, and presumably some further enrichment took place. Finally, with the removal, in late Quaternary time, of the Gila conglomerate from much of the ore-bearing ground in the Ray and Miami districts, erosion once more attacked the metallized schist and porphyry. In all probability enrichment was resumed and, except in those parts of the ore bodies that have been carried by postdacite and post-Gila faulting below the present level of underground water, has continued to the present time. This later enrichment, however, is thought to have been of little importance in comparison with the results achieved in the much longer period of erosion that preceded the dacite outflows.

PROBABLE CLIMATIC CONDITIONS.

The only clew to climatic conditions immediately antecedent to the dacite eruptions is given by the Whitetail formation. The fact that this in many places is composed largely of angular fragments of diabase—a rock which in a humid climate would readily disintegrate into soil—indicates that at least moderate aridity prevailed. The character of the deposit, also, suggests that although water was at times abundant it was more fitful and violent in its action than in humid regions.

RELATION BETWEEN ENRICHMENT AND FORMER TOPOGRAPHY.

The coarseness of the material of the Whitetail formation and the great and local variations in the thickness of that deposit are indicative of a surface of fairly strong relief, although perhaps not as rugged as that of to-day. It is not possible, however, from data so scanty to reconstruct that surface in imagination or to ascertain the particular relation that formerly existed between it and the ore.

INFLUENCE OF GEOLOGIC STRUCTURE.

The effectiveness of enrichment, like that of hypogene deposition, is conditioned upon permeability of the metallized rocks. Consequently any structural features that facilitate the descent of air and oxygenating waters into the earth favor enrichment, while, on the other hand, unusual closeness of rock texture or the presence of flat-lying impervious seams of gouge tend to prevent or limit enrichment.

The schist in which the greater part of the ore occurs is so uniform in character that it has not proved possible to subdivide it into units such as might serve for determining the manner in which this rock has been folded, squeezed, and faulted since it lay as a sedimentary deposit at the bottom of a pre-Cambrian sea. For all practical purposes, as regards ore deposition, the schist apparently may be considered as homogeneous material. The porphyry is also homogeneous. Consequently, as concerns these two rocks, the only structural elements that may have influenced enrichment are fissures and the contacts between the schist and porphyry or diabase.

Undoubtedly enrichment has been favored by fissuring, the ore in well-fractured rock being as a rule of better grade and thicker than elsewhere. It is not always the larger and more conspicuous fissures, however, that are the most effective channels for enriching solutions. Much of the downward migration of copper has taken place through small irregular cracks such as generally accompany the larger fractures. These larger fractures may contain relatively impervious gouge and thereby hinder rather than facilitate the movement of underground water. On the side of such a gouge upon which the enriching solutions impinge the ore may be exceptionally good, while on the other side little or no enrichment may have taken place. Enrichment, however, is not necessarily on the upper side of an inclined gouge seam; for although the enriching solutions are generally descending and the process may consequently be referred to as supergene, nevertheless not all the water sinks directly downward. It is quite possible for meteoric water, through certain relations of a gouge-filled fissure to the topographic surface or to other fissures, aided by differences in the amount of fracturing that different parts of the rock mass have undergone, to find its way more readily and more abundantly to the footwall side of a gouge than to the hanging wall and to move there under local artesian conditions. In this way are probably to be explained those occasional drill records which show an inversion of the usual sequence—those, for example, in which ore occurs under protore or "capping" under ore. Such occurrences, as will presently be shown, indicate that enrichment was effected chiefly in a zone or layer of rock above any general level of underground water.

It has already been noted that some of the best portions of the ore bodies at Miami and Ray occur where the schist is cut by small bodies of porphyry, either projecting from the main mass or as detached masses and dikes. It has been concluded that the existence of these bodies probably favored the deposition of protore. It is even more likely that they contributed materially to the effectiveness of the enriching processes. Their influence, so far as known, was not chemical but was due to the fact that by their presence fracturing of the rocks under stress was facilitated.

Probably the most notable example of the local influence of a contact in determining enrichment is the relation between the ore and diabase in the No. 1 and No. 3 mines of the Ray Consolidated Copper Co. This relation has been described on page 150. A considerable part of the ore in both of these mines rests on an intrusive sheet of diabase, apparently because the action of enrichment was stopped by the layer of gouge that generally accompanies the upper surface of the diabase. The diabase carries rather more copper than the average protore, and there is no apparent reason why it should not be as susceptible of enrichment as schist or porphyry. That it was not enriched in this place and that the schist just above it was converted into exceptionally good ore are apparently physical consequences merely of the form and character of the contact between schist and diabase.

INFLUENCE OF COUNTRY ROCK.

Such facts as have been gathered do not indicate any marked difference in the susceptibility of metallized schist, granite porphyry, or diabase to enriching action except such differences as have just been mentioned as probably due to structure. Assays as a rule afford no clue to indicate whether the ore is enriched schist or enriched porphyry, as may be well seen in the Miami mine, where a porphyry dike is included in the ore body, or in the No. 1 mine at Ray, where irregular bodies of porphyry occur in parts of the workings. Whether the diabase can be enriched as well as the schist and porphyry remains to be established. The lack of enrichment in certain masses of that rock in the No. 1 and No. 3 mines at Ray, as already stated, is believed to be due to structural features rather than to inherent insusceptibility of the diabase to enriching action. Both porphyry and diabase are more readily decomposed than schist, and the decomposed material tends to crush into soft claylike material or gouge, probably less pervious than fractured schist. The presence of such material in a rock mass, unless in extensive fissures with low angles of dip, is not likely to inhibit enrichment but may have the effect of making the ore less uniform in grade than in the schist.

RELATION OF ENRICHMENT TO GROUND-WATER SURFACE.

Spencer[1] in his report on the Ely district brings out in a striking way the inadequacy of rain water to carry enough dissolved oxygen to effect the observed enrichment of the deposits and concludes that "the greater part of the oxidation must take place when the sulphides are merely moist rather than when they are flooded, because then the water could receive oxygen from the air in contact with it at the same rate at which oxygen was being taken out of solution by the reactions of oxidation." The facts in the Ray and Miami districts fully support this conclusion. Even when all allowance is made for the effect of faulting and tilting of the ore bodies since the major enrichment took place, it is difficult to reconcile the irregularities of the upper and lower surfaces of the ore with the supposition that chalcocitization took place only near the then existing water table. Conditions favoring the maximum deposition of chalcocite appear to be a generally deep water table with sufficient precipitation to furnish slow percolation through the rocks above it but not enough to supply a rapid underground outflow. Under such conditions the percolating water will be rich in soluble constituents and of high chemical activity, and deposition of chalcocite will take place throughout a rather irregular but on the whole fairly thick layer of rock.

The water table is likely to be both irregular and indefinite. Where the atmosphere as well as oxygen-bearing water participates in the reactions the oxidation of finely disseminated pyrite is likely to give rise to SO_2, and this reducing agent by converting cupric sulphate to cuprous sulphate accelerates the deposition of chalcocite, as has been shown by Winchell.[2] That, when finely disseminated pyrite is oxidized, SO_2 may form in considerable abundance without immediate conversion into sulphuric acid is shown by the characteristic pungent odor of this gas in the vicinity of certain pyritic mine dumps and in some disused superficial mine openings. It is, of course, not a stable constituent, and any chemical effect produced by it is likely to be close to its point of origin. Nevertheless, it is probable that when oxidation and enrichment are going on in moist rock penetrable by air SO_2 plays an important part in enrichment. Although the reducing action of this gas accelerates enrichment, the reaction produces sulphuric acid, which tends to retard enrichment if the acid remains free. In many places, however, there will be compounds present that will react with the free sulphuric acid to form sulphates. This complexity of composition of a natural deposit makes it difficult, as previously pointed out, to make confident field application of some of the laboratory results.

[1] Spencer, A. C., The geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, pp. 80-81, 1916.

[2] Winchell, H. V., Synthesis of chalcocite and its genesis at Butte, Mont.: Geol. Soc. America Bull., vol. 14, p. 273, 1903.

CHAPTER XI.—PRACTICAL DEDUCTIONS.

Certain surface features, not only in the two districts here described but elsewhere in arid or semiarid regions, are generally recognized as indicating the presence of copper ores due to enrichment. Given the fundamental association of a granitic rock, usually a granitic porphyry, intrusive into rocks favorable for pyritic dissemination and subsequent enrichment, the most obvious suggestion of the existence of ore is likely to be a general rustiness of the rock outcrops, due to the presence of limonite, and probably other hydrous oxides of iron, left behind in the oxidation of pyrite. Experience seems to show that intense redness is not a very favorable sign. At what are called the Red Hills north of Ray and in the part of the Miami district just west of the No. 3 shaft of the Miami mine drilling has shown practically no enrichment or only thin and low-grade ore beneath the conspicuously red surface. On the typical surface above an ore body the prevailing hue is brown or yellow, the general effect produced by the presence of iron oxide as films on or along innumerable fractures in a rock that has itself been bleached nearly white. Although it is possible that enriching solutions may have moved laterally and in some places accomplished enrichment beneath rock that does not at the surface show any notable oxidation or leaching, yet it is very doubtful whether any large masses of ore occur in such situations. This, of course, does not mean that ore may not be found under unaltered rocks that are younger than the period of hypogene mineralization or that may have been shoved by faulting over previously metallized rock.

In attempting to estimate the probability of the existence of ore under an oxidized surface, search should be made for the presence of quartz stringers in the oxidized material. Abundant small quartz stringers indicate that the rock was at one time fissured and permeable and that it has been traversed by silica-bearing solutions such as might have deposited cupriferous sulphides. If the quartz shows cavities recognizable as having once been filled by pyrite, the probability of the presence of an ore body is increased.

The surface may not everywhere show the presence of copper minerals, such as malachite or chrysocolla, but in both the Ray and the Miami districts there are places where before any prospecting was done the rocks displayed unmistakable evidence, in the form of green stains, that copper-bearing solutions had been active.

Experience at Miami shows that the possibility of considerable changes in underground water level since the ores were deposited must be kept in mind. It can not, for example, be safely concluded, unless the geologic history of the district is well known, that if water is reached at a depth of only 100 feet enrichment in a zone above water level could not have gone on in rocks now far below the present water table.

The conclusion reached with regard to the Miami and Ray ores that enrichment took place before the accumulation of the Whitetail formation carries the very important corollary that ore may occur under this and the two later formations, the dacite and the Gila conglomerate. Such a possibility obviously opens the door for ventures of highly speculative character, although consideration of all available geologic facts must show that the possibilities of the occurrence of ore are much better under certain areas of conglomerate or dacite than under others. For example, there is nothing to indicate the presence of ore under the large area of Gila conglomerate southeast of the Miami district, between Globe and the main Pinal Range. On the other hand, the manner in which the Miami ore body ends at the Miami fault, considered in connection with the occurrence of the Old Dominion and other copper deposits due east of the Miami ore body and on the other side of the conglomerate area, suggests that an attempt to explore the intervening area by drilling through the conglomerate, dacite, and possibly some of the Whitetail formation would be by no means a forlorn hope. As noted on page 96, the Miami Copper Co. attempted to drill through the conglomerate but had to abandon the hole at 2,050 feet without having reached the ore-bearing schist or porphyry. The Old Dominion Co. also bored some holes west of Pinal Creek. One of these, 1,000 feet deep, penetrated the Gila conglomerate and was abandoned in the Madera diorite. It is possible, however, that this is some of the same broken overthrust material exposed at the base of the Gila conglomerate near the Old Dominion mine and is not in its normal position in relation to younger rocks.[1] If so, the hole if continued deeper might go through dacite and possibly into ore, although this comment is not made as a prediction. The Van Dyke Copper Co. has also begun to explore by drilling the conglomerate-covered ground just south and east of the property of the Miami Copper Co. Although the outcome of the explorations mentioned in this paragraph is highly problematic, none of the efforts are without reasonable expectation of possible success.

The search for ore under the Gila conglomerate between Miami and Globe would be greatly facilitated if the direction and amount of displacement on the Miami fault were known. The present investigation gave no clew to this much-desired information, and although special study devoted to this particular problem might possibly lead to its solution, it is difficult to see what line of attack would be likely to yield definite results. One suggestion is that a careful study be made to determine the character and amount of the displacement of the main porphyry dike in the Miami workings. This is cut off, of course, by the Miami fault, and it is as difficult to predict where its eastern continuation may be found as to determine the position of a possible continuation of the Miami ore body beyond the fault. The dike, however, is crossed by other faults in the footwall of the Miami fault, and by doing a little additional development work under the direction of a geologist it should be possible to determine how the dike has been shifted by these faults. Probably the movement along the Miami fault has been of the same kind and direction as that in the minor faults in its footwall, and data obtained in the manner shown would at least indicate whether the search for ore east of the fault is more likely to succeed to the north or south of the latitude of the known ore.

Those planning to drill would also like to know the thickness of the Gila conglomerate and dacite overlying the older rocks at any locality selected for operations. There appears to be no way to determine this except by actual drilling. The conglomerate covered an uneven surface and is known to be exceedingly variable in thickness. It contains, so far as known, no persistent stratum that can be recognized over large areas, and consequently there is nothing in the appearance of the deposit at any particular place to indicate how much more conglomerate lies below it.

[1] Ransome, F. L., Geology at Globe, Ariz.: Min. and Sci. Press, vol. 100, p. 257, 1910.

GLOSSARY.[1]

Albite. An end member of the plagioclase series of feldspars, the one containing no calcium and consisting of sodium-aluminum silicate. Sodium feldspar. Less common than the intermediate members, which may be considered as mixtures of albite with the other end member, anorthite.

Allanite. A comparatively rare mineral closely related to common epidote and occurring generally as a microscopic constituent of igneous rocks. It contains a number of the rarer elements.

Allotriomorphic. *See* Anhedral.

Alluvial fan. The outspread sloping deposit of boulders, gravel, and sand left by a stream where it passes from a gorge out upon a plain or open valley bottom.

Alunite. A white or light-colored, generally soft, and earthy mineral consisting of hydrous sulphate of potassium and aluminum. Closely resembles kaolinite and occurs in similar situations. Generally, the result of the action of water containing sulphuric acid on feldspathic rocks, as when pyrite in granite porphyry is oxidized. Where abundant, utilized as a source of alum or potash.

Amphibole. A large group of rock-making silicate minerals of a wide range of color and composition. The group is related in various ways to the pyroxene group. Hornblende is a common member of the amphibole group. All amphiboles have a characteristic cleavage along two sets of planes, one meeting at angles between 54° and 56° and the other between 124° and 126°.

Andalusite. A light-colored, usually white, pink, or gray mineral of elongated prismatic form common in rocks that originally contained clayey material and have been metamorphosed by intrusive igneous rocks. A silicate of aluminum. Crystals often rough and irregular in form.

Andesine. One of the plagioclase group of feldspars. A silicate of sodium, calcium, and aluminum, in which the sodium is in excess of the calcium. Generally white and not often identifiable without the microscope. An abundant constituent of andesite and diorite.

Andesite. A lava of widespread occurrence, usually of dark-gray color and intermediate in chemical composition between rhyolite and basalt.

Anhedral. Applied to a crystal without crystal planes, and consequently of rounded or irregular outline. Same as xenomorphic or allotriomorphic.

Anorthite. An end member of the plagioclase feldspar series, the one consisting of calcium-aluminum silicate and containing no sodium. The intermediate plagioclases may be regarded as mixtures of anorthite with the other end member, albite.

Anticline. An arch of bedded or layered rock suggestive in form of an overturned canoe. (*See also* Dome and Syncline.) The term has reference to the structure of the rocks, not to the form of the land surface.

Apatite. A mineral composed chiefly of calcium phosphate, in small six-sided prisms. A common but not abundant constituent of many igneous rocks. Generally microscopic.

Aphanitic. Having a texture so fine that the individual grains or crystals can not be distinguished with the naked eye.

Arkose. A sedimentary rock composed of mineral particles derived from disintegrated granitic rock and present in approximately the proportions that they had in the igneous rock. Arkose is often difficult to distinguish from granite by the eye alone.

Arkosic. Having wholly or in part the character of arkose.

Augite. A common rock-forming mineral, generally black and in short stout prismatic crystals. An essential constituent of diabase and basalt. Largely a silicate of calcium, magnesium, iron, and aluminum, but composition is complex and variable. Distinguishable from hornblende by its two sets of cleavage planes meeting nearly at right angles, as compared with the oblique cleavage angles of hornblende. *See also* Hornblende.

Azurite. The mineral form of the blue carbonate of copper containing a little less copper and water than malachite.

Basalt. A common lava of dark color and of great fluidity when molten. Basalt is less siliceous than granite and rhyolite and contains much more iron, calcium, and magnesium.

Biaxial. Applied to crystals whose molecular structure and behavior toward light are not completely symmetrical about any single line or axis. As explained under "birefringence," a beam of ordinary (unpolarized) light on entering any crystal not of the isometric system is split into two beams, which, in most directions within the crystal, travel with different speed. In a biaxial crystal, however, there are two directions or optic axes (hence the name) along which the two beams travel with the same speed and consequently emerge without birefringence. Most of the common rock-forming minerals are biaxial.

Biotite. The common black mica present in many granitic rocks and in metamorphic rocks. A complex silicate of hydrogen, potassium, iron, aluminum, and other elements.

Birefringence. The property possessed by crystals belonging to other than the isometric system of splitting a beam of ordinary light into two beams which traverse the crystal at different speeds and as they pass out of it produce characteristic optical effects that are recognizable with the proper instruments or, in some cases, by the eye alone. Birefringence is also known as double refraction.

[1] This glossary of terms that may be unfamiliar to some readers of the report, is, of course, not prepared for geologists or for mining engineers with geologic training. They will realize that full and accurate explanation of most scientific terms in familiar language is impossible. The best that can be hoped for is a rough approximation to the truth.

Bolson (pronounced bowl-sown′). A flat-floored desert valley that drains to a central evaporation pan or playa (pronounced nearly plah′-yah).

Bornite. A sulphide of copper and iron having when freshly broken a characteristic metallic brown tint which soon changes, on exposure, to various bright colors. From the latter circumstance the mineral gets one of its common names, "peacock ore." Bornite contains about 55 per cent of copper, 16 per cent of iron, and 28 per cent of sulphur.

Brachiopods (Brachiopoda). A class of marine shelled animals very abundant in past geologic ages but represented by few species in the present seas.

Breccia (pronounced bretch′a). A mass of naturally cemented angular rock fragments. Breccias are of various kinds. Some are formed by the crushing of the rock along a fault, some by explosive volcanic eruptions, and others have been deposited by running water where the fragments were not carried far enough to round them. The Gila conglomerate grades into material that is nearly or quite a breccia of the last kind mentioned.

Calcite. The most abundant mineral form of calcium carbonate. A white or light-colored mineral, easily cut with a knife and cleaving perfectly in three directions along planes that meet obliquely. Calcite is the chief constituent of limestone and marble, is a product of the weathering of most igneous rocks, and occurs in many veins.

Cartographic. Pertaining to a map. In geology a cartographic unit is a rock or group of rocks that is shown on a geologic map by a single color or pattern.

Chalcedony. The form of silica which, when artificially colored, is familiar to all as agate. It is very finely crystalline quartz with sometimes more or less opal and other less common forms of silica also present. In the Miami district some of the chalcedony, delicately colored by chrysocolla, has been used as a gem.

Chalcocite. A mineral composed of sulphide of copper and containing about 80 per cent of copper and 20 per cent of sulphur. Chalcocite is what is known to chemists as the cuprous sulphide of copper, in which two atoms of copper are combined with one atom of sulphur, whereas the blue sulphide of copper, covellite, is the cupric sulphide containing one atom of copper to one atom of sulphur, or 66.4 per cent of copper to 33.6 per cent of sulphur. Chalcocite is of metallic appearance when freshly broken and of dark lead-gray color. It is easily cut with a knife. The mineral is the characteristic and most valuable product of the downward enrichment of copper ores and is the chief source of copper in the Ray and Miami districts.

Chalcopyrite. A brass-yellow mineral consisting of sulphide of copper and iron. It contains 34.5 per cent of copper, 30.5 per cent of iron, and 35 per cent of sulphur. A common source of copper and probably the mineral from which much of the copper in the Ray and Miami ore bodies was originally derived. Distinguishable from pyrite by its greater softness, being easily cut or scratched with a knife.

Chalcotrichite. A variety of cuprite in which the crystals are slender and hairlike.

Chlorite. A group of soft green mica-like minerals common in schists formed from igneous rocks and as decomposition products of biotite, augite, and other minerals.

Chrysocolla. A mineral consisting of hydrous silicate of copper and containing about 36 per cent of copper and 20 per cent of water. Generally green or blue-green, in curved layers suggestive of the structure of agate. A product of the oxidation of sulphides containing copper. Some varieties are brown or black in consequence of impurities such as manganese oxide.

Cleavage. In mineralogy the property possessed by some crystals of splitting in certain definite directions, the result of the break being flat surfaces whose smoothness or polish varies in different crystals but is always the same for the same direction of splitting in crystals of the same substance. Cleavage is always parallel with some crystal face, and a particular cleavage is designated with reference to that face. Galena, for example, is said to have a cubic cleavage, for it breaks into right-angled blocks each side of which is parallel with the face of the cube, a common crystal form of the mineral. The familiar mineral quartz has no cleavage and breaks irregularly, like glass. The cleavage of minerals is a highly characteristic property and is very useful in identifying them.

Clinochlore. A green mica-like mineral belonging to the chlorite group.

Continental deposits. Sedimentary deposits laid down within a general land area and deposited in lakes or streams or by the wind, as contrasted with marine deposits, laid down in the sea.

Corrasion. The mechanical wearing away of rocks by running water. The Grand Canyon of Arizona is a magnificent example of work done mainly by corrasion.

Correlation. In geology, the age relationships between the rocks of different areas; especially, with reference to stratified rocks, the relation of having been deposited at approximately the same time or by processes continuously in operation, under identical conditions, from one area to the other. Fossils constitute the chief evidence in problems of correlation. For example, the Devonian limestone in the Ray-Miami region contains the same fossils as the Martin limestone at Bisbee, and as these fossils are thoroughly characteristic of Devonian marine life it is safe to conclude that the beds in the two areas were deposited at about the same time and probably in the same sea. The Scanlan conglomerate, if the supposition that it is a marine wave-worked deposit is correct, was laid down along the shore of an advancing sea and was thus deposited progressively and continuously under identical conditions from one area to another. Correlation in the one case is established principally by fossils; in the other, principally by the physical character of the deposit and its relation to beds above and below it.

Corundum. A mineral consisting of crystallized oxide of aluminum. Exceeded in hardness only by the diamond. In the Ray-Miami region known only as a microscopic constituent of some schists.

Covellite. An indigo to dark-blue mineral consisting of cupric sulphide. *See also* Chalcocite.

Crinoids (Crinoides). A class of stemmed, flower-like marine animals inhabiting generally rather deep water. Popularly known as sea lilies.

Cross-bedding. An oblique or inclined layering in some sedimentary rocks which may form a considerable angle with the true bedding planes. Cross-bedding is especially characteristic of sands deposited by streams or by winds.

Crystal. Most matter, when it passes from a dissolved or melted state into the solid state, tends to form regular faceted or flat-faced bodies known as crystals—that is, it tends to crystallize. The resulting solid mass may be a single crystal or an aggregate or group of crystals. If the passage from the melted to the solid condition is too rapid crystals may not have time to form, and the product is a glass. Each crystal is a little structure or miniature building in which the blocks, invisible particles of matter termed molecules, are arranged in a perfectly definite way that is always the same for each kind of crystal. Every substance, moreover, capable of crystallizing has its own set of crystal forms that are unlike those of any other substance. As a result of its definite molecular structure a crystal is bounded by certain regular planes or facets which are the outward expression of its inner structure. Even if these faces are worn or broken off and only an irregular grain remains, the mineralogist by special methods can find out the structure of this grain and tell what its original crystal form must have been. A quartz crystal, for example, may be ground and polished into a ball, but the mineralogist can readily ascertain, by various means which can not be described here, that the ball is not glass but has the crystal structure of quartz and therefore must be quartz. The crystals in an igneous rock, like granite, may have so crowded one another in growing that all are packed together as closely fitting irregular grains with no crystal faces; yet the petrographer by the use of the microscope can tell from the structure of each grain what its general crystal form would have been had it been given ample space to develop.

As has been intimated, crystals grow. They do not, however, like plants and animals, absorb nutriment and build it into their bodies from within. On the contrary, they grow by adding one thin layer after another to their outer surface.

The chief regularity in the outward form of a crystal consists in the fact that the angle at which one face meets another face is always the same for certain crystal forms and is always the same between corresponding pairs of faces on all crystals of the same substance. For example, the mineral cuprite, the red oxide of copper, sometimes crystallizes as cubes. All six faces of such cubes may be true squares, but more commonly they are oblong and the crystal may be so slim as to resemble a hair more than a cube. Nevertheless, each of the six faces will be found to meet its neighbors exactly at right angles, and the hairlike crystals are mineralogically cubic, although not geometrically so. Again, as is well known, quartz forms sharp-pointed crystals. The shape and size of the triangular faces that come together to make the point may vary greatly in different crystals, but the angle over the point, or the sharpness of the point, is always exactly the same in all crystals of quartz.

Crystals are divided, in accordance with the kind of symmetry shown by their structure, into six systems or, more in detail, into thirty-two classes. For example, the isometric system includes those crystals in which there are three imaginary lines or axes at right angles about which every particle of matter in the crystal is symmetrically arranged. The cube and the octahedron are common isometric forms. In the hexagonal system everything in the crystal is completely symmetrical about a single axis, and the crystals belonging to this system are generally long or prismatic with hexagonal cross sections. Quartz is hexagonal.

Crystalline rock. A rock composed of closely fitting mineral crystals that have formed in the rock substance, as contrasted with one made up of cemented grains of sand or other material or with a volcanic glass.

Cuprite. The naturally occurring red oxide of copper, containing about 11 per cent of oxygen and 89 per cent of copper. Usually crystallizes in small cubes or octahedrons, or combinations of these forms.

Cyclic. Applied to any action or process that after going through a certain course or accomplishing a definite order of changes begins again the same course or order, and so on indefinitely until some new influence stops or changes the action.

Deformation. In geology any change in the original shape of rock masses. Folding and faulting are common modes of deformation.

Deltaic deposits. Sedimentary deposits laid down in a river delta.

Denudation. In geology, the same as erosion, although there has been an effort by some to restrict the term to the stripping away of overlying material from some particular rock or surface. *See also* Erosion.

Devitrification. In geology the change from a clear volcanic glass to a dull opaque rock as the result of the growth of innumerable minute crystals within the glass. Under suitable conditions and with sufficient time any glass will crystallize and lose its transparency.

Diabase. A dark, heavy intrusive rock having the same composition as basalt but, on account of its slower cooling, a more crystalline texture. (*See also* Ophitic texture.) Its principal constituent minerals are feldspar, augite, and usually olivine. Olivine is easily changed by weathering and in many diabases is no longer recognizable.

Differentiation. The process or processes whereby cooling magma separates into rocks of different kinds, usually connected by gradations. The causes of such variations, or differentiation facies, as they are called, have been much discussed and are not yet fully understood.

Dike. An upright or steeply dipping sheet of igneous rock that has solidified in a crack or fissure in the earth's crust.

Diopside. A light-colored member of the pyroxene group, to which augite also belongs. Chiefly a silicate of calcium and magnesium. Color generally white or pale green.

Diorite. An even-grained intrusive igneous rock consisting chiefly of the minerals feldspar, hornblende, and very commonly black mica. If the rock contains considerable quartz, it is called quartz diorite. Quartz diorite resembles granite and is connected with that rock by many intermediate varieties, including quartz monzonite and granodiorite. The feldspar in diorite differs from that in granite in containing calcium and sodium instead of potassium.

Dip. The slope of a rock layer, vein, or fissure, measured by the angle made with a horizontal plane. *See also* Strike.

Dissected. Cut by erosion into hills and valleys or into flat upland areas separated by valleys. Applicable especially to plains or peneplains in process of erosion after an uplift. *See* Dissection.

Dissection. In geology, the work of erosion in destroying the continuity of a relatively even surface by cutting ravines or valleys into it.

Dolomite limestone. A limestone containing besides the mineral calcite (calcium carbonate) a considerable proportion of the mineral dolomite (calcium-magnesium carbonate). A magnesian limestone.

Dome. Rock layers or beds bent into a short anticline, suggestive of an inverted basin.

Drusy. Coated or lined with closely set, projecting crystals.

Epidote. A mineral silicate consisting chiefly of calcium, aluminum, and iron, generally of a peculiar yellow-green color and of prismatic crystal form. A common product of rock alteration and so what is generally termed a secondary mineral. It may occur in limestone as a result of metamorphism by an intrusive igneous rock.

Erosion. The group of processes whereby earthy or rocky material is loosened or dissolved and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation. The mechanical wear and transportation is effected by running water, waves, moving ice, or winds, which use rock fragments to pound or grind other rocks to powder or sand. *See also* Denudation.

Erosion surface. A land surface shaped by the disintegrating, dissolving, and wearing action of streams, ice, rain, winds, and other land and atmospheric agencies.

Eruptive rock. A rock poured out from a volcano or a volcanic vent as molten lava or as a hot mud flow. Lava. An extrusive, effusive, or volcanic rock. Eruptive rocks may flow over a land surface or over a sea bottom. Rocks composed of volcanic fragments blown into the air from a volcano are often classed as eruptive or volcanic rocks, but although their material is volcanic their mode of deposition from air or water allies them very closely to the sedimentary rocks. There are gradations between such fragmental volcanic rocks and ordinary sandstones.

Euhedral. Denoting a crystal that is well faced or completely bounded by crystal planes. Same as automorphic, or idiomorphic.

Eutaxitic. Applied to the streaky texture of some glassy lavas in which included fragments of lava, while still hot and plastic, have been drawn out into streaks by the motion of the lava flow.

Facies. Variety; especially applied to an igneous rock that in some respects is a departure from the normal or typical rock of the mass to which it belongs. Thus a mass of granite may grade into porphyritic facies near its borders.

Fault. A movement or displacement of the rock on one side of a fracture in the earth's crust past the rock on the other side. If the fracture is inclined and the rock on one side appears to have slid down the slope of the fracture the fault is termed a normal fault. If, on the other hand, the rock on one side appears to have been shoved up the inclined plane of the break the fault is termed a reverse fault.

Fault block. A part of the earth's crust bounded wholly or in large part by faults.

Fault scarp. The cliff formed by a fault. Most fault scarps have been modified by erosion since the faulting.

Fauna. The animals that inhabited the world or a particular region at a certain time.

Feldspar. A group of light-colored, mostly white rock-forming silicate minerals, chiefly silicates of potassium and aluminum, or of sodium, calcium, and aluminum in various proportions.

Felsic. A short term applicable to the group of feldspathic minerals and quartz and to the rocks composed predominantly of these minerals. *See also* "Mafic."

Fibrolite. A mineral of the same composition as andalusite, which it closely resembles in crystal form, although generally in more slender crystals.

Fissile. Splitting readily into thin sheets, like shale, slate, or some kinds of schist.

Fissure. An extensive crack, break, or fracture in the rocks. A mere joint or crack persisting only for a few inches or a few feet is not usually termed a fissure by geologists or miners, although in a strict physical sense it is one.

Flood plain. The nearly level land that borders a stream and is subject to occasional overflow. Flood plains are built up by sediment left by such overflows.

Flora. The assemblage of plants growing at a given time or in a given place.

Fluviatile deposits. Sedimentary deposits laid down by a river or stream. The Gila conglomerate is a fluviatile deposit.

Fold. A bend in rock layers or beds. Anticlines and synclines are the common types of folds.

Formation. A rock layer, or a series of continuously deposited layers grouped together, regarded by the geologist as a unit for purposes of description and mapping. A formation is usually named from some place where it is exposed in its typical character. For example, Troy quartzite, Pinal schist.

Fossil. The whole or any part of an animal or plant that has been preserved in the rocks, or the impression left by a plant or animal. This preservation is invariably accompanied by some change in substance, and in impressions the original substance has all been removed.

Galena. The mineral sulphide of lead, containing, when pure, 86.6 per cent of lead and 13.4 per cent of sulphur. A metallic lead-gray mineral recognizable by its color, weight, and softness and the fact that when crushed it breaks into little cubes (cubic cleavage). A very important ore of lead. In many places it contains silver.

Garnet. Commonly a brown or red mineral in crystals which, when perfect, are isometric polyhedrons, often with 12 diamond-shaped faces, known as rhombic dodecahedrons. There are several kinds of garnet differing in chemical composition. The common sorts are silicates of aluminum and of calcium, magnesium, iron, or manganese. Garnet is a frequent product of contact metamorphism.

Globulites. Tiny rounded incipient crystal forms visible in some volcanic glasses when they are examined in thin sections under a microscope.

Gneiss (pronounced "nice"). A rock resembling granite but with its mineral constituents so arranged as to give it a banded appearance. Most gneisses are metamorphic rocks derived from granite or other igneous rocks.

Gneissic, gneissoid. Having the appearance or character of gneiss.

Granite. A crystalline igneous rock that has solidified slowly deep within the earth. It consists chiefly of the minerals quartz, feldspar, and one or both of the common kinds of mica, namely black mica, or biotite, and white mica, or muscovite. Some varieties contain hornblende. The feldspar is of the kind known as orthoclase and may be distinguished from quartz by its pale-reddish tint and its property of breaking with flat, shining surfaces (cleavage), while quartz breaks irregularly. The micas are easily recognized by their cleavage into thin, flexible flakes and their brilliant luster.

Granodiorite. A granitic rock closely allied to quartz monzonite and quartz diorite.

Groundmass. The finer-grained part of a porphyritic rock, in which the larger crystals, or phenocrysts, are embedded.

Hade. The vertical angle between a fault plane and a vertical plane parallel with the fault strike or trend. The complement of the fault dip.

Holocrystalline. Applied to a rock composed wholly of crystal grains and containing no volcanic glass. Intrusive igneous rocks are almost invariably holocrystalline.

Homocline. A body of strata that dip uniformly in one direction. A homocline may be a tilted fault block, a monocline, or the remnant of an anticline or syncline of which the other limb or side has disappeared through faulting or erosion.

Horizon. In geology, any distinctive plane traceable from place to place in different exposures of strata and marking approximately the same period of geologic time. The beds at a particular horizon may be characterized by distinctive fossils.

Hornblende. A dark-green to black mineral silicate of complex and variable composition but containing usually considerable iron and magnesium. Usually in elongated or prismatic crystals. An abundant constituent of many rocks, especially of diorite and andesite. In fresh rocks the mineral may show flashing surfaces that might lead to its being mistaken for black mica (biotite). An original mineral in some igneous rocks but also a common alteration product of the chemically similar augite.

Hypidiomorphic. Nearly or not quite idiomorphic. *See also* Euhedral.

Hypogene. Applied to ores or ore minerals that have been formed by generally ascending waters as contrasted with supergene ores or minerals.

Idiomorphic. *See* Euhedral.

Igneous rocks. Rocks formed by the cooling and solidification of a hot liquid material, known as magma, that has originated at unknown depths within the earth. Those that have solidified beneath the surface are known as intrusive rocks, or, if the cooling has taken place slowly at great depth, as plutonic intrusive or plutonic rocks. Those that have flowed out over the surface are known as effusive rocks, exclusive rocks, or lavas. The term "volcanic rocks" includes not only lavas but bombs, tuff, volcanic ash, and other fragmental materials or ejecta thrown out from volcanoes.

Ilmenite. Titanic iron ore. A hard black mineral resembling magnetite but only slightly attracted by a magnet. An oxide of iron and titanium.

Induration. Hardening; especially the hardening of loose or soft material into firm rock or the change of soft rock into harder rock.

Interference figure. A system of colored rings and curves combined with black bars and curves seen when a thin section of a mineral is examined in a certain way through the microscope or other suitable optical instrument. The interference figure is due to birefringence and is one of the most useful optical aids in identifying minerals. *See also* Birefringence.

Intratelluric. Within the earth or formed within the earth.

Intrusion displacement. Faulting coincident with the intrusion of an igneous rock.

Irruptive rock. An igneous rock which was forced into or invaded other rocks as molten magma. An intrusive rock. The distinction between "irruptive" and "eruptive" is often disregarded.

Kaolinite. A white soft earthy mineral consisting of a hydrous silicate of aluminum and one of the chief constituents of clay. A common product of rock decay and of oxidation in veins.

Lacustrine. Pertaining to a lake. Lacustrine deposits are sediments laid down in a lake.

Limonite. A brown mineral consisting of hydrous oxide of iron and containing, when pure, 85.6 per cent of iron and 14.4 per cent of water. The mineral is earthy or of irregular form, never occurring in distinct crystals. It is the usual product left behind in the oxidation of pyrite. The minerals turgite and göthite are also hydrous iron oxides not always readily distinguishable from limonite. They contain less water than limonite.

Lithoidal. Applied to those fine-grained groundmasses of volcanic rocks that are dull and comparatively opaque in consequence of the presence of minute crowded crystals as contrasted with those in which the groundmass is shining and glassy. Stony.

Lithologic. Pertaining to lithology, or the study of rocks. (*See also* Petrology.) Pertaining to rock character.

Lithosphere. The rocky and interior part of the earth's body, exclusive of the oceans and other water masses (hydrosphere) and the atmosphere.

Littoral. Pertaining to a shore. Particularly to sedimentary deposits laid down along a shore.

Mafic. A short substitute for ferromagnesian. Applied to minerals containing iron and magnesium as essential constituents or to rocks composed chiefly of such minerals. *See also* Felsic.

Magma. The fused liquid material that solidified as igneous rocks. If magma reaches the surface it is known as lava.

Magnetite. Magnetic oxide of iron. A black opaque mineral almost universal as a minor constituent of igneous rocks and fairly abundant in some, as in diabase. Often recognizable only with the microscope. A valuable ore of iron in some localities.

Malachite. The green carbonate of copper. A beautiful deep-green mineral occurring generally in long, slender crystals which may be closely crowded into radial sheaves or crusts. It contains about 57 per cent of copper and 8 per cent of water. A product of the oxidation of sulphides of copper.

Massive rock. An igneous rock as opposed to a bedded or stratified rock.

Megascopic, megascopical. Large enough to be seen without the use of the microscope. The megascopic features of a rock are such as are apparent on ordinary inspection, as opposed to the microscopic features.

Melaconite. The soft, earthy, mineral form of the black oxide of copper, containing 79.8 per cent of copper.

Metallization. The process or group of processes whereby valuable metals, or minerals containing such metals, are introduced into the rocks. The term "mineralization" is often used in this sense but is really more comprehensive. The formation of garnet in limestone, for example, is a result of mineralization but may have no economic significance whatever.

Metamorphism. Any change in rocks effected in the earth by heat, pressure, solutions, or gases. A common cause of the metamorphism of rocks is the intrusion into them of igneous rocks or, more accurately, of magma. Rocks that have been so changed are termed metamorphic.

Miarolitic. Applied to cavities lined with projecting crystals of quartz and feldspar that occur in some granitic rocks and were formed during the cooling and crystallization of the magma into rock.

Microcline. A potassium feldspar of the same composition as orthoclase and of nearly identical appearance, but crystallizing in a different crystal system.

Micropegmatitic texture. A microscopic intergrowth of two minerals, especially of quartz and feldspar, in which one mineral contains particles of the other arranged in a more or less regular pattern which, from its fancied resemblance to certain ancient inscriptions, has been called also "graphic" texture.

Microperthite. A microscopic intergrowth of the two feldspars orthoclase and albite in a certain regular way.

Monocline. A simple bend in bedded rocks which is equivalent to one side of an arch or sag. Usually a monocline appears as a steplike flexure in nearly horizontal beds and may pass into a break or fault in one direction and gradually die out in the other direction. Monocline is a less general term than homocline. *See also* Homocline.

Monzonite. An intrusive igneous rock of general granitic appearance but containing a larger proportion of calcic feldspar than granite. There is commonly quartz present and the rock is then a quartz monzonite. Quartz monzonite is intermediate in composition between granite and quartz diorite.

Muscovite. The common white mica abundant in many granites and schists. A complex silicate chiefly of hydrogen, potassium, and aluminum.

Norm. A theoretical and in part arbitrary mineral composition of a rock, calculated, in accordance with certain rules, from the chemical analysis, for the purpose of assigning the rock its place in the norm system of rock classification. The norm rarely coincides with the real mineral composition, or mode, of a rock.

Norm system. A system of classification and nomenclature for igneous rocks based on the norm (which see) of each rock. Only undecomposed rocks of which accurate chemical analyses are available are classifiable in this system, which consequently is more used in detailed petrologic studies than in ordinary geologic or mining work. The system was devised by Messrs. Cross, Iddings, Pirsson, and Washington, who designated it originally "the quantitative system" and later the "C. I. P. W. system." It has also been referred to as the "American system."

Oligoclase. One of the plagioclase group of feldspars containing much more sodium than calcium. Common in igneous rocks of the granite and quartz diorite groups.

Olivine. A dark yellowish-green silicate of iron and magnesium common in certain dark igneous rocks, particularly in basalt and diabase. Not as a rule in well-formed crystals and often recognizable only with the microscope. Decomposes readily to the mineral serpentine. Also known as chrysolite and peridote.

Ophitic texture. The characteristic texture of diabase and closely related rocks in which the feldspar crystals have fairly complete crystal boundaries, and the augite fills the angular spaces between them.

Orthoclase. The common potash feldspar. A common constituent of granites. Usually white to reddish. Splits or cleaves so as to give smooth, shining surfaces.

Outcrop. That part of a rock that appears at the surface. The appearance of a rock at the surface or its projection above the soil.

Peneplain. The nearly level surface to which erosion in time reduces a mountainous region, provided the land does not rise or sink during the process of wearing down.

Petrography. The branch of science that deals with the description of rocks; in practice especially the igneous and metamorphic rocks studied with the aid of the microscope.

Petrology. The general study of rocks, with special reference to their origin and broader relations. In current usage the term applies particularly to the problems relating to igneous and metamorphic rocks.

Phenocrysts. The larger crystals of a porphyritic igneous rock that are distinct from the groundmass or fine-grained portion.

Phlogopite. A mica closely related to biotite but containing less iron and of lighter color.

Plagioclase. A convenient designation for the feldspars consisting chiefly of silicates of sodium, calcium, and aluminum as opposed to those consisting chiefly of potassium and aluminum silicates. The name has reference to the oblique character of the cleavage of these feldspars as compared with orthoclase, the common potassium feldspar.

Pleochroic. Possessing the property of pleochroism.

Pleochroism. The property possessed by some minerals of showing different colors or different tints of the same color when rays of light (polarized light) are passed through them in a certain way in different directions. A useful optical aid in the identification of minerals.

Poikilitic texture. That texture in an igneous rock produced by the inclusion in one mineral grain or crystal of many particles of another mineral. The structure may be compared to chips of wood frozen into a block of ice, the chips having their grain running in various directions.

Porphyritic. Having the texture of a porphyry.

Porphyry. Any igneous rock in which certain crystals (phenocrysts) are distinct from a fine-grained matrix (groundmass).

Protore. Low-grade material which by natural processes of enrichment is convertible into ore; as, for example, the so-called primary ore of the disseminated copper deposits, containing generally less than 0.5 per cent of copper.

Pyrite. The familiar pale-yellow mineral sulphide of iron containing theoretically 46.6 per cent of iron and 53.4 cent of sulphur. The common crystal forms are cubes, octahedrons, 12-sided solid figures with 5-sided faces (pentagonal dodecahedrons), or combinations of these. Often without complete crystal form.

Pyroclastic. Applied to rocks made up of igneous rock fragments produced by explosive volcanic action. Tuffs and volcanic breccias are pyroclastic rocks.

Pyroxene. A large and abundant group of minerals of which members occur in igneous and metamorphic rocks. They are silicates of a wide range of composition and color but all closely related in crystal form. Augite, diopside, and wollastonite are pyroxenes.

Quartzite. A rock composed of sand grains cemented by silica into an extremely hard mass.

Rhyolite. A lava, usually of light color, corresponding in chemical composition to granite. The same molten liquid that at great depth within the earth solidifies as granite would, if it flowed out on the surface, cool more quickly and crystallize less completely as rhyolite.

Rugose corals. Fossil corals belonging to the extinct order Rugosa and resembling a ribbed cornucopia in shape.

Rutile. Oxide of titanium in crystals, usually small and of various colors. Occurs commonly only as a minor microscopic constituent of rocks.

Sanidine. A clear variety of orthoclase occurring in some siliceous lavas.

Saprolite. Decomposed or disintegrated rock in place. Saprolite may retain the general appearance of the original rock, save usually for more or less change in color, but is so soft as to be easily picked or shoveled.

Schist. A rock which by subjection to heat and pressure within the earth has undergone a change in the character of the particles or minerals that compose it and in which these minerals are arranged in such a way that the rock splits more easily in certain directions than in others. A schist has a crystalline grain roughly comparable with the grain of a piece of wood. The distinction between a schist and a gneiss is sometimes difficult to make, but in general the layers of a gneiss differ from one another in mineral composition and the rock does not split as freely and evenly as schist.

Sedimentary rocks. Rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eolian deposits). The sediment may consist of rock fragments or particles of various sizes (conglomerate, sandstone, shale); of the remains or products of animals or plants (certain limestones and coal); of the product of chemical action or of evaporation (salt, gypsum, etc.); or of mixtures of these materials. Some sedimentary deposits (tuffs) are composed of fragments blown from volcanoes and deposited on land or in water. A characteristic feature of sedimentary deposits is a layered structure known as bedding or stratification. Each layer is a bed or stratum. Sedimentary beds as deposited lie flat or nearly flat.

Sempatic. Descriptive term applied to porphyritic igneous rocks to indicate that the total volumes of phenocryst and groundmass are nearly equal.

Sericite. A small-scaled variety of the common white mica, muscovite.

Serpentine. A mineral silicate of magnesium containing considerable combined water. Generally some shade of green or yellow. A common alteration product of olivine and other magnesium-bearing silicates. Occurs in various forms from microscopic fibers in other minerals or rocks to extensive rock masses consisting almost wholly of this mineral.

Shale. A rock consisting of hardened fine mud deposited in thin layers that may be split apart.

Sherd. A fragment of pottery. In petrography applied particularly to the characteristic crescentic or cuspate particles into which volcanic glass is sometimes blown, while still hot, by the expansive force of included gases. The glass particles of tuff often show such cuspate outlines.

Sill. A sheet of igneous rock intruded in an attitude more nearly horizontal than vertical and as a rule between beds of sedimentary rock.

Sillimanite. Same as fibrolite. *See* Fibrolite.

Slate. A rock that by subjection to pressure within the earth has acquired the property of splitting smoothly into thin plates. The cleavage is smoother and more regular than the splitting of schist along its grain.

Solute. That which is dissolved in a solvent as the sugar in a cup of coffee.

Sphalerite. Zinc blende, the common crystallized mineral sulphide of zinc. A black, brown, or yellow mineral of resinous luster which splits (cleaves) into pieces having very smooth, even, and shining flat surfaces. Zinc blende contains 67 per cent of zinc and 33 per cent of sulphur. It is one of the chief sources of zinc.

Spherulites. Ball-like bodies, especially common in some volcanic glasses, formed by the growth of radial clusters of crystals within the glass. They vary in size from pellets like small shot to balls several inches across.

Stratigraphy. The branch of geology that deals with the order of deposition and regional relations of the strata of the earth's crust.

Strike. The direction along which a vertical or inclined rock layer, vein, or fissure would meet the earth's surface if that surface were level. The outcrop of a bed or dike on a plain is coincident with its strike.

Structure. In geology, the forms assumed by sedimentary beds and igneous rocks that have been moved from their original position by forces within the earth, or the forms taken by intrusive masses of igneous rock in connection with effects produced mechanically on neighboring rocks by the intrusion. Folds (anticlines and synclines) and faults are the principal effects considered under structure. Schistosity and cleavage are also structural features.

Subhedral. Applied to a crystal that is only partly bounded by crystal planes. Same as hypautomorphic or hypidiomorphic.

Supergene. Applied to ores or ore minerals that have been formed by generally descending water. Ores or minerals formed by downward enrichment.

Syncline. An inverted arch of bedded or layered rock suggestive in form of a canoe. The term relates to the structure of the beds, not to the surface of the land.

Talus (pronounced tay′lus). The mass of loose rock fragments that accumulates at the base of a cliff or steep slope.

Tectonic. Pertaining to structure. A tectonic feature on the earth's surface is one due to rock movements as opposed to a feature produced by erosion or deposition.

Terrace. A steplike bench on a hillside. Most terraces along rivers are remnants of valley bottoms formed when the land was lower or when the stream flowed at higher levels. Other terraces have been formed by waves. Some terraces have been cut in solid rock, others have been built up of sand and gravel, and still others have been partly cut and partly built up.

Thin section. A fragment of rock or mineral ground to paper thinness, polished, and mounted between glasses as a microscopic slide. Rocks and most minerals, except the oxides and sulphides of the metals, are translucent to transparent in thin section, and the optical properties of each mineral can be studied with the microscope.

Thulite. A pink mineral of the epidote group, which owes its color to the presence of manganese.

Titanite. A crystalline mineral composed of titanium, calcium, silicon, and oxygen (a titanosilicate of calcium). A fairly common but rarely abundant constituent of some granitic igneous rocks. Generally yellow or brown with waxy luster. Can frequently be recognized without the aid of a lens.

Tourmaline. A complex mineral silicate of boron and aluminum with other constituents. Commonly in black prisms with curved triangular cross sections. A microscopic constituent of some of the Pinal schist.

Transportation. In geology, the shifting of material from one place to another on the earth's surface by moving water, ice, or air. The carriage of mud and dissolved salts by rivers, the passage of a dust-laden whirlwind across a desert, the inland march of sand dunes from a sea shore, and the creeping movement of rocks on a glacier are all examples of transportation.

Trichites. Hairlike incipient crystal forms visible in some volcanic glasses when examined in thin section under the microscope. Trichites are formed by the aggregation of globulites. *See also* Globulite.

Tuff. A rock consisting of a layer or layers of lava particles blown from a volcano. A fine tuff is often called volcanic ash, and a coarse tuff is called breccia.

Tuffaceous. Having the character or appearance of a tuff.

Tuff-breccia. A stratified tuffaceous rock in which the fragments are angular and larger than in a tuff.

Type locality. The place at which a formation is typically displayed and from which it is named; also the place at which a fossil or other geologic feature is displayed in typical form.

Unconformity. A break in the regular succession of sedimentary rocks, indicated by the fact that one bed rests on the eroded surface of one or more beds which may have a distinctly different dip from the bed above. An unconformity may indicate that the beds below it have at some time been raised above the sea and have been eroded. In some places beds thousands of feet thick have been washed away before the land again became submerged and the first bed above the surface of unconformity was deposited. If beds of rock may be regarded as leaves in the volume of geologic history an unconformity marks a gap in the record.

Uniaxial. Applied to crystals whose molecular structure has the highest possible grade of symmetry with reference to one crystal axis. In the direction of this axis both beams into which a ray of ordinary light is split on entering the crystal travel with the same speed and consequently emerge without birefringence. Quartz is uniaxial.

Uralitization. The change of the mineral augite into the green fibrous variety of the mineral hornblende. The change is often due to weathering but may be a result of more intense metamorphism.

Vein. A mass of mineral material that has been deposited in or along a fissure in the rocks. A vein differs from a dike in that the vein material was introduced gradually by deposition from solution, whereas a dike was intruded in a molten condition.

Versant. One side or slope of a mountain range, as the east versant.

Vesuvianite. A green, yellow, or brown mineral, generally in short, square prismatic crystals occurring characteristically in limestone where altered by the heat and emanations from an intrusive rock. Vesuvianite is a silicate of calcium and aluminum.

Vitrophyric. Applied to that structure in lavas in which the larger crystals or phenocrysts are embedded in a volcanic glass.

Volcanic glass. Lava that has cooled and solidified before it has had time to crystallize.

Volcanic rocks. Igneous rocks erupted at or near the earth's surface, including lavas, tuffs, volcanic ashes, and like material, which are also classifiable as sedimentary rocks.

Weathering. The group of processes, such as the chemical action of air and rain water and of plants and bacteria and the mechanical action of changes of temperature, whereby rocks on exposure to the weather change in character, decay, and finally crumble into soil.

Wollastonite. A white mineral of the pyroxene group consisting of silicate of calcium. A common product of the metamorphism of limestone by intrusive igneous rocks. Often in aggregates of flat prismatic crystals without distinct crystal planes or faces.

Zircon. The mineral silicate of zirconium. A fairly common but nowhere abundant microscopic constituent of many igneous rocks, especially of the granitic rocks.

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