DEPARTMENT OF THE INTERIOR
HUBERT WORK, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 763

GEOLOGY AND ORE DEPOSITS

OF THE

ARAVAIPA AND STANLEY MINING DISTRICTS GRAHAM COUNTY, ARIZONA

BY

CLYDE P. ROSS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1925

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GEOLOGY AND ORE DEPOSITS OF THE ARAVAIPA AND STANLEY MINING DISTRICTS, GRAHAM COUNTY, ARIZONA

By Clyde P. Ross

SUMMARY

The region in which the Aravaipa and Stanley mining districts are situated contains the rugged Santa Teresa and Turnbull mountains and the southeast end of the Mescal Range. It is not crossed by any railroad, and lack of good transportation is a serious obstacle to its development. The principal industries are mining and stock raising; there is also some farming by irrigation. The climate is semiarid but healthful. The rocks consist of pre-Cambrian metamorphosed igneous and sedimentary formations; Paleozoic quartzite, shale, and limestone of marine origin; Upper Cretaceous shallow-water marine deposits and volcanic beds; granite and quartz monzonite, probably intruded at the beginning of the Tertiary period; lava, pyroclastic rocks, and alluvium of Miocene (?) age; the Gila conglomerate (including tuff); and Quaternary alluvium. The lower part of the Paleozoic section differs from that in neighboring regions. After the intense crustal disturbances of pre-Cambrian time, there was extensive warping in the Paleozoic and Mesozoic eras. The batholithic intrusions at the beginning of the Tertiary were accompanied by doming and faulting. The overthrusts in the northern part of the region probably were produced at this time. Normal faulting continued with diminishing intensity into geologically recent time. There appear to have been five partial cycles of erosion from the Pliocene to the present.

The presence of deposits of silver, copper, and lead in this region has been known for 50 years, but only about 35,000 tons of ore has been mined. There are several small mines and numerous prospects, but development has been hindered by inaccessibility and lack of capital, so that the possibilities of the region as a metal producer have not even yet been adequately tested. At the present time mining, except for necessary assessment work, is practically at a standstill, but with improvement in conditions governing the mining industry in general development here will probably be renewed, and the future of the region may be regarded optimistically.

A lode system 11 miles long crops out west of the Santa Teresa Mountains. The lodes consist of fractured and replaced rock of various kinds and banded vein matter. The gangue is largely quartz and fluorite. The principal sulphides are galena with argentite in it, chalcopyrite, sphalerite, and pyrite. There are contact-metamorphic deposits which have been developed for copper; curious copper deposits in granite, which are closely related genetically to the intrusion; two types of veins related to the Tertiary volcanism, one containing principally copper with calcite as the characteristic gangue mineral, the other containing silver minerals with a gangue of quartz, barite, and fluorite; and some unimportant quartz veins containing gold. There has been some oxidation and a little enrichment.

INTRODUCTION

PURPOSE AND SCOPE OF THE REPORT

This report is the result of a little less than two months' field work in the summer of 1922. In order to obtain a basis for the study of the mineral deposits it was necessary to understand the general geology of the region. Consequently a geologic map was prepared, and a study of the stratigraphic and structural relations of the rocks was undertaken. As no adequate topographic map of this region had ever been made, however, it was necessary to prepare such a map to serve as a base for the geologic mapping. This restricted the time that could be devoted to geologic work. Nearly all the mines and prospects in the region mapped were visited. A few prospects on which little development work has yet been done were omitted for lack of time. The purpose in view was to gain an insight into the types of ore deposits rather than to make detailed examinations of individual mines such as would be undertaken by an engineer in commercial practice.

The facts gathered regarding the general geology of the region and the inferences drawn from them are presented both because they are necessary to a clear understanding of the ore deposits and because of their scientific interest. Available knowledge regarding the geology of southeastern Arizona is still incomplete, and the results of this investigation partly fill the gap. The mode of origin and general features of the ore deposits are discussed, and all the mines and prospects regarding which any information is available are described. The data in the report, though unavoidably incomplete, should be sufficient to give anyone a good general idea of the districts and their ore deposits. It is hoped that the descriptions of the ore deposits will aid mining men in the region to arrive at such an understanding of the characteristics of the deposits on their own properties as will assist them in planning future development.

There is some confusion as to the form of the word "Arivaipa." This spelling has been adopted by the United States Geographic Board for the canyon, creek, valley, and village and is etymologically correct. The name of the post office is, however, officially spelled "Aravaipa" by the Post Office Department, and the two mining companies in whose names the word occurs have followed the post-office spelling, which is also in accord with local usage.[1]

LOCATION AND EXTENT OF THE REGION

This report covers the Aravaipa and Stanley mining districts and a corner of the Black Rock mining district, in Graham County,

[1] On December 3, 1924, after this report was in type, the United States Geographic Board reversed its former decision and adopted the spelling "Aravaipa" for the canyon, creek, valley, and village.

Ariz. (see Pl. I), and includes a description of the coal fields on Deer Creek in Pinal County.

The greater part of this region has not been surveyed by the General Land Office, but it lies approximately in Tps. 4 to 7 S., Rs. 18 to 21 E., and comprises a total area of about 300 square miles.

The region is not yet crossed by any railroad, but the Bowie-Globe line of the Arizona Eastern Railroad passes within 10 miles of its northern border. Klondyke, the center of most activity in the region at present, is about 56 miles northeast of Tucson, 48 miles southeast of Globe, and 62 miles southwest of Clifton, measured in straight lines. Because of the lack of direct transportation facilities the distances that must be traveled to reach any of these places from Klondyke are much greater.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the hearty cooperation of the residents of the Aravaipa-Stanley region. A list of all who gave information, hospitality, and assistance in the course of the field work would include the majority of those engaged in mining in the region and a number not directly interested in that industry. Messrs. Jack Adair, of Klondyke, and H. T. and C. A. Firth, of Arivaipa, gave information and assistance of much value. Others are mentioned in appropriate places in the text. To acknowledge specifically all the courtesies received would require too much space, but all may feel assured that their assistance is appreciated.

Mr. H. A. Wentworth, president of the Aravaipa Leasing Co., has been most kind in furnishing maps and information regarding the various properties in the Aravaipa district, on which his company has done work. Among other things, he supplied notes by C. E. Minor, former superintendent of the Grand Reef mine, which were of great assistance, especially in regard to those portions of the mine now inaccessible. Mr. E. H. Bachman, of Globe, furnished assay maps of the Windsor mine prepared by him. The preparation of the report has also been aided by the cooperation of fellow members of the United States Geological Survey. Kirk Bryan generously supplied unpublished information and critically read the chapter on physiography. E. S. Larsen and C. S. Ross aided in some of the petrographic work, and W. T. Schaller helped in the determination of some of the minerals. Others gave suggestions of value. My wife, Ruth C. Ross, gave assistance in preparing the text and some of the illustrations.

HISTORICAL SKETCH

The Stanley and Aravaipa districts lie within the region acquired from Mexico by purchase in 1853. Remnants of cliff dwellings in the canyon known as Arivaipa Box testify to its settlement in very early times. Until the early seventies this area was but little visited by white men. The Apaches dominated the country so completely that settlement was practically impossible. Even as late as the eighties and early nineties there were sporadic Indian troubles, but some prospecting was in progress. The difficultly accessible canyons in the rocky Turnbull and Santa Teresa mountains are said to have been favorite refuges for rustlers and other lawless characters in the early days. About 1872 two large cattle ranches were established in Sulphur Spring Valley,[1a] and then or soon after cattle presumably ranged up into Arivaipa Valley.

Some of the mineral deposits now owned by the Aravaipa Mining Co. were known, and a little work was done in the late seventies, and it is even reported that a small smelter was erected at this time by Col. W. C. Bridwell, commonly known as "Buford." The coal in the upper end of the Deer Creek drainage basin was discovered by Bob and David Anderson about 1881. The Copper Belle deposit, near Stanley, was found about 1883, and the Friend, a few miles to the west, about the same time. Probably other deposits in the vicinity of Stanley were known at this early date, but the area north of Stanley Butte was then included in the San Carlos Indian Reservation and was not open for the location of mineral claims. The croppings of what is now known as the Grand Reef, in the Aravaipa district, are so prominent and striking that they were probably discovered very early. The veins on Imperial Hill were found in the seventies.

A considerable part of the development of the mines in the Aravaipa district was carried on in the nineties. The Arizona shaft of the Aravaipa Mining Co., the deepest shaft in the district, was put down to its present depth of 580 feet between 1890 and 1895. The Grand Reef mine also attained its present depth of 300 feet in the nineties, and the veins on Imperial Hill were worked about this time. The boundary of the San Carlos Reservation was shifted north to its present position in 1896, and the country between this and the old line, locally known as "the strip," was thrown open to prospectors, resulting in some mining activity in the Stanley district. No accurate data as to ore shipments from mines in either district in these early years are available, but they can not have been large. Small test shipments of coal were made from the "upper field" to Globe, and small quantities of lead-silver and copper ore were mined, and presumably part of it was shipped.

In the first few years of the present century there appears to have been little activity in either district. Between about 1906 and 1920 some of the mines and prospects were reopened. Work at the Star-

[1a] Meinzer, O. E., Water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 13, 1913.

light mine started in 1903, and the claims were patented in 1907, but the mine was closed about 1910. The Friend, Stanley, Copper Reef, and Princess Pat mines and several prospects were worked intermittently up to 1918 or a year or so later. In the Aravaipa district there was also some ore mined, largely by lessees. Most of the development work on the Royal Tinto group was done in 1906 and 1907. Some ore was shipped from the Aravaipa Mining Co.'s property by lessees about 1906. The Grand Reef mine was leased to local people in 1915. A mill was erected and ore in small quantities was shipped until the final shutdown in 1921. During the last two years of this period the mine was operated by the Aravaipa Leasing Co., which now owns the property. A few cars of ore have been shipped from the properties south of the Grand Reef, of which the most developed are those owned by Ted Quinn and James Quinn. Prospecting in both districts has been carried on by a number of people, but very little ore has been shipped except from the properties mentioned. Little or no ore has been shipped from either district since 1920.

INDUSTRIES

Stock raising vies with mining as the principal industry of the region. Cattle belonging to ranchers in Arivaipa Valley, near Stanley, and in the valley of Gila River range in the mountainous country, a large part of which is included in the Santa Teresa division of the Crook National Forest. Herds of goats wander over the country north and west of the Turnbull Mountains and also south of the Santa Teresa Mountains. On the slopes of the valley of Gila River between the Turnbull Mountains and the Indian reservation boundary herds of some hundreds of horses struggle for a livelihood. Ranchers in other parts of the region raise a few horses for their own use.

Agriculture is practiced along Arivaipa Creek and to a moderate extent elsewhere, but mostly as an adjunct to other interests. Insufficient food is raised to support the population, and considerable quantities, both canned and fresh, are shipped in from Willcox and from towns on Gila River. A considerable part of the grain and hay needed for stock must also be shipped in from the irrigated farms along Gila River.

Mining is of more potential than actual importance. Much prospecting and considerable haphazard development work has been done. The total shipments of ore and concentrates from all properties in the Aravaipa district regarding which information could be obtained amount to only about 6,000 tons, of which much the greater part came from the Grand Reef mine. In addition it is probable that a few carloads of ore have been shipped by lessees and prospectors regarding which no data were obtained. The data so far gathered as to production in the Stanley district are so fragmentary that figures can not be given, but the total is certainly much less than that for the Aravaipa district, because there is no single mine in the Stanley district whose production can compare with that of the Grand Reef. There are in the Aravaipa district 56 patented and 137 unpatented claims whose approximate positions are known and a number of unpatented claims for which data are lacking. The total number of claims in the Stanley district is undoubtedly greater than this, as there are several mines, notably the Copper Reef and Princess Pat, that have large groups of claims. The only patented ground in this district is the Starlight group of 12 claims.

From the facts above stated it is obvious that although the districts have been known for 50 years, they are still in the prospecting stage of development. There is no mine in either district which has yet been put on a firm foundation of successful production. On the other hand, it has by no means been proved that an adequate amount of correctly planned and directed development would not accomplish such a result.

CLIMATE

The region lies near the southern border of the mountain province of Arizona and has the climate characteristic of this province. It is so mild that outdoor work can be continued throughout the year with little difficulty or discomfort. During the greater part of the year the weather is most pleasant and healthful.

The temperature ranges from 20° F. up to somewhat over 100° F. The coolest weather comes in the first two months of the year, and June and July are usually the hottest months. The temperature does not soar to such heights as are characteristic for the southwestern part of the State. Even in midsummer oppressively hot days are rare.

A Weather Bureau station for recording the rainfall was maintained at Klondyke during the four or five years prior to 1919, but complete annual records are available for 1915 and 1916 only. These indicate that the annual rainfall at this place is about 19 inches. There are usually less than 60 days in a year in which 0.1 inch or more of precipitation takes place. These are concentrated into two rainy seasons. About half the annual precipitation occurs in July and August, and the greater part of the remainder falls in January and February. The annual snowfall is usually less than a foot, and in some years there is very little snow.

THE MAP

The topographic map was prepared by me by means of a plane-table survey. Section corners in the surveyed portion of Arivaipa Valley were utilized as known points from which to start the triangulation net. Any discrepancy between the assumed and actual positions of the section corners chosen is evidently within the allowable error for a map on the scale of 1:125,000, as the triangulation based on them proved to be consistent throughout. Thus the control is believed to be fairly good, so that the different parts of the area are mapped nearly in their proper relations. The topography as shown, however, is correct only in a general way. It was sketched from numerous points whose positions had been determined by triangulation. Every effort was made to sketch as accurately as possible, but errors of detail have undoubtedly been made. Altitudes were determined by means of an aneroid barometer, supplemented by vertical-angle measurements on the more prominent peaks with a Gale telescopic alidade. The data thus obtained were later adjusted so as to be consistent with themselves and with points of known altitude in the region mapped and in the Christmas quadrangle, adjoining it on the west, which has been accurately mapped by the United States Geological Survey. The determination of altitudes by such methods is subject to unavoidable errors, but the resulting inaccuracies are principally in matters of detail, and the map is an essentially correct representation of the topography of the region. A contour interval of 100 feet was adopted in order to show adequately differences in topographic form, even though the measurements of altitude are not strictly accurate or complete enough for this interval.

The latitude and longitude of Mount Turnbull, in the northeastern part of the Turnbull Mountains, have been accurately determined by the United States Geological Survey. This peak was carefully tied in to the triangulation net, and the latitude and longitude of the region were determined from it. The determinations thus made check closely with the position of the east boundary of the Christmas quadrangle as found by triangulation in the field.

The township net in the Aravaipa district is based on the plats of the General Land Office adjusted to the positions of a number of section corners determined in the field. The boundary of the Crook National Forest is based on the Forest Service's map of 1921, adjusted by means of several boundary markers tied in the triangulation net in the field. The boundary between Pinal and Graham counties is drawn on the basis of one boundary monument found in the field and the position of the boundary shown on the General Land Office's map of Arizona, 1921. It accords closely with the location of the boundary as indicated by several persons familiar with the region.

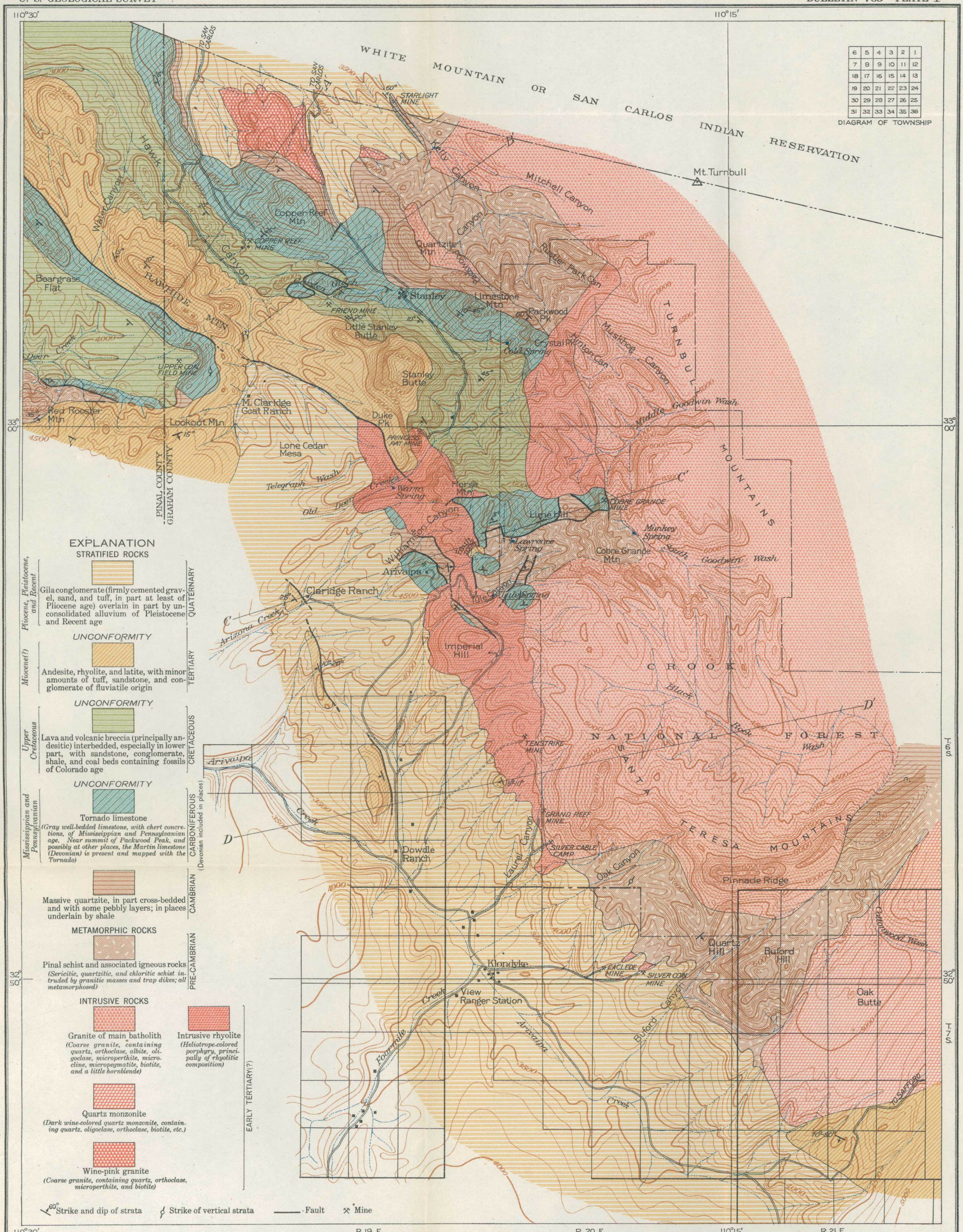
The geology was mapped simultaneously with the topography. Positions on or near geologic boundaries were determined by means of plane-table intersections, and the geologic features were sketched in the same manner as the topographic features. Thus the delineation of the geology is as accurate as that of the topography but is similarly generalized. No attempt has been made to show dikes and other small masses of intrusive rock. In areas of complicated normal faulting, like that near Arivaipa village, it was necessary to generalize, as some of the blocks into which the rocks have been broken are too small to be shown.

TOPOGRAPHY

The Aravaipa-Stanley region is made up of small mountain ranges such as are characteristic of southern Arizona. In the eastern part are the Turnbull and Santa Teresa mountains, separated by the rocky valley of Black Rock Wash. On the north side is the detritus-floored valley of Gila River. The hilly and mountainous country in the Stanley district is drained by a series of rather closely spaced and sharply incised gulches that lead northward into Gila River. On the west side of the Stanley district is the valley of Deer Creek, surrounded near its head by a horseshoe-shaped rampart of narrow ridges. This stream, which drains westward into Gila River, must not be confused with Old Deer Creek, on the boundary between the Aravaipa and Stanley districts. In the northwestern portion of the region are the mountains that form the southeast end of the Mescal Range. The valley of Arivaipa Creek forms the west end of the Aravaipa district. This stream is the largest in the area mapped and has water flowing at the surface in the portion of its valley known as the box canyon during the greater part of the year.

TURNBULL MOUNTAINS

The Turnbull Mountains form the largest mountain mass in the region. The northeastern part of this range was not reached during the present investigation. In plan, the range as a whole has the shape of a quadrilateral, roughly approximating a square 7 miles on a side, with several ridges projecting beyond the flanks of the main mass. (See Pl. II.) The component ridges on the west side trend about N. 35° W., parallel to the west side of the range as a whole, but most of the larger ridges in the center of the mass trend almost at right angles to this. The range as a whole is a less compact unit than many others in southern Arizona. It has the appearance of a group of connected, serrate ridges, rather than a single dissected block. A number of the peaks in the area mapped reach altitudes of 7,000 feet above sea level, and Mount Turnbull itself may be almost 1,000 feet higher. The mountains rise 2,000 feet above the more open country to the west and south and even higher above Gila River, which encircles the range on the east and north. The maximum relief in the



GEOLOGIC SKETCH MAP OF THE ARAVAIPA-STANLEY REGION, GRAHAM COUNTY, ARIZ.

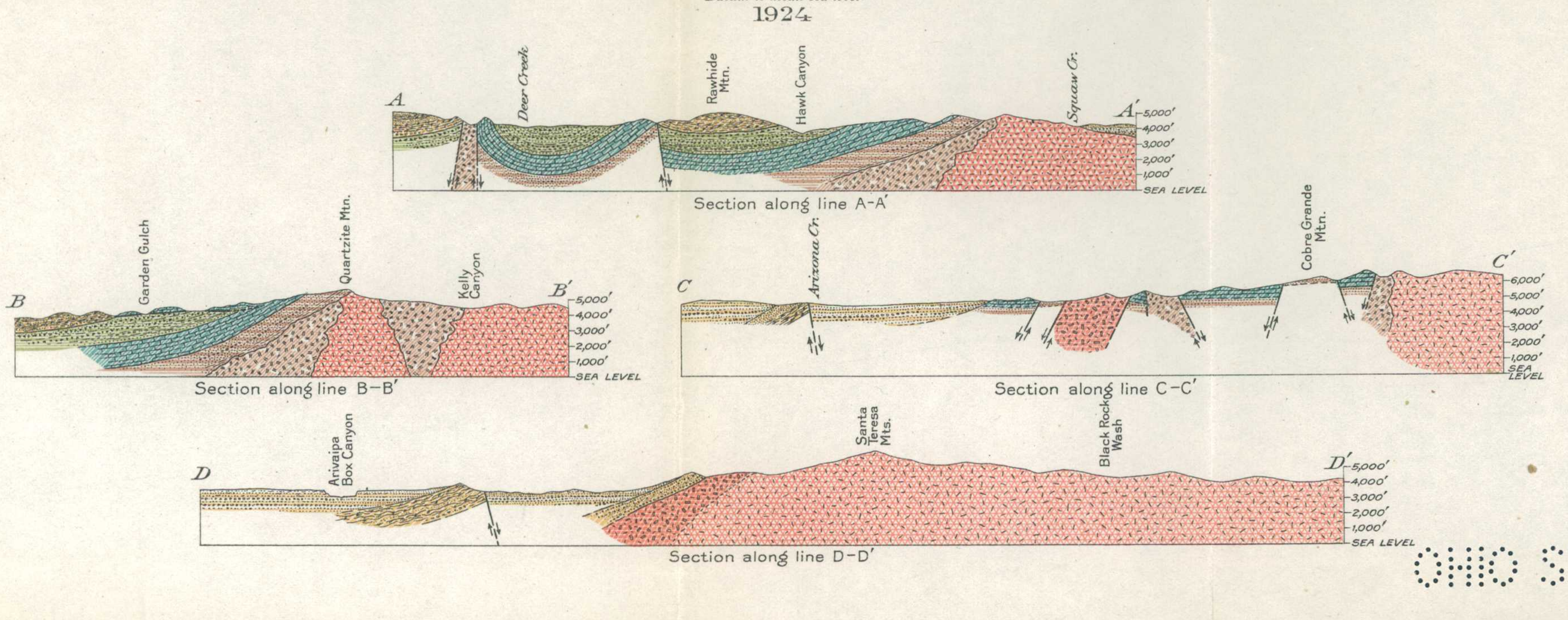
Scale $\frac{1}{125,000}$

Contour interval 100 feet

Datum is mean sea level

1924

Geology and topography by Clyde P. Ross, 1922



TOPOGRAPHIC SKETCH MAP OF THE ARAVAIPA-STANLEY REGION, GRAHAM COUNTY, ARIZ.

Scale $\frac{1}{125,000}$

1 0 1 2 3 4 5

Contour interval 100 feet

Datum is mean sea level

1924

area mapped is about 4,000 feet. The slopes are very steep, and most of the divides are sharp. The soil cover is thin, and rock projects through it in numerous places. The stream beds in general consist of bare rock, and there are many cliffs and rocky pinnacles. Large areas of the ridge slopes, however, are covered with a heavy growth of manzanita, scrub oak, and other brush. In places there are cedar, oak, and pine trees, some of which grow to considerable size. On the east flank of Cobre Grande Mountain and elsewhere in the eastern portion of the range are pine forests. Mescal and other agaves are rather generally distributed, especially on the lower slopes, cucumber cactus and other small rounded forms are common, and cholla and prickly pear are also found. The topography of this range is very rough. The trails follow the ridges for the most part, as the canyon bottoms are so encumbered with boulders and dry waterfalls that a mounted man can not follow them for any distance. Even on the ridges traveling is precarious.

The Turnbull Mountains are surrounded by gently sloping plains into which numerous streams have cut gulches. (See Pl. III.) All these streams are ephemeral, but near the heads of many of them water stands in pools and pockets or flows for short stretches during a large part of the year.

On the slopes of some of the gulches in the northern part of the region are a few giant cacti, or sahuaros, not present elsewhere. The mountains rise above these dissected plains with striking abruptness. A surface whose grade is so slight as to be almost imperceptible to the casual observer may lie at the foot of a slope so steep that a horse can scarcely maintain his footing on it.

Stanley Butte is an impressive outlier of the Turnbull Mountains connected with the main range only by the narrow divide at the head of Garden Gulch. (See Pl. III.) It appears to be exceeded in height among the peaks of the range only by Cobre Grande Mountain and Mount Turnbull. Copper Reef Mountain and the ridges north of it form connecting links of rugged heights between the Turnbull Mountains and the east end of Mescal Range.

The streamways across the mesa lands about the mountains are very sharply incised into them. The steep walls of the V-shaped canyons break off abruptly from the nearly level surface above. So sharp is the change in grade that to an observer on the surface of the mesa canyons at a little distance appear more like gentle swales than the deep gulches they are. An example of this is shown in Plate II, *A*. Between the observer and Stanley Butte is a precipitous-sided canyon, but only the rounded edges of the cut are visible in the picture. As the view also shows, the vegetation on these uplands is sparse. There are a few small cedars here and there, acacias and other bushes on the canyon slopes, low, inconspicuous rounded cacti in spots, a few agaves and cholla, and a scanty cover of bunch grasses everywhere.

MESCAL RANGE AND DEER CREEK BASIN

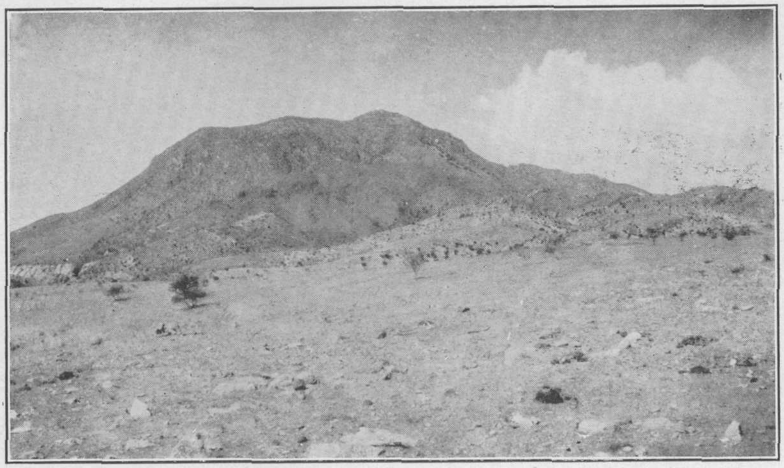
The Mescal Range ends in the northwest corner of the region in the rugged mass of Rawhide Mountain.[2] The mountain rises 2,000 feet above Hawk Canyon in a series of irregular scarps. This impressive northeast front, in which the frayed edges of the strata show in parallel bands of color, is pictured in Plate IV, *A*. On the southwest the slopes are smoother, have less diversified coloring, and rise only 1,000 feet above the base.

The basin at the head of Deer Creek southwest of Rawhide Mountain is one of the striking features of the region. It is a roughly rectangular area of rolling land into which the headwaters of Deer Creek are gnawing their way in a set of steep-walled, branching gulches. On three sides the basin is inclosed by a line of hills that form a continuous rampart except where streams have cut notches in them. The average width of the hills is less than a quarter of a mile, and their height is in most places little over 200 feet above the base. The slopes of these little hills are so steep as to be generally almost unclimbable by a mounted man. Many of the streams intersecting them on the south side have small but steep waterfalls in the gaps between the hills, adding to the effectiveness of the barrier. The rampart of hills is broader and less distinctly marked at the east end of the basin than at the sides. Beyond the hills at this end is the head of Hawk Canyon, in which the stream bed is more than 200 feet lower than the Deer Creek basin, at the foot of the hills. Outside the narrow rampart is an outer border of larger and more irregular elevations, of which Rawhide Mountain, already described, is the most prominent. Lookout Mountain, on the south side, is reported to have been so named because sentinels were stationed there by the coal prospectors to warn them of movements of troops from San Carlos in their direction. This was at the time when the coal fields were included in the Indian reservation, and mining was prohibited. South of Lookout Mountain, in the unmapped area, the country slopes off gradually into dissected uplands that broadly resemble Lone Cedar Mesa and the area around it.

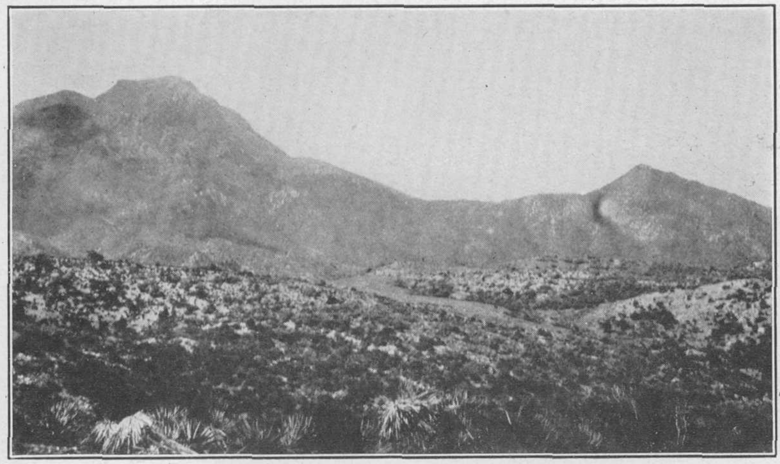
SANTA TERESA MOUNTAINS

The Santa Teresa Mountains form a somewhat more compact unit than the Turnbull Mountains. In plan the shape of the range is that of a roughly equilateral triangle, approximately 7 miles on a

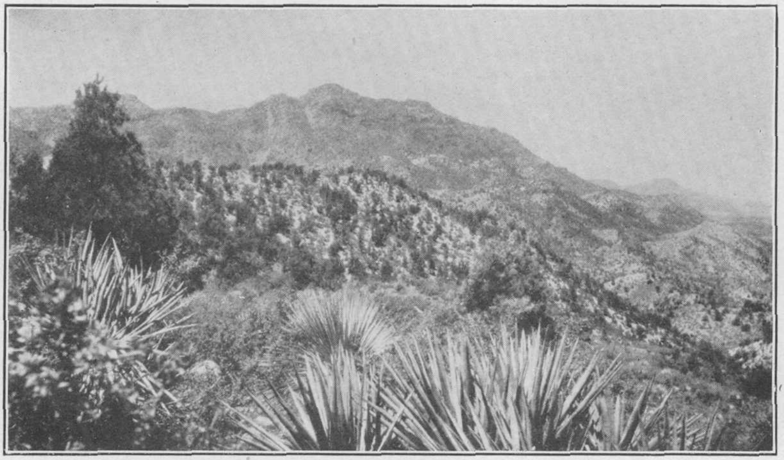
[2] Name adopted by the United States Geographic Board, December 1922; also known locally as Hobson Mountain and Spion Kop.



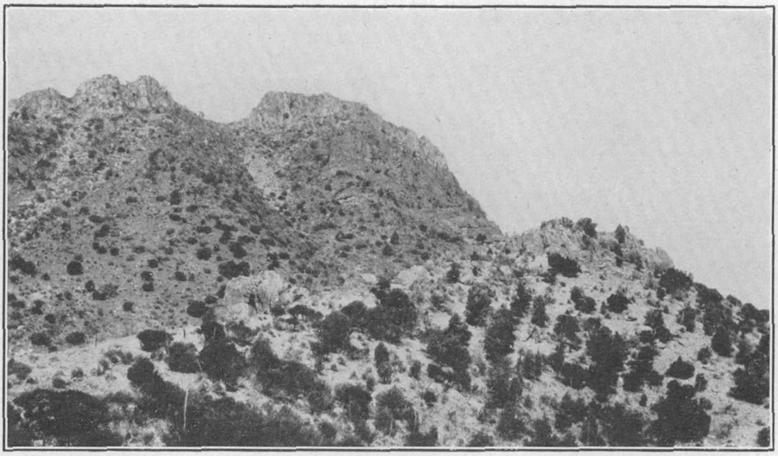
A. STANLEY BUTTE AND THE DISSECTED UPLAND SURFACE AT ITS BASE, FROM LONE CEDAR MESA



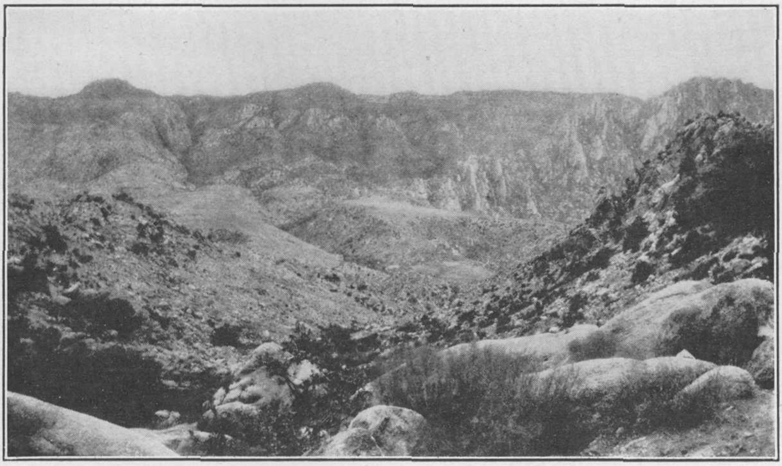
B. STANLEY AND LITTLE STANLEY BUTTES AND THE DISSECTED UPLAND AT THEIR BASE, FROM THE NORTH



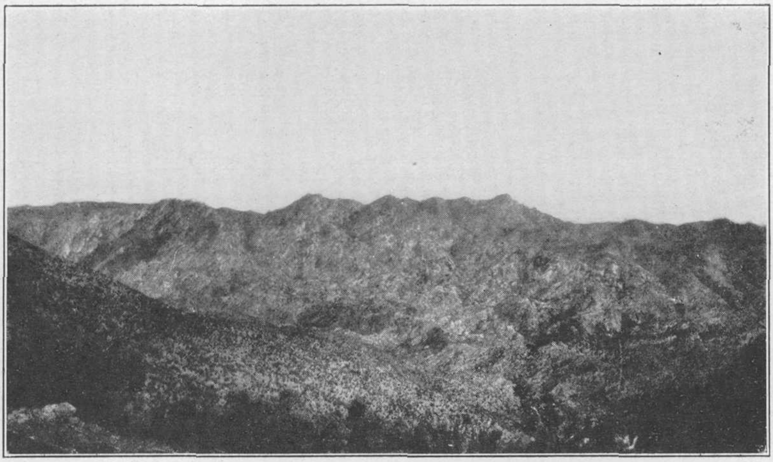
A. RAWHIDE MOUNTAIN, FROM THE SOUTHEAST



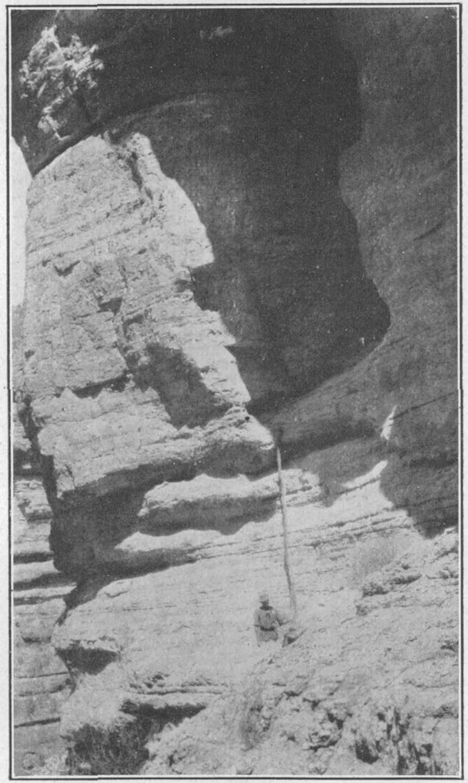
B. THE SUMMIT OF RAWHIDE MOUNTAIN, FROM A POINT ON ITS NORTHEAST FACE



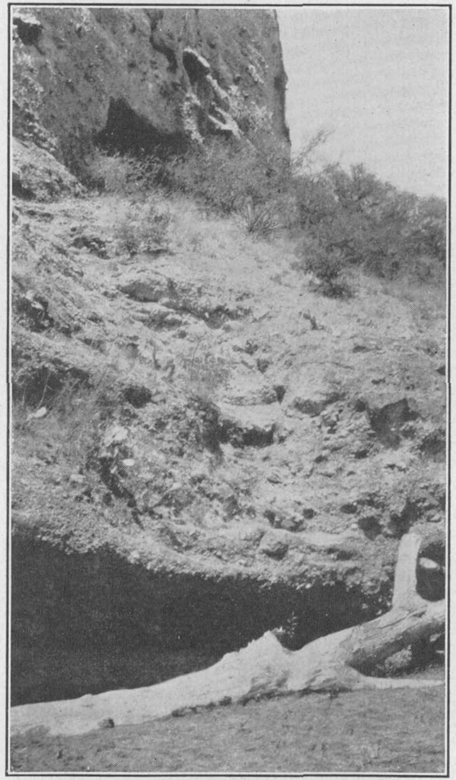
A. NORTH SIDE OF THE SANTA TERESA MOUNTAINS, FROM FISHER PROSPECT



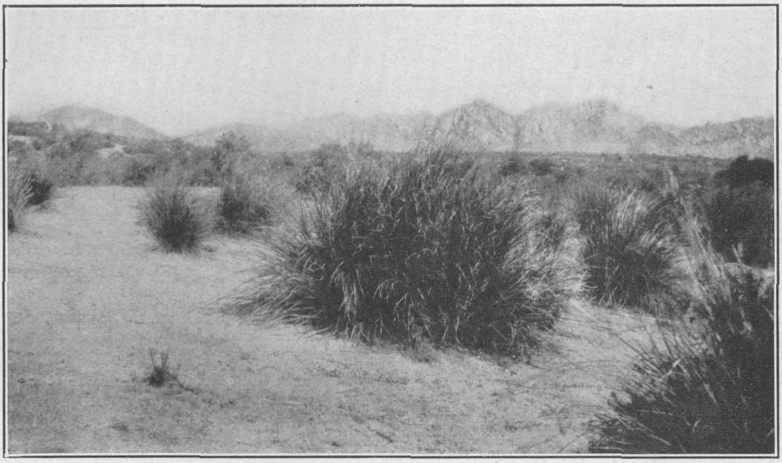
B. NORTHEAST FLANKS OF THE SANTA TERESA MOUNTAINS, FROM COBRE GRANDE MOUNTAIN



A. CLIFF OF TUFF AND SANDSTONE OF THE GILA FORMATION ON THE EAST SIDE OF TURKEY CREEK

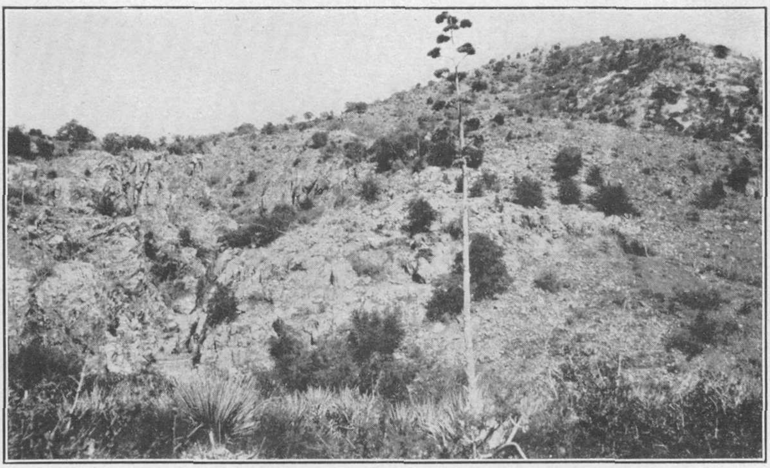


B. CLIFF OF CONGLOMERATE OF THE GILA FORMATION IN ARIVAIPA BOX, NEAR T RAIL RANCH

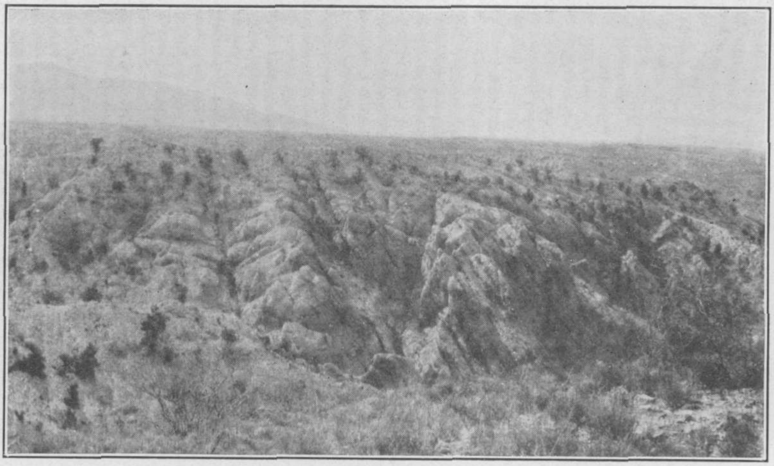


A. THE SOUTH SIDE OF THE SANTA TERESA MOUNTAINS AND THE PLAIN AT ITS BASE

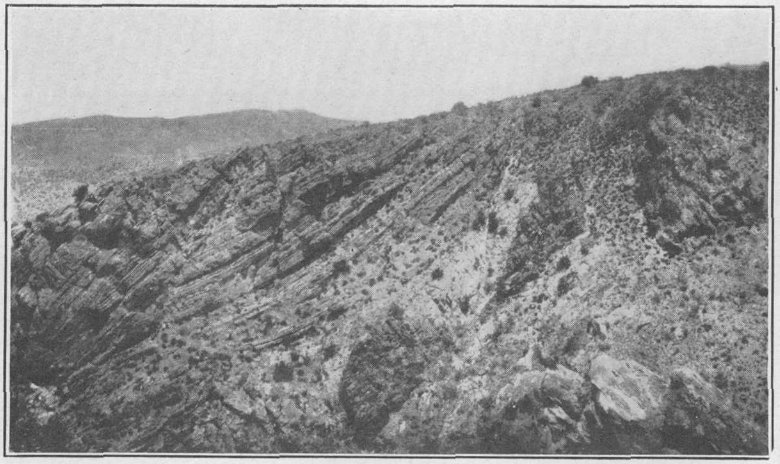
The plain is cut in quartz monzonite; the mountain at the left side of the picture is Buford Hill, formed of metamorphic rocks; in the center is Pinnacle Ridge, carved from granite



B. CAMBRIAN QUARTZITE IN ARIZONA CANYON NEAR ARIVAIPA



A. TILTED MIOCENE (?) CONGLOMERATE SOUTH OF THE SAFFORD ROAD



B. TILTED CROSS-BEDDED SANDSTONE WITH LAVA BELOW, BOTH OF MIOCENE (?) AGE, IN ARIZONA CANYON JUST BELOW THE CLARIDGE RANCH side. (See Pl. II.) The apex is formed by Buford Hill, on the south side, and the base on the north trends nearly east. The main portion of the range, exclusive of Buford Hill and its attendant outliers, is a narrow irregular but continuous ridge, concave on the north side. The altitude of the summits increases from about 6,300 feet in the west to about 7,000 feet in the east. The western half of this ridge, especially on the north, is rugged in the extreme. Soil is scanty everywhere in this portion of the mountains, and in most places it is almost completely absent. Rocky pinnacles, rough cliffs, and narrow canyons abound. Such vegetation as exists finds precarious footholds in crevices in the rocks and in canyon bottoms. In the eastern portion of the range there is a considerable area on the top of the main ridge which is comparatively flat and covered with pines and other vegetation. On the north side are impressive cliffs, as can be seen in Plate V, *A*. On the south the slopes are steep but less intricately carved than those farther west.

West of the Santa Teresa Mountains is a dissected plain like that west of the Turnbull Mountains, forming the upper slopes of the east side of this portion of the valley of Arivaipa Creek. Corresponding level areas, dissected, especially on their edges, by steep-walled gulches, are present on the west side of the valley.

South of the Santa Teresa Mountains is a broad, slightly rolling plain, separating them from the Graham Mountains. (See Pl. VII, *A*.) Tributaries of Arivaipa Creek have bitten deeply into the periphery of this plain, but several square miles of almost featureless surface still remains. The comparatively level areas described above and the gulches between them support a scattered vegetation of bunch grasses, manzanita, laurel, mesquite, and other bushes, various cacti, mostly small, and several species of agave. The bushes are more abundant on the gulch walls and the grasses on the level uplands.

North of the Santa Teresa Mountains is Black Rock Wash. Except at the head of this stream, where erosion has not yet accomplished so much, little suggestion of level surfaces remains. On the contrary, this side of the mountains is rugged and desolate in the extreme. Steep, branching canyons are so closely spaced that no room is left for gentle slopes. Everywhere are cliffs and pinnacles, whose fantastic shapes have been carved from bare granite. The scene has a grim, forbidding beauty all its own. (See Pl. V, *B*.)

ARIVAIPA CREEK

Arivaipa Creek flows through a broad valley west of the Santa Teresa Mountains. Its slopes, above the box canyon, are smooth, steep, and terraced, with occasional small bluffs, especially in the southern part. The average width of the valley is about 6 miles. The stream has cut below the level of the upland plains at the base of the mountains to a depth of some 1,500 feet. The divide between Arivaipa Valley and Sulphur Spring Valley, on the south, is so low and smooth that a traveler might well pass from one valley to the other without realizing it. Along Arivaipa Creek is a flood plain more than a mile in width over which are dotted numerous ranch houses with small irrigated patches near them. There are groves of cottonwoods and other trees in the upper part of the valley, and mesquite and acacia thickets below.

About 3 miles below Klondyke the topography of the valley changes. Here the stream enters a precipitous-walled gorge carved out of Gila conglomerate. This is the upstream end of Arivaipa Box, which farther west is cut in resistant beds of Tertiary volcanic rocks that form the north end of the Galiuro Mountains. The walls in many places are nearly vertical. (See Pl. VI. One of these views was taken in the tributary Turkey Creek, but it is characteristic of large parts of the main canyon also.) Water flows at the surface throughout the year in Arivaipa Box. It is confined between banks some 3 feet high on the average, and the streamway is notably narrower than that in the more open valley above. The presence of flowing water has produced verdure which makes this canyon a place of unusual beauty in this semiarid land. There are green grass, bushes of various sorts, and stately cottonwood trees. A number of the level patches of ground have been utilized for irrigated crops, principally forage.

The divide west of Stanley Butte, between the drainage basins of Arivaipa Creek and Hawk Canyon, is almost as unobtrusive as the divide on the south already mentioned. The stream valleys in the upper part of the Hawk Canyon drainage basin are steep-sided gulches cut in an originally almost level plain. Farther north, Hawk Canyon passes for a few miles between narrow ridges, outliers of the Turnbull Mountains, on the east, and the steep and rough east end of the Mescal Range, on the west. Near the northwest corner of the area mapped it swings west and eventually finds its way into Gila River.

STRATIGRAPHY AND PETROLOGY

MAJOR FEATURES

The basement of pre-Cambrian metamorphic rocks underlying southern Arizona crops out in several places in the Aravaipa-Stanley region. The Paleozoic strata are well represented in the northern part of the region, and there are fragments of them to the south. In several particulars the Paleozoic section does not correspond with those in neighboring regions. The Apache group, at the base of the section, regarded as chiefly if not wholly of Cambrian age, is represented only by quartzite of variable thickness, lithologically resembling the Troy quartzite, and minor amounts of other kinds of rock. Above this is the Devonian Martin limestone, but it is nowhere prominent and in places appears to be absent. The Carboniferous Tornado limestone is typically developed. The character of some poorly preserved and scanty fossils from this limestone near Arivaipa suggests the possibility that beds of upper Mississippian age, apparently absent in the Tornado limestone farther west, are present here. Above the Tornado are volcanic and sedimentary beds of shallow marine origin containing fossils of Colorado age, thus shifting the known extent of the inland Cretaceous sea farther south and west. Batholithic masses of granite and quartz monzonite, probably intruded near the beginning of Tertiary time, occupy a large part of the region. There are extensive exposures of Tertiary volcanic strata and Tertiary and Quaternary alluvium.

METAMORPHIC ROCKS (PRE-CAMBRIAN)

PINAL SCHIST

Definition and distribution.—All the metamorphic rocks in the region, except those of intrusive igneous origin, are included under the term Pinal schist, which has been adopted by Ransome[3] for similar rocks in the Pinal Range and elsewhere in Arizona. The resemblance in stratigraphic relations, metamorphism, and most of the petrologic characters is so striking as to leave no doubt of the validity of the correlation.

Schist crops out in a number of places in this region but on Plate I has not been separated from the metamorphosed igneous rocks. One of the largest areas of schist is on the south and southwest borders of the Santa Teresa Mountains, where it covers several square miles, including Buford Hill and most of the adjacent heights. There is another large area at the south end of the Turnbull Mountains, where a large part of Cobre Grand Mountain is composed of this formation. Some schist occurs in the metamorphic igneous complex on the north side of the Turnbull Mountains, and small strips of similar rocks are found on the south side of the headwater basin of Deer Creek and north of Copper Reef Mountain.

Character.—In the area about Buford Hill the schist is of two general types. On Buford Hill itself and on Quartz Hill, north of

[3] Ransome, F. L., Geology of the Globe copper district, Ariz.: U. S. Geol. Survey Prof. Paper 12, p. 23, 1903.

it, the rock is largely hard quartzitic schist. In some outcrops bedding can be distinctly seen. The schistosity strikes nearly parallel to the bedding and dips in the same direction but at steeper angles. The rock is composed essentially of quartz and muscovite. It is white with a silvery sheen on the schist planes, caused by the mica. It is harder than the rocks around it and therefore forms ridges, but, like many schists, it is friable, and its outcrops tend to weather into masses of small fragments. The contrast between the topography of Buford Hill, formed largely of quartzitic schist, and that of Pinnacle Ridge, formed of granite, can be seen by a glance at Plate VII, *A*.

The other type of schist in this area is a rather soft greenish-gray rock, intensely sheared and thoroughly recrystallized, with a dull satin sheen on schist planes composed essentially of quartz, alkali feldspar, sericite, and chlorite. In some specimens there is a faint banding which may be bedding. This rock is similar in appearance, composition, and degree of metamorphism to much of the typical Pinal schist of the Pinal Range. It covers most of the area mapped as pre-Cambrian along the southern border of the Santa Teresa Mountains and extends eastward beyond the area mapped. The rocks of intrusive origin described below are of subordinate areal extent.

The quartzitic schist was noted only in the two localities already mentioned. It is interbedded with the fine-grained schist. The lenticular masses of quartzitic schist strike approximately parallel to the average strike of the schistosity. The fine schist weathers down even more readily than the quartzitic variety. Few outcrops project notably above the surrounding surfaces, and the characteristic topographic forms are smooth and, considering the location, not steep. A number of small dikes of metamorphosed dioritic and diabasic rocks cut the schist in places.

From the data summarized above, it is evident that the two varieties of Pinal schist in the Buford Hill area are derived by metamorphism from stratified rocks, probably of sedimentary origin. The quartzitic variety was probably derived from a rather pure quartz sandstone, and the fine variety doubtless came from a mudstone.

The other large area of schist is on Cobre Grande Mountain. The most abundant rock here, although thoroughly metamorphosed, is less markedly schistose than that just described. It is composed largely of quartz with subordinate sericite and breaks up readily into small angular blocks bounded by joint planes. In some places there is fairly well marked schistosity, which has an average strike of N. 40° E. and a nearly vertical dip. The rock is nearly white on fresh surfaces but in most outcrops is stained yellow or brown by limonite. It is probably a much metamorphosed sedimentary rock. It is cut by numerous felsitic dikes, mostly light-colored rhyolite. These dikes in their bleached and weathered outcrops can not always be readily distinguished from the schist, and not only have they been omitted in mapping, but the actually irregular contact of the schist with the rhyolite to the west has been generalized. This is probably in part a fault and in part an intrusive contact. Similar schist crops out on the north side of the Turnbull Mountains but has not been separated in mapping from the metamorphosed igneous complex.

North of the Copper Reef mine is a narrow strip of metamorphic rock exposed in a gulch on the west slope of the ridge. It is overlain on the south by Cambrian quartzite and adjoined on the north by wine-pink granite. The rock is a gritty schistose quartzite with numerous scattered pebbles, most of which are quartz. It is distinguished from the younger quartzite above it by the greater metamorphism and by the lack of well-marked bedding. A wedgelike mass of schist resembling that on the southwest side of the Santa Teresa Mountains lies on the south side of the basin of Deer Creek. The depression south of the limestone rampart here is carved in such rock.

Age.—The rocks described above are all similarly metamorphosed. They are by far the most thoroughly metamorphosed rocks of sedimentary origin in the region, if local alteration due to mineralization is excluded, and are older than any of the other formations. The oldest nonschistose rock in the region is of Cambrian age. From these facts it seems evident that the schistose rocks here, as in neighboring parts of Arizona, are pre-Cambrian. Possibly, as Ransome [4] has suggested for the same formation in the Ray-Globe region, their age may be somewhat more closely given as Archean.

GRANITIC GNEISS

The rock described under the name granitic gneiss is the metamorphosed rock of granitic composition on the south side of the Santa Teresa Mountains. It is readily distinguished from the other granite in this vicinity by its much greater metmorphism. This rock forms most of the southern slopes of the line of ridges between Buford Hill and Cottonwood Wash and may occur farther east.

The rock is medium grained and predominantly pinkish gray mottled by greenish-brown biotite spangles which are grouped in thin, roughly parallel bands, giving it a distinctly gneissic appearance. It is composed essentially of quartz, orthoclase, andesine, and biotite. The gneissic texture is due partly to a segregation of coarse

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[4] Ransome, F. L., Copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 32, 1919.

and fine grains of quartz and feldspar in bands and partly to the parallel arrangement of the biotite shreds. The biotite is somewhat chloritized, but the feldspar is little altered—less so, in fact, than much of that in the younger granite in the vicinity. The texture is clearly that of a medium-grained intrusive rock that has been subjected to much compressive stress. Quartz is abundant, and the plagioclase is subordinate in amount to the alkali feldspar, so that the rock is evidently a granite rendered gneissoid by metamorphism.

This rock is very probably intrusive into the Pinal schist, which surrounds it, and is therefore younger than that formation. Like the schist, however, it has been subjected to strong metamorphism and is therefore assigned to the pre-Cambrian.

METAMORPHIC IGNEOUS COMPLEX

The rocks on the north side of the Turnbull Mountains mapped as pre-Cambrian on Plate I are, with the exception of a number of small dikes, all metamorphosed, and most of them are of igneous origin. They may therefore be grouped under the term "metamorphic igneous complex." They occupy more than 8 square miles in the northwest end of the Turnbull Mountains and are almost completely circumscribed by granite and the related rhyolite.

This part of the region received only a somewhat cursory examination. There are no mines and no prospects of consequence in it, and the ruggedness of the country and the thick cover of brush and trees, coupled with the scarcity of satisfactory outcrops in many places, made an adequate study of what is obviously somewhat complicated geology too time-consuming to be practicable. Four general types of rock were noted—chloritic schist; a coarse-grained, foliated igneous rock akin to diorite; quartzitic schist; and dikes of later, unmetamorphosed felsite.

The chloritic schist is evidently a metamorphosed trap. It is widely distributed in the southern part of the metamorphic area. Its relations to the other rocks are not clear, but it seems to form irregular masses of considerable size and is believed to be a fine-grained subsilicic intrusive igneous rock that has suffered strong metamorphism. Quartzitic schist like that of Cobre Grande Mountain was noted near the chloritic rock on some of the high ridges. Farther north, on the south side of Kelly Gulch, some of the ridges are composed of a rather coarse-grained intrusive rock which seems to be a diorite, although some phases of it may be more silicic. This rock is less metamorphosed than those mentioned above, but most outcrops show distinct foliation. The later dikes in this area are mostly quartz porphyry related to the granite batholith.

The chloritic and quartzitic schists are so metamorphosed that they can scarcely be other than pre-Cambrian, and the quartzitic variety doubtless belongs to the Pinal schist. The dioritic rock is less altered, but its texture is distinctly foliated, a feature which seems to indicate more intense pressure than affected the Paleozoic rocks. It is therefore also considered pre-Cambrian, although probably much later than the Pinal schist. Slightly metamorphosed granitic rock has been referred to the pre-Cambrian in the Clifton-Morenci [5] and other districts in Arizona.

STRATIFIED ROCKS

CAMBRIAN QUARTZITE

Definition and distribution.—The lowest formation of the Paleozoic section is here termed simply the Cambrian quartzite. The lack of the other formations of the Apache group makes positive correlation with the section worked out by Ransome [6] in the Ray-Globe region difficult. Consequently a noncommittal name has been adopted, but the evidence for correlation is discussed below in the paragraph on age.

The Cambrian quartzite is scattered in small areas throughout the region. Although doubtless once continuous over the whole region it has since been shattered by faulting, carved by erosion, and covered by later deposits, until comparatively little of it is now exposed. Strips of this formation occur in the northern part of the region in several places; the largest one is on Copper Reef Mountain and in the band that stretches from Quartzite Mountain to the northeast flank of Limestone Mountain. There are blocks of it on the south side of the Deer Creek basin, in the vicinity of Arivaipa, and on the northwest end of Cobre Grande Mountain. There seems to be a notable thickness of quartzite in the east end of the Santa Teresa Mountains, but this part of the range was not visited during the present investigation. The quartzite shown on Plate I as occurring at the east end of the range was mapped on the basis of long-distance observation supplemented by information furnished by Frank Landsman, who has prospected in that part of the region. The cliffs formed on the thick resistant beds of this rock and the contrast between the topography developed on them and that on the granite which forms the western part of the range are shown in Plate V, *A*. Loose quartzite blocks and a small amount of conglomerate in place were found near the La Clede mine, east of Klondyke.

Character.—The quartzite is white to buff on fresh surfaces, though in places stained yellow or red by iron oxides. Quartz pebbles

[5] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, pp. 56–58, 1905.

[6] Ransome, F. L., Copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, pp. 30–31, 1919.

scattered through or arranged in narrow bands in the fine to medium grained quartzite were seen in a number of outcrops. The beds are from 1 foot to several feet thick, with considerable small-scale cross-bedding.

On the hill east of Arivaipa, sometimes called Quartz Hill, the quartzite is underlain by several score feet of banded greenish-gray shale, which crumbles readily. The contact between the shale and the quartzite is even and sharp, with no indication of unconformity except the abrupt change in the character of the sediments. The lower part of the shale rests against a fault block of Tornado limestone. Similar shale was noted on the slopes of Cobre Grande Mountain, but it was not observed in the Stanley district.

The thickness of the formation is variable, and the prevalence of normal faults makes measurements somewhat unreliable. In the vicinity of Arivaipa the total thickness of quartzite and underlying shale can not much exceed 200 feet. In the Stanley district the thickness of the quartzite is more than 400 feet, and in the vicinity of Quartzite and Limestone mountains it seems to be over 500 feet. Walcott[7] estimated 1,000 feet of quartzite north of Rawhide Mountain, but this estimate is probably too large. As seen from a distance, the thickness of quartzitic beds in the east end of the Santa Teresa Mountains seems to be great. It is easily as much as 1,000 feet and may well be more. The quartzite here is reported to be underlain by granite.

Between Quartz Hill and the border of the Gila conglomerate a number of blocks of nonschistose quartzite and quartzitic conglomerate were noted lying loose on the surface of the ground. The only known outcrop of rock of this sort in place in this part of the region is in the gulch where the La Clede mine is situated, a few hundred feet upstream from the mine. These loose blocks vary somewhat in lithologic character, but all bear a resemblance to members of the Apache group of Ransome.[8] Some are light-colored quartzite, with or without cross-bedding, which might belong to either the Troy or the Dripping Spring quartzite. Some are conglomerate with quartzose pebbles resembling the Barnes conglomerate. These blocks are so numerous and have outlines so angular that they can not have been transported far from the place where they were formed, yet no such rock is known in place here. The conglomerate in place near the La Clede mine resembles lithologically the Scanlan conglomerate of the Ray-Globe region. It is composed of fairly well rounded but poorly sorted pebbles of quartz, schist, and decomposed granitic rock in a coarse arkosic matrix. It is a hard, thor-

[7] Walcott, C. D., and Bannon, M., Deer Creek coal field, White Mountain Indian Reservation, Ariz.: 48th Cong., 2d sess., S. Ex. Doc. 20, p. 7, 1885.

[8] Ransome, F. L., Copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 50, 1919.

oughly cemented rock but not in the least schistose. It is clearly younger than the Pinal schist, on which it lies. The outcrop is so small that it is not distinguished from the schist on the geologic map.

Age.—The stratigraphic relations and general lithology of the quartzite and accompanying shale indicate that they are broadly equivalent to some portion of the Apache group. Lithologically the quartzite resembles more closely the Troy quartzite than any other formation of that group. Ransome[9] states that the pebbly character is "a useful means of distinguishing isolated exposures of the Troy quartzite from the pebble-free Dripping Spring quartzite." The quartzite in the Aravaipa-Stanley region contains pebbles in places, although nowhere abundantly. It is also, like the Troy quartzite, cross-bedded. The stratigraphic relations of the formation can be seen on Packwood Peak, in the northern part of the region. Here the quartzite overlies a complex of pre-Cambrian rocks and later dikes. The contact is irregular, and doubtless there is an unconformity, although the pinching out of the quartzite to the south, shown on Plate I, may be due to structural disturbance. The Paleozoic beds here are offset by several small faults. The quartzite beds parallel those of the dark limestone above, and, so far as could be determined, the limestone, which is believed to be part of the Martin limestone, rests conformably on the quartzite, just as the Martin limestone of the Ray-Globe region rests on the Troy quartzite. The relations are similar north of the Copper Reef mine, except that here the Martin limestone was not identified and it appears that the Tornado limestone rests directly on the quartzite. Thus it seems probable that the quartzite of the Aravaipa-Stanley region is equivalent to the Troy quartzite of the Ray-Globe region, but the evidence of exact equivalency seems insufficient to justify the application of that formation name. The Cambrian quartzite of the Aravaipa-Stanley region has some points of lithologic similarity with the Coronado quartzite of the Clifton-Morenci district,[10] which is probably of Cambrian age. Ransome[11] has suggested that the Coronado quartzite may be equivalent to the Bolsa quartzite of Bisbee, and further that the Bolsa may be equivalent to the Dripping Spring quartzite or to that quartzite and all the Apache group below it. Unless the formations can be adequately traced from one region to another uncertainties in correlation are likely to remain.

The proper correlation of the shale that in places appears at the base of the quartzite and has been mapped with it is even more

[9] Op. cit., p. 44.

[10] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, pp. 59–60, 1905.

[11] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 164, 1916.

puzzling. Doubtless it belongs somewhere in the Apache group, but whether it is equivalent to shaly beds in the Dripping Spring quartzite or to part of the Pioneer shale or is the time equivalent of some lithologically different rock is not known.

If, as suggested above, the quartzite is equivalent to the upper part of the Apache group, then it is probably of Upper Cambrian age.[12]

MARTIN LIMESTONE (DEVONIAN)

Definition and distribution.—The Martin limestone is defined by Ransome[13] as the thin-bedded limestone, chiefly if not wholly of Devonian age, which is stratigraphically between the Troy quartzite and the Tornado limestone. Beds correlated with this formation are present in the Aravaipa-Stanley region, but the area covered by rock known to be of this age is so small that it has been included in mapping with the overlying Tornado limestone. Rock believed to belong to this formation is present near the summit of Packwood Peak. It has not been identified elsewhere in the region during the present investigation. Walcott[14] found limestone of this age somewhere in the vicinity of the coal prospects on Deer Creek, apparently on the south side. His description is not sufficiently clear to make it possible to determine the exact locality. The limestone observed during the present investigation south of the "upper coal field" is lithologically similar to characteristic Tornado limestone, but a small exposure of Martin limestone might have been overlooked in the course of the necessarily hasty examination. If any Martin limestone is present between the Cambrian quartzite and Tornado limestone on the ridges north of Copper Reef Mountain it is either a narrow band or else so similar lithologically to the Tornado as to be mistaken for that rock.

Character.—The formation lying between the Tornado limestone and Cambrian quartzite on Packwood Peak is in part black, rather soft shale, in part black dense limestone. This is the only place where rock differing in this way from the formation above and below was observed in this stratigraphic position. The shale and limestone together have a thickness estimated as of the order of 100 feet. Walcott[14] gives the thickness of the Devonian limestone he found as 50 feet, but one side is bounded by a fault, so that the total thickness may not be present. The Devonian is evidently not thick anywhere in this region and is apparently absent in places.

[12] Ransome, F. L., Copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 31, 1919. Ross, C. P., Ore deposits of the Saddle Mountain and Banner mining districts, Ariz.: U. S. Geol. Survey Bull. 771 (in preparation).

[13] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 141, 1916.

[14] Walcott, C. D., and Bannon, M., Deer Creek coal field, White Mountain Indian Reservation, Ariz.; 48th Cong., 2d sess., S. Ex. Doc. 20, p. 7, 1885.

Age.—As no fossils were found in the dark limestone on Packwood Peak the age can not be fixed from data gained in this investigation closer than somewhere between the Cambrian and the Mississippian. Walcott,[15] however, found the following fossils of Devonian age in limestone near the " upper coal field ":

Stromatopora sp.?
Michelina sp. undet.
Heliolites sp.?
Alveolites sp.?
Cladopora sp.?
Aulopora, 2 sp.
Acervularia pentagona Goldfuss.
Phillipsastrea verneuili Milne-Edwards.
Diphyphyllum simcoense Billings.

Walcott's collection in the National Museum was kindly reexamined by Edwin Kirk for the present report. Possibly the fossils in this collection came from a slightly different locality from those in the above list, but the label with the collection states that they came from a point 13 miles south of the San Carlos Agency, which is the distance of the coal field from the agency according to Walcott, so they are probably from nearly the same place as those he listed. Mr. Kirk's list, given below, is so similar to that of Walcott that there can be no doubt of the similarity of the faunas, if they are not actually identical.

Aulopora sp.
Stromatopora sp.
Pachyphyllum sp.
Cladopora sp.
Alveolites sp.
Acervularia sp.
Syringopora sp.

In regard to this collection Mr. Kirk states:

> No specific determinations of these corals have been given, as they could be of little value. Little attention has been paid to the Devonian corals for many years, and accurate comparison of western forms with eastern species is at present out of the question. The fauna is doubtless the same as that of the Martin limestone, the age of which has been discussed by Williams in Professional Paper 21. The age is late Middle Devonian, and the resemblance to the Upper Devonian of New York is perhaps less striking than suggested by Williams.

E. M. Kindle [16] has shown that the Martin limestone also includes rocks of Upper Devonian age.

The paleontologic data above set forth are sufficient to establish the presence of the Martin limestone in the Aravaipa-Stanley region. On account of their stratigraphic position and lithology, the beds on Packwood Peak, described above, are believed to belong to it, and closer study would doubtless reveal other outcrops.

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[15] Op. cit., p. 7.
[16] U. S. Geol. Survey Prof. Paper 98, p. 142, 1917.

TORNADO LIMESTONE (CARBONIFEROUS)

Definition and distribution.—The Tornado limestone as defined by Ransome [18] in the Ray-Globe region is the Carboniferous limestone overlying the Martin limestone. As will be shown below, the equivalency of the principal limestone formation in the Aravaipa-Stanley region to the Tornado limestone has been clearly established.

The Tornado limestone is found in a number of fault blocks of varying size in the vicinity of Arivaipa and around Cobre Grande Mountain. Like those of the Cambrian quartzite, the exposures here are more cut up by faults than could be indicated on the map (Pl. I). The most prominent and continuous exposure of the formation in the region is that which stretches from Packwood Peak through Stanley and Copper Reef Mountain and extends to the northwest beyond the limits of the area mapped. The rampart of hills around the headwater basin of Deer Creek, described in some detail in the sections on topography and structure, is composed of this formation.

Character.—The Tornado limestone is a massive formation built up of beds from 1 foot to several feet thick. The color of fresh surfaces varies from rather light gray to almost black with a bluish cast. Weathered surfaces have a lighter color, resembling that of Portland cement. Irregular siliceous concretions, usually small, are present in many beds. The formation contains little argillaceous material and is resistant to weathering, forming cliffs in many places. Where cliffs have not been formed elevations underlain by the limestone commonly ascend in a series of steps composed of resistant beds. It does not form soil readily and stands up in prominent bare outcrops, on most of which the scanty vegetation finds foothold only in cracks and crevices. A characteristic outcrop is shown in Plate IX, *A*.

The full thickness of the Tornado limestone is nowhere exposed in the Aravaipa district unless it is on Lime Hill, northwest of Cobre Grande Mountain, where, allowance being made for faulting near the base, about 1,000 feet of limestone is estimated to be present. The section measured by Tolman [19] on the claims of the Royal Tinto group contained only 500 feet of limestone, and the exposed thickness in some of the fault blocks is much less than this. Northwest of Copper Reef Mountain, in the Stanley district, where the formation is better exposed, the thickness is about 1,200 feet, and on Limestone Mountain it is probably equally great. Walcott [20] gives 1,200 feet as

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[18] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 142, 1916.

[19] Tolman, C. F., unpublished report on the property of the Royal Tinto Mining & Smelting Co., Dec. 3, 1910.

[20] Walcott, C. D., and Bannon, M., op. cit., pp. 5–7.

the thickness of Carboniferous limestone on the north side of the headwater basin of Deer Creek but adds that north of this locality there is a mass of Carboniferous limestone 2,500 to 3,000 feet thick. No such thickness as that exists in the Aravaipa-Stanley region. The average thickness in the Stanley district is about 1,200 feet, and the maximum does not exceed this by more than 200 feet. This is slightly greater than the average thickness of the Tornado limestone in the Ray-Globe region as at present exposed.

Age.—The limestone north of Deer Creek is an extension of that in the Mescal Range and can be traced in practically continuous outcrop along that range from the head of Deer Creek into the Ray quadrangle, where it has been mapped by Ransome [21] as Tornado limestone. The correlation based on continuity along the strike and similarity in lithology and stratigraphic position is strengthened by the paleontologic evidence. Traces of organisms were found in many outcrops of the limestone, but they were for the most part broken and poorly preserved. All the fossils obtained from the limestone are considered by G. H. Girty to be of Mississippian age. The forms, however, differ from those he identified in collections made by Ransome [22] in the Ray quadrangle. The collections from the Aravaipa-Stanley region came from fault blocks in the area between Arivaipa and Lime Hill. They doubtless all came from beds in the lower part of the formation. There can be little doubt that the Pennsylvanian is represented in the upper part of the Tornado limestone in the Aravaipa-Stanley region, as it is in the Ray quadrangle and elsewhere in Arizona. The fossils are listed below.

Lot 4202:
- Hydreionocrinus aff. H. acanthophorus.
- Derbya? sp.
- Productus aff. P. altonensis.
- Productus aff. P. setiger.
- Spirifer aff. S. pellensis.
- Spiriferina sp.
- Griffithides sp.

Lot 4202–a:
- Productus ovatus.
- Productus sp.
- Productella? sp.
- Pustula aff. P. punctata.
- Spirifer aff. S. pellensis.
- Spiriferina sp.
- Composita sp.

Lot 4205:
- Lithostrotion aff. L. basaltiforme.

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[21] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Ray folio (No. 217), 1924.

[22] Ransome, F. L., The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 47, 1919.

Mr. Girty, in his report on these collections and others from the vicinity of Christmas, Ariz., submitted to him at the same time and to be discussed in a forthcoming paper, makes the following comments:

The material from the Aravaipa district is exceptionally poor and unsatisfactory, so that no reliable conclusions can be drawn from it. Furthermore, it does not fit in well with the faunas from the Christmas district, as one would naturally expect. Lots 4202 and 4202-a were collected at about the same locality, but the faunas are by no means identical. They are clearly unlike any of the Pennsylvanian faunas from the Christmas district, nor do they present any of the well-known aspects of the lower Mississippian faunas. These two facts, if they imply that the faunas are neither lower Mississippian nor Pennsylvanian, suggest that the horizon is upper Mississippian, and such may actually be its age, though no upper Mississippian is as yet known in the region. An upper Mississippian age is also suggested by the *Lithostrotion* found in lot 4205, for this type of coral is very common in rocks of upper Mississippian age in both the East and the West, especially the East. In the West, however, it seems to occur also in the Pennsylvanian, real refinement in specific or even in generic distinctions not having been made in this group.

Thus the paleontologic evidence, while confirming the Carboniferous age of the limestone, suggests the interesting possibility that the upper Mississippian, hitherto unknown in this part of Arizona, may be present in the Aravaipa district.

Paleontologic data as to the presence of Pennsylvanian beds in this formation are available to supplement the evidence of field relations. Walcott[23] collected fossils in the upper part of the limestone north of the "upper coal field," which are, according to G. H. Girty,[24] clearly of Pennsylvanian age. The list of fossils as determined by Walcott follows:

Fusulina cylindrica.
Crinoid stems.
Zaphrentis.
Syringopora.
Productus semireticulatus.
Spirifera camerata.
Spirifera rockymontana.
Spiriferina cristata.
Retzia radialis.
Athyris subtilita.

Thus, on lithologic, stratigraphic, and paleontologic grounds and on the evidence of field relations to previously known outcrops of the formation, the thick series of limestone beds in the Aravaipa-Stanley region may be confidently correlated with the Tornado limestone. As already explained, in some places in the region a small thickness of beds at the base of the limestone as mapped belongs to the Martin limestone.

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[23] Walcott, C. D., and Bannon, M., op. cit., p. 7.
[24] Personal communication.

CRETACEOUS ROCKS

Definition and distribution.—The rocks lying stratigraphically above the Tornado limestone are here termed simply the Cretaceous rocks. Their age has been determined on fossil evidence, but the available data do not seem to warrant assigning a formation name. The sedimentary part of the assemblage may, as explained below, be equivalent to the Pinkard formation of the Clifton-Morenci district. This name might have been tentatively used were it not for the large amount of volcanic rock present in the Cretaceous of the Aravaipa-Stanley district. No volcanic rocks are present in the Pinkard formation in the Clifton-Morenci district, and the extension of the formation name to include them is not warranted on present information. On the other hand, the equivalence of part of the Cretaceous rocks in the Aravaipa-Stanley region to the Pinkard formation is sufficiently probable to make a new name seem inadvisable.

The Cretaceous rocks form a band extending from the northwest corner of the area mapped up Hawk Canyon to Garden Gulch, passing around the northeast side of Stanley Butte, and reaching the ridge crests on the south side of Old Deer Creek. Another mass forms the floor of the headwater basin of Deer Creek inside the line of limestone hills.

Character.—The Cretaceous rocks in this region are of two general types—sedimentary and volcanic. The rocks of these two types are so interbedded, both here and in the Christmas quadrangle, to the west, that it was impracticable to separate them in mapping. In a broad way, the lower strata are predominantly of sedimentary origin and those above of volcanic origin. Lava is, however, found near the base of the series, and sedimentary strata occur well up among the volcanic beds.

The sedimentary beds consist of sandstone, shale, and conglomerate. The sandstone is hard and somewhat calcareous. It is distinctly though in places irregularly bedded. Weathered surfaces are rather light yellow, but in some beds fresh fracture surfaces are darker and in places almost black. Fragments of fossil wood are plentiful in some sandstone beds. The shale is soft and easily crumbled. It varies in color from greenish yellow to black according to the amount of carbonaceous matter which it contains. In places beds of coal are associated with the sandstone and shale. (See pp. 114–117.) Conglomerate is not as abundant in the Aravaipa-Stanley region as it is in the Christmas quadrangle, most of the sedimentary beds being finer grained. Conglomerate containing pebbles of white to yellow sandstone, 3 to 6 inches in greatest diameter, crops out east of Stanley Butte. The pebbles were doubtless derived from underlying Cretaceous sandstone, and the beds therefore indicate contemporaneous erosion during the deposition of the formation. Elsewhere the conglomerate beds contain pebbles of the Paleozoic limestone and quartzite, metamorphosed granitic rocks, quartz, and other rocks derived from the underlying formations. These are especially prominent in the Christmas quadrangle, where thick beds, some of them full of large cobbles, are found. The greater part of the sedimentary rock is sandstone. Next in amount is the shale, which is widely distributed in beds a few inches to a few feet thick. Conglomerate, especially in the Aravaipa-Stanley region, is a subordinate part of the formation. In the basin northeast of Little Stanley Butte, above the Friend mine, there is reported to be red sandstone containing scattered flakes of native copper. The outcrop was covered with recent wash and not visible at the time of visit.

The volcanic rocks are in part lava, in part pyroclastic rocks of several kinds, the latter probably predominating. They are colored various shades of purple, green, gray, and red. All the colors are dull, and the outlines of crystal grains and included fragments are hazy and indistinct, owing to widespread alteration of the rocks after their deposition. Such alteration is rather common in volcanic rocks of this sort. The various strata differ somewhat in composition, but all are of intermediate types, and most of them are andesites. Those examined microscopically contain soda-lime plagioclase and chlorite, epidote, and other alteration products of ferromagnesian minerals. A little unaltered biotite is present in some specimens, and hornblende occurs in others.

The thickness of the Cretaceous beds is somewhat variable and is difficult to measure accurately because of the numerous minor structural disturbances of the strata. There are many small faults whose cumulative effect on the apparent thickness in some places may be large but can not be ascertained without detailed investigation. There are also minor crenulations or small folds which, as Campbell [25] has suggested, may have a large effect on the apparent thickness but one that is difficult to evaluate. The numerous dikes probably also tend to increase the width of outcrop. On the northeast side of Stanley Butte there is about 1,000 feet of Cretaceous rock, of which one-third or more is sedimentary. On the northeast side of Rawhide Mountain the width of the outcrop as mapped indicates a thickness of about 1,400 feet, of which more than half is of sedimentary origin, but there may be some duplication by faulting. Campbell [26] estimates the thickness of sandstone and shale below the volcanic beds on the north side of the basin of Deer Creek as 400 to 500 feet and shows that the thickness varies

[25] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 246, 1904.

[26] Campbell, M. R., op. cit., p. 246.

markedly in different localities. Walcott[27] gives a much greater thickness for the formation, but, as Campbell has indicated, his estimate is probably in error. Probably the average thickness of the whole is of the order of 1,000 to 1,500 feet, of which 500 feet or more is of sedimentary origin and the rest of volcanic origin. Most of the sedimentary beds are in the lower part of the formation in all exposures, but the amount of volcanic strata interbedded with them varies.

Age.—The age of the sedimentary beds is definitely established as Upper Cretaceous by means of fossils collected from a calcareous bed in Garden Gulch at Abe Reed's ranch house. The bed is only a few tens of feet above the base of the series. Similar fossils can be found at the same horizon for a considerable distance on both sides of the place where the collection was made but were not observed elsewhere. The list of fossils as kindly determined by T. W. Stanton, together with his comment, is given below:

Exogyra sp. related to E. laeviuscula Roemer. Identical with the Utah form described by White under this name.
Trigonarca sp. related to and possibly identical with T. depressa (White).
Callista (Dosiniopsis?) n. sp.
Glauconia coalvillensis (Meek).
Turritella sp.
Undetermined gastropods belonging to one or two other genera.

These fossils belong to an Upper Cretaceous fauna of Colorado group age found in the lower part of the Mancos shale in northwestern New Mexico and southeastern Utah. Arizona collections representing about the same horizon have been received from the vicinity of Morenci, from Cottonwood Creek above White River Agency, from a locality 2 miles south of Showlow, and from a coal field south of Holbrook.

The sedimentary rocks wherever observed are so similar that they can all be assigned to the same age with little hesitancy, and they are so intimately interbedded with the volcanic strata that the latter must be also essentially of the same age. This fact is even more convincingly shown in the Christmas quadrangle than it is in the Aravaipa-Stanley region.

Fossil wood was found south of Copper Reef Mountain and on the north side of the headwater basin of Deer Creek. All the specimens observed are broken pieces, mostly square-ended, from a few inches to about 3 feet in length. Some of the trunks are more than a foot in diameter. Some are embedded in the rock; others lie loose on the surface. Probably all the fossil wood observed is driftwood that was buried in the rocks and later silicified by circulating solutions, which removed the woody matter and deposited silica in its place. The original woody structure is well preserved and, according to

[27] Walcott, C. D., and Bannon, M., op. cit., p. 7.

F. H. Knowlton, shows beyond question that the trees were dicotyledons. He states that wood of this type is rare in strata as old as Upper Cretaceous, most of the wood preserved in such rocks being coniferous. He considers that the presence of such wood precludes the possibility that the beds containing it are older than Upper Cretaceous. Specimens of the fossil wood have been examined by I. W. Bailey, of the Bussey Institution for Research in Applied Biology. He named the species *Paraphyllanthoxylon arizonense* and describes it in an as yet unpublished manuscript.

The lower part of this series of sedimentary and volcanic rocks is thus equivalent in age to part of the Colorado group, in the lower part of the Upper Cretaceous. As no fossils have been found in the upper beds, it is impossible to determine the length of time occupied by the deposition of the series. The upper beds, principally of volcanic origin, are obviously younger than the beds that have yielded fossils, but the time occupied in piling up a thickness of 1,000 feet of such rocks as these is not necessarily great measured in terms of geologic chronology, and the whole may be safely referred to the Upper Cretaceous. This conclusion is in accord with the opinions expressed by Walcott[28] and Campbell,[29] both of whom found poorly preserved plant remains that were doubtfully referred to the Cretaceous. Campbell also collected imperfect specimens of *Ostrea* and *Exogyra*, and the latter, according to Stanton, indicates that the formation is of Cretaceous age.

The part of the Cretaceous rocks of the Stanley-Aravaipa region which is of sedimentary origin bears some resemblance to the Pinkard formation of the Clifton-Morenci district, over 50 miles to the northeast, described by Lindgren.[30] This formation consists of several hundred feet of sandstone and shale containing fossils some of which, according to Stanton, belong to the Colorado group fauna and are known elsewhere only in the upper part of the Benton formation and its equivalents, thus indicating a close similarity in age between these beds and those in the Aravaipa-Stanley region. Lindgren states that the formation consists of black shale in the lower part with alternating shale and yellowish-gray sandstone, in places calcareous, in the upper part. He found no volcanic strata associated with these beds. In view of the great distance of the Aravaipa-Stanley region from known outcrops of the Pinkard formation, the large amount of volcanic material in the beds of this region, and other lithologic differences, it seems best not to refer these beds definitely to the Pinkard formation at this time.

[28] Walcott, C. D., and Bannon, M., op. cit., p. 7.

[29] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Surey Bull. 225, p. 245, 1904.

[30] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, pp. 73–74, 1905.

MIOCENE (?) STRATA

Definition and distribution.—The comparatively unmetamorphosed beds above the Cretaceous strata and below the Gila conglomerate will be described under the name Miocene (?) strata. The largest mass of such rock mapped extends from a point near the northwest corner of the area through Rawhide Mountain and Stanley Butte to Old Deer Creek and connects southeast of Rawhide Mountain with a mass that swings around the upper end of Deer Creek and reaches northward into the Galiuro Mountains, just off the area shown on Plate I. As seen from a distance, these mountains appear to be built up largely of Tertiary lava. Similar rock forms the backbone of the hills west of the valley containing the Dowdle ranches. Remnants of it still remain visible on the east side of Arivaipa Valley. Small patches of it were noted in the fault complex in the general vicinity of Arivaipa. Only one of these is shown on the map, and the size of this is exaggerated somewhat to make it visible.

Character.—The Miocene (?) beds are composed predominantly of lava and tuff, but in a number of places sedimentary strata are interbedded with the volcanic rocks.

Rhyolite is one of the most widespread types of Tertiary lava in this region, but less silicic flows make up a large part of the whole in most places. These include rhyolite, quartz latite, latite, and latitic and rhyolitic flow breccia. Obsidian, rhyolitic tuff, and tuffaceous conglomerate are also found. These rocks are of various colors. Many are of different shades of purple and heliotrope. Some are wine-pink, resembling somewhat the intrusive rhyolite associated with the batholith that forms a large part of the Turnbull and Santa Teresa mountains. Some beds are nearly white, and others are yellow, buff, salmon-pink, and gray. All the lavas are fine grained, and many have a glassy or cryptocrystalline groundmass. Most of them are porphyritic, but in many the phenocrysts are inconspicuous. Some of the glassy rocks are markedly spherulitic. In general, the rocks are composed essentially of quartz, orthoclase, sodic plagioclase, and biotite in various proportions. Many contain finely divided iron oxides. They are fairly fresh for the most part, but in some the feldspar is clouded with alteration products. Views of the Miocene (?) beds are given in Plate VIII.

The sedimentary rocks associated with the lavas are apparently of alluvial origin and are derived in part from the lavas and in part from the older rocks. Some are conglomerates composed of rather poorly sorted subangular to angular pebbles. Others are coarse, highly cross-bedded sandstones. Although not as hard or as much altered as the Paleozoic sedimentary strata, they are firm, well-consolidated rocks that stand up in prominent outcrops, as can be seen by a glance at Plate VIII.

Age.—The Miocene (?) rocks in and near Rawhide Mountain and Stanley Butte lie nearly parallel to the underlying Cretaceous strata, but there is a marked difference in degree of metamorphism of the two formations, and in places there appears to be an angular discordance. The Gila conglomerate, which is the next succeeding formation and is believed to be of upper Pliocene age, is separated from the Miocene (?) strata by an angular unconformity. Faulting took place after the eruption of the lava and before the deposition of the Gila formation. Such structural disturbances, however, do not necessarily occupy a long period of geologic time, and, especially as the tuff in the formation shows that volcanism was active during the deposition of the Gila, it may be that the time interval represented by the unconformity was short. Perhaps it is equivalent to the part of the Pliocene epoch preceding the deposition of the Gila formation. The age of similar volcanic formations as determined by various authors in numerous localities in the Southwest ranges all the way from Eocene to Pleistocene, but a large part of the lava in localities where the period in which the volcanism took place was determined is considered to be Miocene. In the absence of fossils it is impossible to fix the age of these Tertiary strata in the Aravaipa-Stanley region with assurance, but consideration of the several lines of evidence leads to the opinion that the major part of the volcanism took place in the Miocene epoch.

GILA CONGLOMERATE

The Gila conglomerate, originally described by Gilbert,[31] is a thick deposit of fairly well consolidated alluvial material in valleys in southern Arizona. Deposits which it is believed should be correlated with this formation underlie a large part of the Aravaipa-Stanley region. They extend in a broad belt southward from a point below Little Stanley Butte to and beyond the southern limit of the area mapped and also crop out in the northern part of the region on the upper slopes of the valley of Gila River.

A large part of the formation as exposed in this region is conglomerate of various grades of coarseness. In most beds the pebbles are subangular and poorly assorted. All the older formations are represented among the pebbles in different parts of the region. In some beds the pebbles have probably been transported a considerable distance from the outcrops whence they came, but in many the pebbles are obviously derived from near-by hard-rock formations. The

[31] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pp. 540–541, 1875.

conglomerate beds are sufficiently indurated to stand up in steep slopes and bluffs, but they are by no means hard rocks. (See Pl. VI, *B*.) Firmly cemented, generally coarse sand is interbedded with the conglomerate in many places. In the Arivaipa box canyon the greater portion of the formation is tuff and tuffaceous conglomerate, which has been sorted more or less by the action of water. (See Pl. VI, *A*.) The tuff is composed of fragments of glass, quartz, feldspar, biotite, and various alteration products.

The Gila formation rests in angular unconformity on the Miocene(?) strata just described and is in turn unconformably overlain by unconsolidated alluvium. No fossils have been found either in the Gila formation or in the rocks above or below it in this region, so that from the local evidence its age can only be surmised. Although a gap in geologic mapping still exists between the formation here termed Gila and the corresponding deposit in the Winkelman, Christmas, and Ray quadrangles, enough is known regarding the intervening country to warrant the belief that the correlation will eventually be established by actual mapping. Bryan [32] has found that the beds in the San Pedro Valley, in the Winkelman quadrangle, from which he and Gidley collected numerous fossils are, in his opinion, equivalent to the Gila conglomerate of the Ray and Christmas quadrangles, and Gidley [33] has shown that the fossils from two localities are of Pliocene age and probably belong to a late stage of the Pliocene. On the basis of this determination, which is in accord with the field evidence in the Aravaipa-Stanley region, the Gila conglomerate in this report is considered Pliocene, at least in part.

QUATERNARY ALLUVIUM

All the unconsolidated or slightly consolidated alluvial material in the region is termed Quaternary alluvium. This includes the deposits in the present stream channels, the flood-plain deposits along the larger streams, such as those in Arivaipa Valley and Hawk Canyon, and the detritus on the terrace tops and mountain pediments. Representatives of the Quaternary alluvium are thus distributed generally over the region. In nearly all the areas mapped on Plate I as underlain by Gila conglomerate there are also deposits of later alluvium. On parts of the pediments cut on rock older than the Gila there is a more or less continuous cover of detritus, in most places scarcely more than one pebble or boulder thick. The stream channels contain shifting deposits of gravel and sand. Because of the shifting character of the deposits, the thinness of some, and the

[32] Bryan, Kirk, and Smith, G. E. P., Geology and water resources of the San Pedro Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper—(in preparation).

[33] Gidley, J. W., Preliminary report on fossil vertebrates of the San Pedro Valley, Ariz.: U. S. Geol. Survey Prof. Paper 131, pp. 120–121, 1922.

small areal extent of many, no attempt was made to differentiate them in mapping. It would be quite impracticable to show many of them on a map such as Plate I, which is intended primarily to indicate the distribution of the bedrock formations. The most extensive and also the thickest deposits of Quaternary alluvium rest on the Gila conglomerate, and in places they can scarcely be distinguished from disintegration products of that rock.

The alluvial material ranges from coarse fan conglomerate containing large boulders in the mountains to fine silt in parts of the flood plains. Some of it is composed of angular blocks of diverse sizes derived from near-by outcrops, and some is composed of sorted and rounded grains which have in the course of many years been carried far from their sources in the swift torrents that fill the streamways in prompt response to rainfall. It is the rather heterogeneous, irregularly bedded material characteristic of the more recent deposits in southern Arizona. The thickness of the deposits is variable. In few places does it much exceed 20 feet, and in many it is only a few inches, but in parts of the valley of Arivaipa Creek it is probably a few score feet. There are wells in the valley as much as 40 feet deep which are probably all in unconsolidated alluvium.

The alluvial deposits just described are all younger than the Gila conglomerate, which can hardly be older than Pliocene, and some of them are in process of formation at present. Thus some may be as old as Pleistocene and some are Recent, but all have been deposited in the Quaternary period. The stages in the formation of the Quaternary alluvium are discussed in the section on physiography (pp. 54–57).

INTRUSIVE ROCKS

GRANITE OF THE MAIN BATHOLITH

The main granite batholith of the Aravaipa-Stanley region is that which forms the major part of the Santa Teresa and Turnbull mountains and floors the valley between these ranges. The total area is not known, as its eastern border has not been mapped, but it is evidently over 50 square miles. It extends in a direction a little west of north for nearly 20 miles from the southern border of the Santa Teresa Mountains. The width is probably everywhere less than half the length. A small outlier composed of similar rock crops out on the northeast flank of Quartzite Mountain. Two masses of red granitic rock that are probably genetically related to the main batholith are described separately below. The masses of rhyolite on the west side of the batholith are also genetically related to it. Granitic dikes, in some of which the rock is indistinguishable from that of the main batholith, cut the rhyolite and other rocks near it, but these are all so small that they have not been mapped.

The granite is everywhere rather coarse grained and in nearly all exposures is porphyritic. Feldspar phenocrysts over an inch long are common in some outcrops. Most of the rock is flesh colored, but in some outcrops, especially near the head of Black Rock Wash, the rock is dark greenish gray mottled with white and pink feldspars, some of which are large.

The essential minerals of the rock are quartz, albite, oligoclase, microperthite, microcline, micropegmatite, and biotite. A little hornblende is present in some of the specimens, and small grains of black iron ore and titanite were also noted in a few thin sections. Most of the feldspars are somewhat clouded with alteration products, and the biotite shows incipient alteration to chlorite. Secondary epidote was noted in places. The iron ore in some sections has partly altered to leucoxene, showing that it contains titanium. The texture of the groundmass is in general allotriomorphic, but the feldspars in some specimens exhibit approximations to crystal form. The proportions of the several feldspars listed above vary in different specimens. Micropegmatite was noted in only a few and is not characteristic of the main mass of the batholith. Microperthite is abundant in all the specimens studied, and microcline is present in most of them. As a rule the other feldspars are subordinate. Quartz is plentiful in all specimens. The only ferromagnesian mineral present in any considerable amount is biotite, and even this is not abundant. Some of the biotite flakes have crystal form, but many are ragged. The rock is thus a granite, but the relative abundance of the albite molecule in the feldspars indicates that the sodium content is higher than in normal granite. In places near the head of Black Rock Wash the rock is less silicic than the average and approaches a quartz monzonite in composition. A characteristic exposure is shown in Plate IX, *B*.

The batholith is intrusive into strata of Colorado age near the head of Old Deer Creek and is therefore younger than these rocks. Beds of older Tertiary flow breccia rest on the rhyolite associated with the granite a short distance northwest of the Grand Reef mine in what appears to be depositional contact, and the Gila conglomerate has clearly been laid down on the eroded surface of the rhyolite along a line 10 miles long on the west side of the batholith. Hence the intrusion can not have taken place before the last of the Cretaceous period and must have happened sufficiently long before the time of Tertiary volcanism to allow the intrusive mass to be deeply eroded. It probably occurred early in Tertiary time, perhaps in the Eocene.

QUARTZ MONZONITE

Microscopic examination of a typical specimen of the granitic rock on the plain south of the Santa Teresa Mountains shows that it is a quartz monzonite, and the mass is therefore so denominated. The pediment that extends from the mountains south to the Safford road is floored with this rock. About 10 square miles has been mapped, and it extends eastward an undetermined distance.

The quartz monzonite is a dark wine-colored rock dotted with numerous rounded lead-gray quartz grains. It is medium to coarse grained and has abundant feldspar phenocrysts, some of them 1½ inches long.

The essential minerals of the rock are quartz, oligoclase, orthoclase, biotite, and perhaps microperthite. Small flakes of hematite are scattered throughout, and a little apatite is present. Most of the feldspar is clouded with alteration products. Quartz is very abundant, both in rounded phenocrysts, some of which show strain shadows, and in small grains inclosed in the feldspar. Most of the feldspar has roughly rectangular outlines. Oligoclase is more abundant than orthoclase. Some of the feldspar seems to be microperthite, but it is so altered as to make identification uncertain. The biotite is in irregular green, pleochroic flakes and is not abundant. From these data it is evident that the rock is a quartz monzonite.

The field relations of the quartz monzonite do not furnish evidence by which its age can be closely fixed. It is evidently younger than the pre-Cambrian rocks in the vicinity and older than the Tertiary beds, but there is a tremendous interval between the dates of formation of these two. Its petrologic character differs somewhat from that of the granite of the main batholith, yet there are several points of similarity. The extent and character of alteration in the monzonite are similar to those in the granite. The two rocks are so similar that they may well be related to each other and have been intruded during the same period of igneous activity. The quartz monzonite may therefore be tentatively considered, like the granite, of early Tertiary age, but proof of this inference is lacking.

WINE-PINK GRANITE

The granite of Squaw Creek and its vicinity is here called the "wine-pink granite," because its color corresponds to that designated "vinaceous pink" in Ridgway's "Color standards." This designation is considered sufficient to differentiate it from the granite of the main batholith, which it resembles petrographically. This granite is exposed north of Copper Reef and Quartzite mountains. Only about 2 square miles of it is shown on the map (Pl. I), but outcrops of it can be found in the bottoms of gulches cut in the Gila conglomerate over a larger area. If these exposures are taken into account, the granite covers fully 5 square miles south of the Indian reservation boundary and extends an unknown distance north of the boundary.

The general tone of a fresh surface of this rock is wine-pink mottled with small sage-green areas. Closer inspection reveals numerous light lavender-gray spots. It has a medium to coarse granitic texture, with some tendency to the development of feldspar phenocrysts. The essential minerals are quartz, orthoclase, andesine, microperthite, and biotite. The rock is fairly fresh, but the feldspars are clouded with alteration, and the biotite is somewhat chloritized. Quartz is very abundant in large rounded grains, most of which show strain shadows. It also forms intergrowths with alkali feldspar that resemble micropegmatite. Andesine is much less abundant than the more alkalic feldspars. Biotite is more abundant than in the typical granite of the main batholith but is decidedly subordinate in amount to the quartz and feldspar. The rock is clearly a granite, probably with a fairly high sodium content.

This granite cuts the pre-Cambrian rocks near it and probably the Cambrian quartzite also and is cut by dikes resembling the rock of the main granite batholith. Consequently it was produced before the end of the period of intrusion in which the main batholith was formed and is probably post-Cambrian. The petrologic characters of the two granites differ sufficiently to be recognized in the field, yet they are so similar as to suggest that the granites may be closely related to each other. In the absence of more definite evidence the wine-pink granite may be tentatively regarded as slightly older than the granite of the main batholith but as formed in the same general period of intrusion and therefore also of early Tertiary age.

INTRUSIVE RHYOLITE

The rock of rhyolitic composition that rims the main granite batholith on the west side is termed intrusive rhyolite to distinguish it from Tertiary lava of somewhat similar composition. Such rock borders the main batholith along its west side but is either absent or shows only as a comparatively narrow and ill-defined band where the batholith cuts pre-Cambrian metamorphic rocks. The only place where the rhyolite has been mapped in contact with metamorphic rock is east of Crystal Peak, in the northern part of the Turnbull Mountains. Most of the rock mapped as rhyolite at this locality is coarser grained than the average rhyolite and merges so gradually into granite that the boundary drawn between the two is of necessity arbitrary. In the vicinity of Arivaipa the area mapped as intrusive rhyolite contains also numerous dikes probably related to the Tertiary lava. The rocks are so much altered by mineralization and weathering as to make discrimination between these two similar types of igneous rock difficult. In places there may also be patches of Tertiary lava not differentiated in mapping.

The intrusive rhyolite is characterized in most exposures by a grayish heliotrope color. The groundmass of the rock is in general fine grained and in some exposures shows flow banding. The rock is everywhere porphyritic and in most exposures is dotted with numerous small rectangular phenocrysts of white feldspar and less conspicuous rounded gray phenocrysts of quartz. Small biotite spangles are also visible in some specimens. Gradations between this typical texture and that of the granite already described are found in a number of places.

The essential minerals are quartz, orthoclase, albite, oligoclase, micropegmatite, microcline, and biotite. Finely divided hematite and grains of black iron ore are also present. The feldspar is clouded with alteration products, and small amounts of chlorite are present in some specimens. In some thin sections there are large corroded quartz phenocrysts, many of which are surrounded with quartz reaction rims; in others the quartz is less prominent, but in all it is fairly abundant. Peculiar rosettes of quartz are present in a number of specimens. The proportions of the feldspars vary, and the alteration in them is sufficient to make precise identification difficult, but they are all alkalic. Apparently none are more calcic than oligoclase. Biotite is rather generally distributed but everywhere in small amounts. Many specimens contain so little that it can be discerned only at high magnifications. It is the only original ferromagnesian mineral present. All gradations in texture from that of a very fine grained porphyritic felsite to that of granite can be found. In most specimens the minerals of the groundmass are without crystal form and the grain is fine, but most of the phenocrysts, except the corroded quartz, exhibit approximations to crystal outlines. These data show clearly that the rock is in general similar in composition to the granite of the main batholith. The average composition and texture correspond to those of a rhyolite rather rich in sodium, but in some places sufficient soda-lime feldspar is present to make the rock a quartz latite.

The fact that in places the intrusive rhyolite and the granite grade into each other and that everywhere they are intimately associated shows that they are genetically related. The similarity in composition of the two rocks is corroborative evidence. The interpretation of the mode of origin and structural relations presented in the section on structure (pp. 41–42) indicates that the main bodies of rhyolite are slightly older than the granite, but they both belong to the same period of intrusion and are of essentially the same geologic age—that is, probably early Tertiary.

GRANITIC DIKES

The dikes composed of rock essentially similar to that of the main batholith are termed granitic dikes. Such dikes are abundant in the intrusive rhyolite from the vicinity of the Grand Reef mine north to Imperial Hill. Some of them occur on and near Cobre Grande Mountain. Similar dikes cut the wine-pink granite near the northwest end of the Turnbull Mountains.

These dikes range from a few feet to over 20 feet in width and can be traced in places for several hundred feet on the surface. Irregular granitic intrusions were noted on Cobre Grande Mountain. There is some tendency to diminution in the coarseness of texture near the contacts, but in many dikes this is not a marked feature. The rock is of the same color and general appearance as that of the main batholith and of variable texture. Nearly all of it is noticeably porphyritic, and some contains numerous large phenocrysts.

The essential minerals of the dikes, as of the main granite mass, are quartz, microperthite, micropegmatite, albite, oligoclase, microcline, and biotite, and the accessory minerals and alteration products are also like those in the rock of the batholith. In outcrops on Cobre Grande Mountain the rock contains more micropegmatite than was noted in the granite of the main mass, but this is not characteristic of most of the dikes.

These dikes are offshoots of the main granite mass. Both the field relations and the close similarity in the character of the rocks show the close genetic relations between them. Therefore the dikes, like the parent batholith, are regarded as of early Tertiary age.

FELSITE

The fine-grained porphyritic dike rocks of silicic composition may be included under the term felsite. Dikes of such rocks cutting the pre-Cambrian metamorphic rocks and strata of Paleozoic and Cretaceous age are numerous in and near the northern part of the Turnbull Mountains and on the southwest side of Cobre Grande Mountain. Dikes of this kind cut Paleozoic beds in the vicinity of Aravaipa. Similar rocks, though mostly somewhat coarser grained, cut the granite east of Imperial Hill. Such dikes were also noted on the northeast flank of Cobre Grande Mountain. In general they crop out around the outer edges of the batholith and cut Cretaceous and older rocks.

Fine-grained dikes of aplitic composition were found in the vicinity of the Fisher prospect, in the southern part of the Turnbull

Mountains. None of the dikes are large enough to be shown on the map.

The rock of most of the dikes has a fine-grained groundmass crowded with small phenocrysts of quartz and feldspar. Many have a gray-heliotrope color closely resembling that of the intrusive rhyolite described above, but some are nearly white, apparently as a result of bleaching during alteration. They all contain abundant quartz in corroded phenocrysts, irregular grains, and some rosettes. Some of the phenocrysts are rimmed with later quartz. The feldspars are microcline and soda plagioclase; most of the plagioclase is near albite in composition. Micropegmatite is abundant in the aplite near the Fisher prospect (see p. 103) and in similar but coarser rocks east of Imperial Hill. Biotite is present in small amount in most of the dikes, but in many it is bleached and inconspicuous. Some of the micropegmatite-bearing dikes near Imperial Hill contain a little hornblende. Some of the rocks in the northern and western parts of the Turnbull Mountains contain muscovite. In general the rocks are fairly fresh, but most of them contain some chlorite or other alteration products. Near the Starlight mine is a mass of chloritized and otherwise intensely altered rock, originally a felsite. (See p. 114.) Most of the felsitic dikes have the composition of rhyolite with a rather high soda content. Some of them are sufficiently rich in soda plagioclase to be considered quartz latites.

Most of the rocks of this group are petrographically similar to the intrusive rhyolite, and many of them may be offshoots of the rhyolite and are probably therefore, like it, of early Tertiary age. It is possible that some of the dikes included in this group, particularly those characterized by muscovite, are related to the Tertiary lavas and are thus younger than the intrusive rhyolite. At one place on Stanley Butte a felsite dike of appearance similar to those just described cuts Tertiary lava.

TRAP

The fine-grained porphyritic dikes and irregular intrusions, principally of intermediate composition, which are common in parts of the region, may be grouped under the name trap. Such rocks are present in a number of places in the northern part of the region, cutting the Tertiary lavas and older formations. They are common in the vicinity of Arivaipa, where they cut Paleozoic beds and where some of them are of considerable size. Rocks of this group were noted in the area southwest of Cobre Grande Mountain. Dikes in Tertiary and older rocks crop out on the southwest side of the Santa Teresa Mountains. Trap rocks are probably also exposed in other parts of the region. None of these rocks have been shown on Plate I.

The rocks included in this group are all fine grained. Most of them are porphyritic, but many have few visible phenocrysts. In the vicinity of Arivaipa, however, are a number of dikes that contain numerous plates of white feldspar, many of which are over three-quarters of an inch long. Some of the rocks of the group contain cavities lined with green crystals of epidote. All the rocks are dark colored.

The rocks of this group that have been examined petrographically have the composition of andesite and basalt. The feldspar in different specimens ranges from oligoclase to labradorite. Altered olivine was found in a basalt from the vicinity of Arivaipa. The ferromagnesian minerals have been so generally altered that positive identifications could not be made, but it is probable that some of the rocks originally contained hornblende and others augite. The feldspars, most of which are lath-shaped, are clouded with hematite dust but have not on the average been much altered.

In spite of a considerable range in composition, most of the rocks here grouped together are closely related in mode of origin and age. Some of them cut Tertiary strata east of Klondyke and also in the northern part of the region, and some north of Arivaipa cut felsite. It is believed that most of the dikes are genetically related to the Tertiary lava and therefore of essentially the same age. In average composition the dikes are more calcic than most of the flows, but lava fully as calcic and of the same age is present in the northwestern part of the region and is abundant in places in the Christmas quadrangle, to the west. Some of these dikes may be genetically related to the Cretaceous volcanic rocks. The composition is similar but there is less alteration in the intrusive rocks.

STRUCTURE

The stratified rocks of this region are tilted, fractured, and bent in various ways, showing that they have been subjected to powerful forces since their deposition. In general, the forces that have acted here are not complex nor difficult to understand. Erosion and the covering up of some formations by later ones have removed or concealed some of the evidence, but enough is known to determine the major features of the structure, and many more details could be learned by longer and more thorough examination than it was possible to make during the present investigation.

PRE-CAMBRIAN FOLDING

The pre-Cambrian record is scanty and throws little light on the structure then produced. Igneous activity occurred on a large scale, and the rocks were subjected to powerful and long-continued compressive stresses, more so than any of the later formations, and in consequence suffered notable textural and chemical changes. The compressive forces doubtless also bent the stratified rocks into close folds. In the small areas of sedimentary pre-Cambrian rock exposed the original bedding planes are now greatly obscured. In intrusive rocks, such as make up a large part of the pre-Cambrian complex, there are no bedding planes, so that the effects of structural forces on them are less easily discerned. The ancient rocks have of course been affected by all the geologic forces that have been at work in their vicinity since their formation, and it is difficult to determine to what extent their present attitude is due to pre-Cambrian folding rather than to later earth movements. The general accord in strike of the schistosity in widely separated areas suggests, however, that in a broad way the attitude of the pre-Cambrian rocks has not been greatly modified by later movements. Faulting has doubtless lifted some blocks and depressed others relatively, but there has been comparatively little twisting or folding of the highly compressed ancient rocks since the dawn of the Paleozoic era.

The metamorphism of the rocks bears striking evidence to the action of mountain-building forces in pre-Cambrian time. These forces acted in a general northwest-southeast direction—the direction taken by mountain-building forces of similar age elsewhere in this part of Arizona.[34] The average strike of the schistosity produced in the rocks by the compression is about N. 40° E.

The pre-Cambrian intrusive rocks differ somewhat among themselves in character and in degree of metamorphism. They may well have been intruded at different times, and there was perhaps more than one period of structural disturbance in the pre-Cambrian. Indeed, it is highly probable that during that long time there were many geologic events of which the evidence is no longer legible.

LATER PERIODS OF EARTH MOVEMENT

There is no evidence of sharp structural disturbance in this region from the end of pre-Cambrian time nearly to the end of the Mesozoic. During these hundreds of millions of years there were oscillations of level of the land and perhaps broad-scale warpings of the strata, but apparently no folding, faulting, or intrusion of large igneous masses.

After the deposition of the Cretaceous strata came earth movements, followed or accompanied by batholithic intrusion. The general arrangement of the rocks as they exist to-day was in large measure produced at this time, but disturbances resulting in further changes in the attitude of the rocks have continued intermittently up

[34] Ransome, F. L., The copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 85, 1919.

to geologically recent time. Obviously forces that affected rocks of a certain age must have been active at a time later than that in which the rocks were originally formed. For this reason it is evident that the earth movements continued at least into Pliocene time and probably later, as is more fully stated below.

IGNEOUS INTRUSIONS

The only intrusion after pre-Cambrian time on a sufficiently large scale to be of structural importance was that of the granitic masses from which the largest parts of the present Turnbull and Santa Teresa mountains and the smaller similar masses near by have been carved. The granite magma that formed the main body surged up from great depths within the earth, in part tearing through the pre-existing rocks, in part shoving them aside and bowing them up. The roots of the mass probably lie buried far below any depths to which erosion is likely to reach. Its sides, in general, are evidently steep, but they are irregular, and tongues of granite or related rock reach out from them into the inclosing formations. Such an intrusive mass is called a batholith. Over an area of many square miles the cover has been stripped from it and a considerable part of the granite itself has been removed by erosion. The thickness of the fine-grained outer layer of the intrusive mass which still remains in places indicates that the magma was rapidly chilled. This conclusion, coupled with the fact that the granite reached well up into the Cretaceous strata, suggests that at the point where the intrusion spent its force and stopped the blanket of older rocks above it was not very thick. There are no quantitative data available by which the thickness of this blanket can be measured, but it is perhaps to be regarded as of the order of hundreds rather than of many thousands of feet. Both the upper surface of the intrusive mass and the surface of the ground above it were irregular, so that the amount of cover must have differed greatly at different places. This variation is reflected in the variations in the thickness of the fine-grained coating of the batholith—the rock here described as intrusive rhyolite.

The similarity in composition and the intimacy of the relations of the intrusive rhyolite and the granite leave no doubt that they came from the same parent magma and were formed during the same period of intrusion. The main rhyolitic masses are interpreted as portions of the magma that were injected into the comparatively cool older rocks and rapidly chilled. In so doing they of necessity heated the rocks into which they had forced their way. Partly because of this rise in temperature in the surrounding rocks and partly because of the effective insulation provided by the consolidated but still hot rhyolite, the magma following closely behind the leading masses was enabled to cool more slowly and thus crystallized with a coarser, granitic texture. The process was not a simple one. Conditions of temperature, pressure, and composition of the magma changed from place to place and from time to time during the course of the intrusion, and the products bear evidence to these changes. In some places rhyolite grades into granite with no perceptible break. Elsewhere there is a sharp boundary between the two. In Laurel Canyon just above the Grand Reef mine the contact between fine and coarse grained rock is sharp, and the latter is clearly intrusive into and includes blocks of the former. Evidently at this place the first of the magma to be injected cooled into a firm fine-grained rock before a later incursion of magma took place. In numerous localities dikes of granite cut the rhyolite. The magma that formed them did not chill into fine-grained masses, like the similar magma from which the rhyolite was derived, because the rhyolite was still hot. Thus it appears that the rhyolite and the granite were formed in the same period of intrusion and consolidated from magma of similar composition. The variations in texture are principally results of variations in the physical conditions affecting the different masses of magma at the time they consolidated.

The smaller masses of wine-pink granite and quartz monzonite were intruded in a manner similar to that of the main batholith. They may have come from the same magmatic reservoir and may still be connected at depth with the main batholith.

FLEXURES

The stratified rocks in general dip away from the granite all along its western front. The mass of Tornado limestone composing Lime Hill is an exception to this rule, and there are probably others. On the southeast the thick mass of Paleozoic strata forming the summits of the east end of the Santa Teresa Mountains appears to dip gently southward away from the batholith. The east and north sides have not been mapped geologically. This attitude of the strata may in part be attributed to the upward thrust of the granite during intrusion, but, as rocks younger than the granite are involved, part of it is clearly later, resulting from a subsequent relative uplift of the mountain masses. Whatever the cause or the date of the flexure, the result is an arrangement of the formations on the west side of the Turnbull Mountains in parallel bands, the oldest on the east, as can be seen from the geologic map and structure sections *A–A′* and *B–B′*, Plate I. The dip is westward and is in general steeper in the older formations and at higher altitudes. The strike is generally northwest but swings somewhat more toward the west in the northern part of the region mapped. This swing is even more pronounced in the continuation of the same formations in the Christmas quadrangle,[35] to the west. There are numerous exceptions to the general arrangement outlined above, but they are principally the result of faulting and will be considered in the next section. Some tendency to a similar arrangement of the formations can be discerned west of the Santa Teresa Mountains and the south end of the Turnbull Mountains, but here the Paleozoic strata are less conspicuous and continuous partly because of faulting and partly because of the extensive cover of later Gila conglomerate. Similar forces were nevertheless active here also, at least in the later stages, for even the Gila conglomerate dips away from the mountains, as shown in structure sections *C–C′* and *D–D′*, Plate I. The Paleozoic beds and perhaps also the later formations doubtless originally arched over the mountains, but they have now been almost completely removed by erosion except on the borders of the ranges.

In the northeastern part of the region mapped there are other flexures which may be related in time of origin to the one just described. Structure section *A-A′*, Plate I, shows one interpretation of the conditions in this area. Such sections are of necessity somewhat diagrammatic, and the actual structure may be somewhat more complicated than that indicated in the drawing. Rawhide Mountain is a syncline whose east flank is a part of the structure described in the preceding paragraph. The west flank is the shorter and steeper side of the synclinal trough. Just west of this downwarp of the strata there may once have existed an anticline, but this has been broken by faults. Around the head of Deer Creek the Cretaceous strata dip gently valleyward, forming a syncline. The combination of folding and faulting about this basin has resulted in a peculiar distribution of the rocks. The gently sloping Cretaceous beds in the basin itself are surrounded by an almost continuous wall of highly inclined Tornado limestone. On the south side there are also areas of Cambrian and pre-Cambrian rocks. Encircling the whole upper end of the basin and everywhere dipping away from it are Tertiary beds, principally of volcanic origin. Part of the bending now visible in the strata was doubtless caused by the faulting, and part of it is to be attributed to earlier folding, but the effects of the two periods of disturbance can not be definitely distinguished. They may have been separated by a long time interval, or the first of the faulting may have followed the folding closely. Wherever the relations can be observed the Tertiary strata rest on the Cretaceous beds with only a small angular unconformity, but in this particular place the discordance may be greater than usual. If so, it is possible that the Tertiary beds originally arched over the

[35] Darton, N. H., U. S. Geol. Survey Geol. Atlas, Christmas folio (in preparation).

location of Deer Creek in a broad anticline. If the Tertiary and Cretaceous beds were essentially conformable here, then the deformation by faulting was very marked. On either assumption, the curved outcrop of the limestone is difficult to account for by faulting alone. It is probably the result of a syncline with its axis plunging to the west formed before the fracturing. A number of small faults exist that have not been plotted, and those which are shown are groups of fractures rather than breaks on single planes as drawn. It is possible that faulting has occurred on the north side of the limestone ridge south of the basin and that consequently the limestone below the surface is broken instead of forming so smooth a curve as is represented in structure section A–A′, Plate I.

NORMAL FAULTS

The minor intricacies of the structure are principally results of faulting. Nearly a score of faults are shown on Plate I, and many others exist. A number of faults too small to plot were observed in the course of the field work, and there are doubtless others which escaped detection. In the vicinity of Arivaipa, in particular, faults are so numerous that it was necessary to generalize in mapping, and a comparatively small part of the total number are shown. To present adequately the intricate checkerwork of faults here would require a map of much larger scale and much more detailed field study. Most of the fault lines plotted probably represent groups of breaks whose composite trend approximates that shown. Most of the faults are of the normal type—that is, the hanging wall is depressed relative to the footwall, as if it had slipped down the inclined fault plane.

There are at least three systems of faults. One of these strikes about N. 20°–30° W.; a second set, probably closely related to the first, strikes N. 70°–80° E.; and a third set, developed particularly in the northwestern part of the region, strikes about N. 60°–70° W. The dips of the fault planes are steep, probably of the order of 70° to 90°, though few quantitative data are available. The fracturing probably started early in the Tertiary period, after the batholithic intrusion. The Tertiary volcanic rocks are extensively faulted, so that it is probable that notable fracturing continued into the Miocene. The Gila conglomerate, which is no older than Pliocene, is faulted in places, but apparently the disturbance that affected it was less powerful than the preceding ones. The conditions of unstable equilibrium set up in the earth's crust, in part, perhaps, as results of the granite intrusion and later volcanic extrusions, were gradually being adjusted by the beginning of Pleistocene time, although complete equilibrium has not even yet been established, as is shown by the minor earth tremors that are still occasionally reported in this part of Arizona.

Most of the faults formed at these different times can not be assigned to one or another period. In general, a fault may be assumed to be younger than the youngest rocks that are clearly involved in the movement, but where only ancient rocks are present, as, for example, along Squaw Creek in the northern part of the region, this assumption leaves a wide range of possibilities. As has been suggested, faulting was apparently recurrent over a long time, and it may be that in each period of stress movement was renewed on the old fault planes, in addition to forming new ones.

Some of the faults around the basin at the head of Deer Creek have a vertical throw of the order of 1,000 feet, as shown in structure section *A–A′*, Plate I, and there may be others of the same magnitude. The largest fault, or rather group of faults, in which the Gila formation is known to have been involved lies along the east front of the line of hills that cuts across T. 6 S., R. 19 E. Its best exposure is in the box canyon in Arizona Creek at the Claridge ranch. The resultant vertical throw on the group of fault planes visible here is probably almost 200 feet. Farther south, near the Dowdle ranch, the throw may be even greater. The fault that displaces the quartzite on the upper part of Squaw Creek has a horizontal shift of about three-quarters of a mile, perhaps the resultant of several related breaks. Horizontal shifts of hundreds of feet were noted in several places but are not adequately represented on the map.

OVERTHRUSTS

Like the normal faults just described, overthrusts result from fracturing of rocks with subsequent relative movement of the blocks on opposite sides of the fracture plane with respect to each other. In normal faults the effect is that which would result from the slipping down of a block of rock under gravitational force along a surface that is inclined toward the relatively downthrown block. The angle made with the horizon by such fault surfaces is usually large. Overthrust blocks, on the other hand, override the adjacent rocks, usually along surfaces inclined at low angles. Many normal faults are produced by a passive settling or readjustment of inadequately supported blocks of rock, but overthrusts seem to imply the work of more active shearing forces.

Only one overthrust of any magnitude has been found in this region, although evidence of the play of similar forces was observed elsewhere, as, for example, at the Starlight mine. (See p. 113.) The thrust mentioned is along the lower course of Garden Gulch between Stanley and Hawk Canyon. (See Pl. I.) Here a block of Tornado limestone has been thrust over the surface of Cretaceous sandstone beds. In structure section *B–B′*, Plate I, it is drawn as accurately as possible from the data available, and a view of a portion of it is given in Plate IX, *A*. The limestone block, which has a maximum residual thickness of over 300 feet, has overridden the younger beds for a distance of more than a mile. Wherever the thrust surface can be observed it is essentially horizontal, as can be seen in Plate IX, *A*. As plotted, the thrust surface dips gently westward, away from the main mass of Tornado limestone, but this may be the result of inaccuracies in the topographic sketching. Probably this surface is in general flat-lying, although there may be irregularities in it. Some brecciation has occurred locally along the contact, but it is nowhere great and in places is insignificant. The thrust that pushed the mass of Carboniferous rock nearly horizontally for more than a mile came from the east, the direction of the batholith. The movement certainly took place after the Cretaceous deposition and probably after the strata had been tilted up around the batholith. Perhaps the tilting had not been completed, and the thrusting was merely one phase of the crustal disturbance that followed the igneous intrusion. If so, the thrust surface would have shared in any tilting movement after its formation, and this would account for the fact that, unlike many thrust surfaces in other regions, it is not inclined upward away from the place of origin. The thrust evidently took place in the Tertiary period, but its date can not be fixed more closely.

GEOLOGIC HISTORY

The geologic history of this region may be inferred from the geologic facts and hypotheses set forth in the preceding sections. The events whose combined effect is seen in the present form and constitution of the rock masses of the region are fitted as well as may be into their proper places in the geologic time scale. The fossil remains of plants and animals that lived in past ages, if sufficiently abundant and well preserved, furnish the most positive clues as to the age of the rocks that contain them. Where fossils are lacking, the relative age of the different rock masses may often be determined by study of their relations to one another and of the degree and character of the changes that have affected them, but doubt may well arise as to the proper place in the time scale which should be assigned to the formation of the rocks and to the events that have occurred since their formation. In this region sufficient fossil evidence is available to warrant the assignment of most of the rock formations at least approximately to their proper places, but in the wide time gaps between the dates of some of these formations many events must have occurred regarding which uncertainty necessarily arises. Many of the events of geologic time in this region are known, and more will be inferred as facts regarding this and neighboring regions accumulate, but parts of the record will doubtless always remain buried in mystery.

PRE-CAMBRIAN TIME

The earliest records available are in the pre-Cambrian rocks. Of the events that occurred before the deposition of these rocks, only remnants of which are now exposed, all trace is now lost. These pre-Cambrian rocks have passed through so many vicissitudes that their original character can be deciphered only with difficulty. Most of them are granular igneous rocks that are clearly of intrusive origin, but there are considerable masses of fine-grained Pinal schist probably derived from marine sediments. The metamorphosed igneous rocks in the southwestern part of the Santa Teresa Mountains intrude and are therefore younger than the schist. The ancient igneous rocks in the Turnbull Mountains may well be of the same age as those farther south. Thus at the earliest time of which we have any knowledge this part of Arizona was buried beneath the waters of an extensive sea.

In the long ages that elapsed between the laying down of the mud and sand in the pre-Cambrian sea and the deposition of the first of the Paleozoic strata there were earth movements on a grand scale, resulting in compression, plication, shearing, and chemical alteration of the rocks. During this time there were one or more periods of igneous activity, in which great masses of granitic and dioritic rocks and dikes of diabase and other rocks were intruded into the sedimentary strata. The heat and pressure resulting from these intrusions doubtless contributed to the metamorphism of the neighboring formations. Comparatively volatile material was given off during their cooling. This doubtless resulted in chemical changes of various kinds in the rocks penetrated. The igneous rocks bear evidence of having been subjected to regional metamorphism, showing that orogenic forces were active after their intrusion. Much the greater part of the profound alteration in the pre-Cambrian rocks took place before the deposition of the oldest Paleozoic beds, for these beds have not been metamorphosed to a comparable degree. The time interval represented by the unconformity between the pre-Cambrian and Paleozoic rocks is certainly very long, probably the longest in all the stratigraphic record of the region. The intrusions and earth movements mentioned above may have been phases in the building of mountain ranges. The uplift was, at all events, sufficient to raise the land above sea level and subject it to active erosion.

PALEOZOIC TIME

In the Cambrian period the sea once more invaded this region. The surface which it covered was not an even one. So far as can be judged from the available evidence there were hills and valleys, but probably no mountains. Mud, sand, and gravel were laid down on the sea floor, but much the greater part of the material deposited was clean, siliceous sand, now altered into quartzite. The irregular distribution and variations in thickness of this formation as at present exposed are in part due to later structural disturbances, but they are certainly in part due to original differences in deposition resulting from variations in the shape of the sea bottom and in the supply of sediment. There is evidence here and in neighboring areas that the Cambrian sea was not deep and that land was probably near at hand throughout the deposition of the formation. The position and shape of the shore and of possible islands doubtless changed progressively during the marine invasion, perhaps with fluctuations. Deposition approximately kept pace with subsidence of the land, as is shown by the absence of deep-water deposits of Cambrian age.

Above the Cambrian strata there is another long gap in the record. No rocks of Ordovician or Silurian age are known anywhere in this region. If rocks were formed during these periods, they appear to have been since removed by erosion, yet evidence has nowhere been found of erosion of the upper surface of the Cambrian rocks. It seems probable that no large amount of Ordovician or Silurian rock ever existed here. Probably the region was out of water during at least a portion of Ordovician and Silurian time.

The existing deposits of Devonian limestone and shale are discontinuous and nowhere very thick, and the fossils they contain represent animals that must have lived in a shallow sea. It may well be that the beds were originally more continuous than might be inferred from the few exposures that have been recognized, but it is unlikely that they were ever very thick, and perhaps in some places they were not deposited at all.

Deposition of marine limestone continued in the Mississippian and Pennsylvanian epochs of the Carboniferous. Although no break in sedimentation has been detected, it is not certain that deposition was continuous, as beds of upper Mississippian age have not been certainly identified. At all events, the sea covered southeastern Arizona during a large part of Mississippi and Pennsylvanian time. There is no evidence of Permian deposition, and the region may have been above sea level during that epoch.

One of the striking things about the Paleozoic stratigraphic record is the lack of angular unconformities. The different formations are known to have been deposited at widely separated intervals of time, yet the beds are all essentially parallel. The strata were originally deposited in approximately horizontally attitude on the sea bottom, and they appear to have remained in that attitude during the whole of the Paleozoic era. There must have been oscillations in the earth's crust at intervals during this tremendously long time, but none of these movements tilted or flexed the beds already deposited so much that later beds, laid down horizontally, made noticeable angles with them. In this region there is no evidence of igneous activity or of mountain building in Paleozoic or early Mesozoic time. It was essentially an era of quiescence, during the greater part of which the land was covered by sea water.

MESOZOIC TIME

The beds stratigraphically above the Carboniferous limestone are of Colorado (Upper Cretaceous) age. No representatives of the Permian or of the earlier Mesozoic systems have been found in this region, and there is no evidence that either igneous or sedimentary rocks of those periods ever existed here. It appears that the Cretaceous beds were laid down on an approximately level surface of the Carboniferous Tornado limestone, and that the limestone had suffered little disturbance since its deposition, except for a relative uplift of the whole mass with respect to sea level. In most places where the contact has been observed the Cretaceous and Carboniferous strata are nearly parallel, in spite of the many millions of years that elapsed between these two periods. No angular discordance of any material amount between the bedding planes of the two formations was observed in the region mapped. This essential parallelism continues in the outcrops farther west, but in the " middle coal field " there is a visible unconformity.[36]

Some of the conglomerate beds in the lower part of the Cretaceous formation contain pebbles of Paleozoic rocks, proving that these rocks were being eroded to some extent at the time the deposition of the Cretaceous beds began. The small variations noted in places in the thickness of the Tornado limestone may in part have resulted from erosion, but there is no known evidence to indicate any large amount of pre-Cretaceous erosion of the limestone. The explanation appears to be that in this region during the greater part of the Mesozoic era there was no mountain building, no igneous activity, and little or no deposition of sediments. It is hardly likely that the region remained absolutely quiescent during so long a time, but no evidence as to the events which may have occurred has yet been found.

[36] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 245, 1904.

Much igneous intrusion and faulting is reported to have occurred in the Ray quadrangle,[37] west of this region, in the Mesozoic beds. These events are supposed to have taken place before Upper Cretaceous time and thus appear to mark a period of disturbance of which there seems to be no evidence in the region here considered.

The character of the Upper Cretaceous sedimentary rocks indicate that they were formed in shallow water along a seacoast. It has long been known that marine conditions prevailed over a broad strip of territory east of this region in Upper Cretaceous time. The sea extended from Mexico and Texas northward through the Great Plains and Rocky Mountain regions into Canada and perhaps reached the Arctic Ocean.[38] Marine deposits of Upper Cretaceous age occur near Pinedale, Holbrook, White River Agency, and Morenci, in northeastern Arizona (p. 27), showing that the sea covered this part of the State.

The near-shore deposits of Colorado age (Upper Cretaceous) in the Stanley district mark the location of a part of the western shore of this ancient sea at one stage in its development. There were fluctuations in the exact position of the shore at different times during the deposition of these sediments, as is shown by the variation in their character and by the extent of the area covered by them. Sedimentary rocks belonging to this formation are known to extend 20 miles west of Stanley, but this seems to mark the western limit of the Colorado sea. The part of Arizona west of this was apparently dry land in Colorado time, and most of it has remained so ever since. It is interesting to note that in Lower Cretaceous or Comanche time a sea extended up from Mexico into southern Arizona. Marine deposits of Comanche age are known on both sides of the southern part of Sulphur Spring Valley[39] and in various places in the general vicinity of Tucson.[40] No sedimentary rocks of Comanche age are known in the Stanley and Aravaipa districts, and there is no evidence that any ever existed. It appears that the northern shore of the Comanche sea in this region lay somewhere between the present north end of Sulphur Spring Valley and the vicinity of Bisbee.

The sea withdrew from this region in Colorado time and has not returned since. Before it finally left the Stanley district and the

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[37] Ransome, F. L., Copper deposits of Ray and Miami, Ariz.: U. S. Geol. Survey Prof. Paper 115, p. 87, 1919.

[38] Stanton, T. W., Succession and distribution of later Mesozoic invertebrate faunas in North America: Jour. Geology, vol. 17, No. 5, p. 419, 1909. Grabau, A. W., Textbook of geology, pt. 2, fig. 1704, 1921.

[39] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Ariz.: U. S. Geol. Survey Prof. Paper 21, p. 57, 1904. Meinzer, O. E., Geology and water resources of Sulphur Spring Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 320, p. 46, 1913.

[40] Schrader, F. C., Mineral deposits of the Santa Rita and Patagonia mountains, Ariz.: U. S. Geol. Survey Bull. 582, pp. 51–53, 1915. Bryan, Kirk, Erosion and sedimentation in the Papago country, Ariz.: U. S. Geol. Survey Bull. 730, p. 24, 1922.

area immediately to the west volcanism on a grand scale broke out, and probably it continued until after the sea had retreated from the region. It is impossible to be sure what part of the hundreds of feet of volcanic strata were formed under water, but probably most of them were laid down on dry land. The large amount of fragmental material formed indicates explosive violence in many of the eruptions, but there are also numerous lava flows produced by quieter effusion. Campbell [41] has suggested that the eruptions came through extensive fissures rather than from craters. This explanation accords with such facts as are yet available, but the presence of so great quantities of pyroclastic material suggests that some craters probably existed, even though no trace of them has yet been found. The Cretaceous strata are cut by innumerable dikes of a variety of types, and some of these may fill former conduits through which certain of the flows found their way to the surface.

INTRUSIVE ACTIVITY

After the volcanism had ceased, probably in late Cretaceous or early Tertiary time, came a period of earth movement and batholithic intrusion. The age of the granite masses that cover large areas in the Santa Teresa and Turnbull mountains has not been fixed with precision, but such evidence as is available in this and adjoining regions indicates that the intrusions took place at about this time. The greatest structural disturbances since the pre-Cambrian appear also to have occurred during this period. Most of the folding and fracturing that determined the present attitude of the rocks took place after the deposition of the Cretaceous beds, and the major movements were probably earlier than the Tertiary volcanism. The igneous and tectonic activity of this period initiated the formation of many of the ore deposits. Indeed, it is probable that all the ore deposits in the Stanley and Aravaipa districts that have yet attained any commercial importance date from this time.

TERTIARY AND QUATERNARY TIME

The manifold geologic activities that began near the end of the Mesozoic era continued to some not yet determined time in the Tertiary. There was probably a lull in the disturbances at some time before the end of the Miocene, perhaps starting in the Oligocene or even earlier. The land had been elevated well above sea level, and a somewhat rugged topography had probably been developed. Very little evidence regarding the events of early Tertiary time has been found, and the lack of fossils makes it impossible to date

[41] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, p. 246, 1904.

accurately such facts as are known. Probably, in a broad way, the appearance of the land bore an approximate resemblance to that of to-day. There were numerous differences in topographic detail, but some of the major features of the topography were probably already in existence, and the climatic conditions may well have been similar to those of the present. There have been marked changes in topographic forms and probably fluctuations in climate, but the general characteristics of both have probably not changed greatly.

In the Miocene, or perhaps earlier, there was a renewal of igneous activity. Sheets of rhyolite and other types of lava were poured out, and rhyolitic tuff was formed. The maximum thickness of volcanic material erupted at this time in the Stanley district may have exceeded the maximum thickness of the Cretaceous volcanic deposits, and the Tertiary flows evidently covered a much larger area in southern Arizona than the earlier flows. Veins in the vicinity of Stanley Butte cut lava of this age. These veins and some others are clearly genetically related to the Tertiary volcanism and are the youngest mineral deposits in the region. The character of the sedimentary deposits associated with the lavas shows that erosional processes similar to those of the present time were active then.

A certain amount of crustal disturbance doubtless accompanied the volcanism and resulted in fracturing of the rocks or renewed movement on old fractures. Faulting continued in the Pliocene and Pleistocene epochs, breaking and shifting about blocks of the Tertiary lava. Earth movements of diminished violence have continued until geologically recent time. Some features of the present topography are direct reflections of these Tertiary and Quaternary faults. There is some evidence of the production of a partial peneplain in the Tertiary, probably before part of the faulting. Valleys formed in this surface, in part as the result of faulting, were filled with the sandstone and conglomerate of the Gila formation, which is now regarded as in part at least of Pliocene age. The presence of tuff in this formation in Arivaipa Box proves that volcanism continued at least into the Pliocene, but no lava of that age has been identified.

The physiographic record shows that there have been several more or less complete cycles of erosion between the beginning of the Pliocene epoch and the present time. The causes of these cycles are not yet clear. There may have been changes in local base-level, due to earth movements, or fluctuations in climate. Probably both of these factors had their effect. If the tentative interpretation of the physiography here adopted is correct, erosion after the deposition of the Gila conglomerate continued long enough to form extensive, coalescing pediments, essentially a partial peneplain. After this came three or four other periods of deposition of gravel, each followed by a period of erosion. The erosion in each succeeding period of which evidence remains appears to have been less than in the previous one.

PHYSIOGRAPHY

The present topographic features of this region are the results of a complicated series of events. Only incidental attention to the numerous physiographic problems could be given in the present investigation, but when the data obtained are compared with the available information regarding neighboring parts of Arizona it is possible to give a tentative summary of the salient physiographic events. Most of the events considered in the following discussion took place after the extrusion of the Tertiary lava flows. Even before that time the blocking out of some of the broad features of the present topography had probably begun, but there is little definite information available as to the early Tertiary topography.

PHYSIOGRAPHIC PROCESSES

Surface forms are changed by both mechanical and chemical processes, but chemical changes have had a comparatively minor effect in the production of the topography of this region. The mechanical effects of running water, wind, and fluctuations of temperature are more marked. The end product of the combination of effects produced by these various agents would be a nearly level surface, called a peneplain. Such a result is seldom attained before some change in conditions causes an interruption. Occasionally the process is interrupted so soon that it has gone only far enough for comparatively small level areas to be produced in the valley bottoms. Later the streams may be rejuvenated and enabled to cut down into the level areas, forming terraces. The particular type of partial peneplain formed under arid conditions at the base of mountain ranges has been called " mountain pediment " by Bryan.[42] Pediments formed in earlier erosion cycles are of course subjected to erosion in later cycles and may eventually be entirely obliterated. In this region there are a number of partly completed pediments and terraces at varying elevations, and it is largely from a study of these features and of the deposits on them that the physiographic history of the region is to be learned.

Many of the features of surface forms, especially the broader features, are related to structural disturbances of the crust, but most of the details of earth sculpture are produced by weathering and erosion acting on rocks of varying resistance. The differences in size and appearance of most of the mountains in the region are due in large measure to differences in the character of the rocks composing them

[42] Bryan, Kirk, Erosion and sedimentation in the Papago country, Ariz.: U. S. Geol. Survey Bull. 730, pp. 52–54, 1922.

and to the relation of their positions to the drainage system developed in response to a complicated series of interrelated processes. Some isolated mountains may be principally the direct results of structural uplifts of geologically recent date. Even these have fallen under the dominating influence of superficial agencies, which exert themselves as soon as a rock mass is brought, by any process, within their sphere of action.

As oxidation and enrichment in ore deposits are results of weathering and of the circulation of ground water, it is obvious that a comprehension of the effects of these processes in any district depends on an understanding of the physiography of that district. The effects of enrichment may remain in a deposit long after the processes that operated to produce it have changed. The data presented in this chapter are general rather than specific, but they form a basis on which the detailed study of the physiography of specific ore deposits in which secondary processes are suspected may be founded.

PEDIMENTS AND TERRACES

Some of the high peaks and ridges in the Turnbull Mountains and perhaps also the Santa Teresa Mountains are capped by small level areas in striking contrast to the steep slopes below them. These may be remnants, isolated by later erosion, of one or more ancient peneplains, the oldest that have left any trace in this region. The so-called mesa lands surrounding the mountains are other and better-defined surfaces of erosion. They occur about both mountain groups but are somewhat more extensive and better preserved about the Turnbull Mountains. If the material that has been removed from them by the many ephemeral streams that issue from these mountains could be replaced in the gulches whence it came, the result would be a set of coalescing plains, which would together form, in a broad way, a truncated cone whose sides would slope at very low angles. The Turnbull Mountains rest on the upper base of this truncated cone as on a pedestal. The sides of the cone, so gently sloping as to appear almost flat to the casual observer, are formed in part on hard Tertiary and older rocks, in part on alluvium, most of which is somewhat consolidated, tilted, and in places broken by faults. At least some of the portion of the plains underlain by this older alluvium has a thin veneer of more recent, unconsolidated alluvium, which is composed mainly of boulders and coarse gravel derived from the near-by mountains, whose rugged slopes rise abruptly from the plains. In brief, the plains that form the sides of this theoretical cone are moderately dissected coalescing mountain pediments, in the sense of the term as defined by Bryan.[43]

[43] Bryan, Kirk, Erosion and sedimentation in the Papago country, Ariz.: U. S. Geol. Survey Bull. 730, pp. 52–54, 1922.

The Santa Teresa Mountains are surrounded by dissected coalescing pediments similar to those around the Turnbull Mountains. The east end of the range was not visited. On the north Black Rock Wash and its tributaries have removed most of the evidence of the pediment which presumably once existed there. On the northwest nearly level remnants of pediments are plainly visible to the most casual observer, and on the southwest similar plains, cut by numerous gulches, can easily be traced. On the southeast there is a broad, rolling plain cut on granite and as yet but little dissected (Pl. VII, *A*). The altitude of these pediments ranges from about 4,600 feet above sea level around the Turnbull Mountains to slightly more than 5,000 feet south of the Santa Teresa Mountains.

Below the pediments just described no extensive plains have yet been carved by erosion, but there is evidence that the process of making such plains has been started several times, only to be interrupted by some change in conditions. Most of the mountain streams in the region flow in comparatively narrow inner gorges cut in more gently sloping valleys. Such changes in slope in valley walls show that at some stage in the history of the valley the stream that formed it gained increased erosive power and cut down more rapidly than it was able to do before the change. These inner gorges in the mountains are doubtless genetically related to terraces farther downstream. As streams grow in length by headward erosion, the tributaries and upper parts of streams that are not completely graded are always more recently formed and consequently have produced less mature topographic forms than those along the lower reaches In this region erosion along some of the larger streams, such as Arivaipa Creek, proceeded far enough in the erosion cycle succeeding that in which the mountain pediments were cut to produce flood plains. Consequently when this cycle was interrupted by increased erosion, terraces were produced along these streams, while in those valleys where flood plains did not yet exist the effect was to produce inner gorges. The topographic forms in Arivaipa Valley indicate that such an interruption of the erosion cycle and renewed cutting has taken place three times since the stream started to cut below the level of the pediments around the mountains. This is shown by the two imperfectly preserved sets of terraces and the cut banks of the present stream channel, where a third set is being made. The terraces have been considerably dissected by later erosion and are not now continuous throughout the length of the valley. West of Klondyke and in several places on the east side of the tributary valley in which the Dowdle ranches are situated the terraces are conspicuous features of the landscape, and they can also be discerned at other points. East of the Dowdle ranches the upper terrace is 200 feet and the lower one a few score feet above the floor of the valley. These heights become progressively less as the head of Arivaipa Creek is approached. The present channel has banks only a foot or two high in most places in the main valley. No unquestionably stream-cut terrace was recognized in the steep-walled canyon known as Arivaipa Box, but there are in places benches which may be remnants of terraces. (See Pl. VI, *B*). Some of these benches, however, are doubtless due to fortuitous spalling off of blocks of the wall rocks.

There are gravel deposits of several different ages in this region, corresponding to the different partial erosion cycles indicated by the topographic forms described above. The extensive pediments around the mountains truncate the edges of tilted blocks of alluvial material of at least two ages. On the surface of the dissected pediments, especially near the outer edges of the present remnants, is a thin veneer of gravel. Thin accumulations of loose gravel occur on each of the two terraces in Arivaipa Valley. The flood plain below them is floored with an undetermined thickness of alluvium, which is later than the terraces. The stream channels are filled with gravel and sand brought down by the floods of the present day. Part of the gravel on the terraces and pediments may have merely weathered out of the Gila conglomerate, on which these forms are cut, but on the pediments certainly, and on the terraces probably, there is stream-laid gravel later than the erosion surface on which it rests. In places on the pediments gravel deposits of two ages lie above the eroded Gila conglomerate.

From the data above set forth it is evident that since the mountains of the region were uplifted and exposed to erosion early in the Tertiary period they have been subjected to fluctuating conditions, a part of the effects of which can still be seen in the topographic forms produced. Doubtless there are events in the physiographic history of the region of which no record has yet been found. The closer spacing of the more recent events, as here sketched, may mean not that alternation in conditions was actually more rapid than in earlier ages but that the record is more completely preserved.

No fossils have yet been found in the Tertiary or later rocks in this region, and there is little by which the events suggested above can be dated. In the valley of San Pedro River, to which Arivaipa Creek is tributary, numerous fossils have been found in the Gila conglomerate, and the physiographic history of the valley since the deposition of that formation has been worked out in detail by Bryan,[44] who has given names to several of the groups of erosion surfaces found in San Pedro Valley. He called the most extensive

[44] Bryan, Kirk, and Smith, G. E. P., Geology and water resources of the San Pedro Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper—(in preparation).

group of pediments the Tombstone. This group can be traced almost continuously through the Winkleman and Christmas quadrangles into the pediments south of the Mescal Range and west of the Turnbull Mountains in the Stanley district. In both regions these pediments are cut on Gila conglomerate, lava, and older rocks, and it is believed that they are to be correlated. The physiographic events in the Stanley and Aravaipa districts inferred from the data given above are summarized below, and tentative correlations with similar events in San Pedro Valley are given.

The events that led to the formation of the old peneplains, of which only remnants are left in the high mountains, and to the deposition of the Gila formation took place in the Tertiary period and perhaps extended into earliest Pleistocene time. The first Quaternary event of which a record remains is the formation of the extensive pediments that correspond to the Tombstone pediments of San Pedro Valley. On these was deposited gravel to a thickness of some tens of feet. Renewed denudation resulted in the production of a broad flood plain in Arivaipa Valley but stopped short of the development of pediments such as those of the corresponding Whetstone stage in San Pedro Valley. Deposition was resumed but was soon interrupted by erosion, which cut some scores of feet into the Whetstone flood plain, producing a narrower one below it. This appears to correspond to the Arivaipa stage in San Pedro Valley. A small amount of deposition ensued, followed by the erosion that resulted in the surface on which the present flood-plain deposits lie. After the formation of these deposits a channel 1 foot to several feet deep was cut in them. If this is to be correlated with the similar channel of San Pedro River, it is very recent, because, according to Bryan, the San Pedro channel was produced in the eighties. The Arivaipa channel is floored with a thin deposit of sand and gravel, which shifts with every flood.

MOUNTAIN SCULPTURE

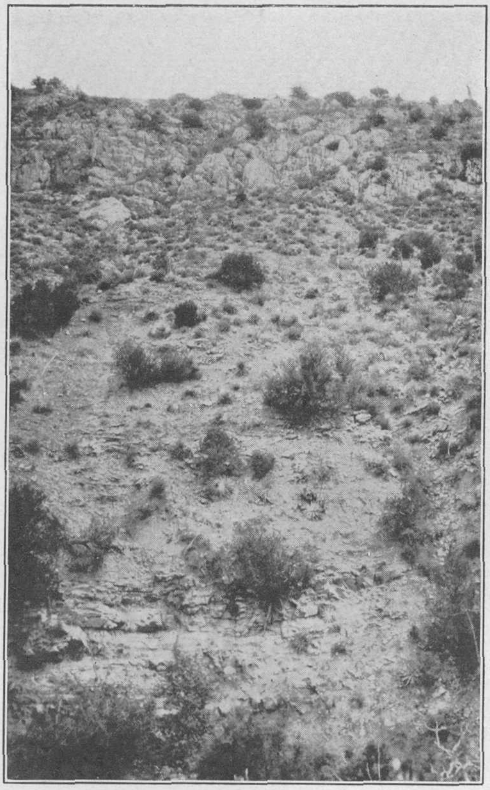
The area occupied by the Turnbull and Santa Teresa mountains was elevated as a result of crustal disturbance related to the batholithic intrusion, but the present mountains bear only the broadest relations to that uplift. The cover of stratified rocks has been largely stripped off, and erosion has bitten deeply into the massive granite beneath. A great body of gently inclined Paleozoic strata still remains in the east end of the Santa Teresa Mountains, producing the nearly flat top and cliffed slopes of that part of the range. Elsewhere in the high mountains the irregularly jointed granite has been attacked by the agents of denudation, and the resulting topographic forms lack regularity of shape and system. The forks of

Goodwin Wash and their tributaries have cut into the very core of the Turnbull Mountains and may some day work their way through and split the range up into more or less isolated ridges. On the flanks of both ranges areas of rocks other than granite still linger, and here the topography characteristic of each of the rock types is developed. The mountains carved on pre-Cambrian rocks, although steep, have in general smoother, more regular slopes with more soil than those carved on granite. Mountains formed of tilted strata are asymmetric. The sides sloping in the direction of dip of the beds tend to have smooth, flowing profiles. Those whose slopes are opposed to the dip of the beds are characteristically steeper and marked by cliffs. Good examples are Rawhide Mountain, in the Mescal Range, and Quartzite and Limestone mountains, in the Turnbull Range. A few elevations, notably those which rim the west side of the valley in which the Dowdle ranches lie, north of Klondyke, originated by faulting at the end of the Tertiary or in the Pleistocene, and their position and general shape result from the structural movement, modified in detail by later erosion.

ORE DEPOSITS

TYPES

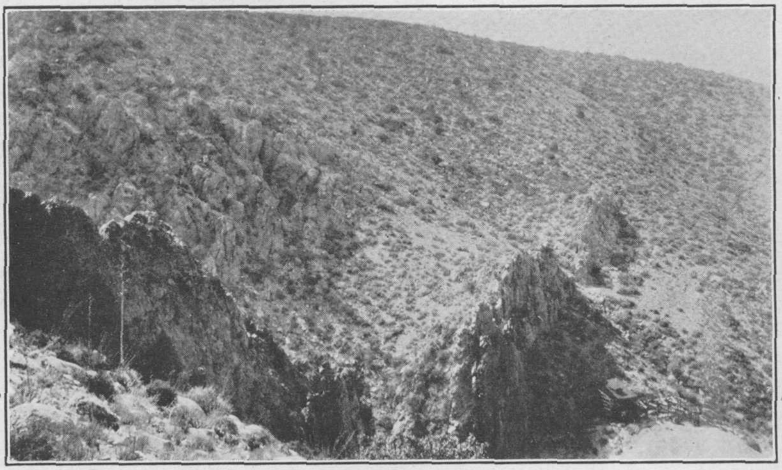
In the Aravaipa-Stanley region there are deposits of metallic minerals of six general types and also beds of coal. The type of greatest areal extent is represented by the Grand Reef and associated lodes. This group might be further subdivided on the basis of variations in both mineral composition and character of deposition. Replacement deposits in limestone constitute a second type of widespread occurrence. There is some overlap between this and the first group, because some of the replacement deposits on fissures in limestone partake of characteristics of both. A third type is represented by the veins with calcite gangue on and near Little Stanley Butte. The shear zones in andesite and the adjoining disseminated deposits south of Stanley Butte are thought to be related to this type. The veins in which barite is a prominent constituent exemplify a fourth type. The copper deposits of Fisher's prospect constitute the only known representatives of a fifth type. The sixth type comprises the gold-bearing veins of the Santa Teresa Mountains. Available knowledge of the coal beds in the valley of Deer Creek is summarized on pages 114–117. All the ore deposits have been subjected to the processes of oxidation, and there has been some enrichment. The effects of these processes are considered in a separate section (pp. 72–76).



A. NORTH SIDE OF GARDEN GULCH BELOW THE FRIEND MINE

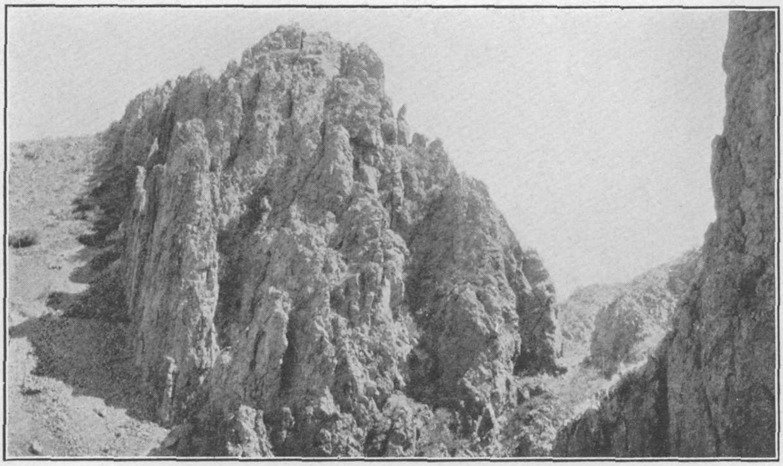
The white rock above is the Tornado limestone, of Carboniferous age. The thin-bedded rock below is Upper Cretaceous sandstone. They were brought into reversed relations by an overthrust

B. GRANITE NEAR FISHER PROSPECT, IN THE SOUTHEASTERN PART OF THE TURNBULL MOUNTAINS



A. GRAND REEF OUTCROP, FROM THE RIDGE ON THE NORTH SIDE OF LAUREL CANYON

The dismantled mill is in the right foreground



B. EDGE VIEW OF THE GRAND REEF OUTCROP, ON THE NORTH SIDE OF LAUREL CANYON, FROM THE MILL

Dumps from the upper workings are visible at the left

CLAIM MAP OF THE ARAVAIPA MINING DISTRICT

Compiled by C. P. Ross from maps supplied by C. A. Firth, Frank Landsman, Aravaipa Leasing Co., and E. H. Bachman and from data obtained in the field. Some claims on which little development work has been done are not shown, and the positions of some groups are indicated only by their names, for lack of information

Aravaipa Leasing Co.

1 Varick
2 Junction (patented)
3 Conundrum
4 Blank (patented)
5 Silver Cable
6 Dog Water (patented)
7 Boston
8 New York
9 Chicago
10 St. Louis
11 Kansas City
12 Laurel
13 Mountain Spring (patented)
14 El Paso
15 Los Angeles
16 Liberty Loan
17 South Point (patented)
18 New Independence
19 Grand Reef No. 2
20 Gulch
21 Grand Reef (patented)
22 Grand Reef No. 1
23 New Liberty
24 Blevin (1/3 owned by T. Finnegan)
25 Aravaipa (patented)

James Quinn group

26 New Year's Gift
27 Copper Prince
28 Homestake
29 Ten Strike

T. Finnegan group

30 Oronoco
31 Guard No. 1
32 Xmas Gift
33 Guard No. 2

Bullis group

34 Anna
35 Josie
36 Maggie
37 Lone Jack
38 Anita
39 Creston
40 Good Luck
41 Little Johnie
42 Black Oak (patented)
43 Imperial (patented)
44 Keynote
45 Nogi
46 Acorn (patented)
47 Western (patented)
48 Winsor (patented)
49 Apex (patented)
50 Blue Oak
51 White Oak
52 San Antonio
53 Lular (patented)
54 May Tustin
55 Copper Queen
56 Red Oak
57 St. Louis
58 Flying Dutchman
59 Octavia
60 Teko (patented)
61 Iron King (patented)

Bullis-Landsman group

62 Vulture
63 Lookout
64 Aleman
65 Lead King
66 Red Queen
67 Red Ruby
68 Ben Hur No. 2
69 Ben Hur No. 1
70 Iron Cross

Aravaipa Mining Co.

71 Sand Carbonate
72 Panama
73 Nina
74 Number 1
75 Number 2
76 Standish
77 Orejana
78 Winthrop
79 Silver Bell (patented)
80 Mammoth Chief (patented)
81 Connection (patented)
82 Keedy (patented)
83 Thanksgiving (patented)
84 Arizona (patented)
85 David (patented)
86 Glory (patented)
87 Maxwell (patented)
88 Gordon (patented)
89 Iron Cap (patented)
90 Ironton (patented)
91 Ionia (patented)
92 Grand Central (patented)
93 Head Center (patented)
94 Forest

Tolman-Babcock group

95 Extension
96 Tolman
97 Babcock
98 Triangle
99 Ramon Coro
100 La Sorrilla

H. T. Firth's claim

101 Curtis

Norton group

102 Box Canyon
103 Norton
104 Number 12
105 Number 11

H. T. & C. A. Firth group

106 Lead One
107 Lead Two
108 Lead Three
109 Lead Four
110 Lead Five
111 Lead Six

C. A. Firth group

112 Woodrow Wilson
113 Tinker
114 Wedge
115 Joe Bush

Moltke group

116 Moltke No. 2
117 Copper Coin
118 Moltke
119 Buffalo

Royal Tinto Mining & Smelting Co.

120 Oak Grove
121 Florida (patented)
122 Frances
123 Maine (patented)
124 New Jersey (patented)
125 Constitution
126 Iron Jacket (patented)
127 New York (patented)
128 Sandy (patented)
129 Tinto (patented)
130 Sam Jones (patented)
131 Charlie Boy (patented)
132 Stranger
133 Rainbow (patented)
134 Anaconda
135 Clansman (patented)
136 Annex (patented)
137 New State
138 Roosevelt
139 Copper Bar (patented)
140 Baldwin (patented)
141 Limelight (patented)
142 Sidney (patented)
143 Pinchot
144 Rosa
145 Newark (patented)
146 Norton (patented)
147 Carrie (patented)
148 Jerome
149 Copper Spar (patented)
150 Cora (patented)
151 Clara (patented)

Landsman group

152 Little Eagle No. 6
153 Little Eagle No. 7
154 Little Eagle No. 5
155 Little Eagle No. 4
156 Little Eagle No. 3
157 Fluoride No. 4
158 Fluoride No. 3
159 Fluoride No. 2
160 Fluoride No. 1
161 Little Eagle No. 2
162 Little Eagle No. 1
163 Iron Reef No. 1
164 Iron Reef No. 4
165 Iron Reef No. 7
166 Iron Reef No. 11
167 Iron Reef No. 14
168 Iron Reef No. 17
169 Alpine
170 Iron Reef No. 2
171 Iron Reef No. 5
172 Iron Reef No. 8.
173 Iron Reef No. 12
174 Iron Reef No. 15
175 Iron Reef No. 18
176 Tip Top No. 1
177 Iron Hat No. 2
178 Iron Hat No. 1
179 Iron Reef No. 9
180 Iron Reef No. 13
181 Iron Reef No. 16
182 Iron Reef No. 19
183 Iron Reef No. 20
184 Tip Top No. 2
185 Iron Reef No. 6
186 Iron Reef No. 3
187 Iron Reef No. 10
188 Raetia

Silver Coin mine

189 Silver Certificate
190 Silver Coin
191 Legal Tender
192 Hard Case
193 Anna
194 Ted

AGE

All the ore deposits in the region appear to have been formed after the intrusion of the batholith. Some, such as those of the Fisher prospect, were closely related in time to that event. Others were not formed until after the extrusion of the Miocene(?) lava. There is evidence of two periods of mineralization in veins near Arivaipa. Probably there were recurrent periods of mineralization extending from the Eocene into Miocene or even later time.

GRAND REEF LODE SYSTEM

On the west side of the Santa Teresa Mountains there is a group of lodes which, although differing in details, have sufficient characteristics in common to indicate that they are genetically related. The principal mineralization in all of them took place during the same period and under similar conditions. They thus form a single lode system. The largest of the lodes and the one on which most development work has been done is known as the Grand Reef, and the group as a whole may for convenience be designated the Grand Reef system.

The system extends from a point west of Buford Hill through Imperial Hill to Old Deer Creek, a distance of more than 11 miles in a straight line. The claim map (Pl. XI) serves to bring out the trend of the deposits in a general way, as the longer sides of many of the claims are approximately parallel to the strike of the lodes in them. The larger groups of claims, however, have been laid out so as to cover a number of adjoining lodes, and the claims do not necessarily bear any relation to the strike. The Landsman claims cover contact-metamorphic deposits of irregular extent, which do not form part of the Grand Reef system. The deposits on the other claims shown on Plate XI probably all belong to this system. The strike of the system as a whole is about N. 20° W. Most of the lodes strike somewhat west of north, but there is a considerable variation, especially near the ends of the system, and a few strike nearly east. Most of the lodes dip steeply west, and many are nearly vertical. A few dip east. The width ranges from a few inches to 200 feet. The lodes clearly extend much deeper than development work has yet gone. Comparison with deposits of similar origin in other regions leads to the supposition that they may in places continue hundreds or even thousands of feet below the lowest points yet reached in the mines. Mineralized outcrops are by no means continuous throughout the 11 miles of extent of the system. It is probably not possible to trace any lode in the district continuously on the surface for much over a mile, and most exposures are far shorter than this. Underground the deposits would probably be found to be more continuous. It seems that at the Grand Reef mine and for several miles north of it the zone in which mineralization took place is narrow, although some of the individual lodes here are wider than any known in other parts of the system. In Imperial Hill several lodes are recognized. Beyond it the lode system spreads out. To the northeast are the lodes on the Royal Tinto and adjoining properties. To the northwest are those of the Aravaipa Mining Co. and the apparently less continuous deposits to the east of them. South of the Grand Reef a number of lodes are also known. The Dog Water and Silver Cable mines are clearly on separate lodes. East of these are still other lodes whose strikes diverge widely from that of the Grand Reef. Farther south are the La Clede and Silver Coin lodes, which are parallel to each other and strike approximately east. It may be noted that the portion of the Grand Reef system in which the zone of mineralization is narrow is entirely in the intrusive rhyolite near its contact with the granite of the main batholith. North and south of this locality, where there is a larger number of lodes and greater divergence in strike, other rocks either form the wall rocks of the deposits or are near at hand. Perhaps the differences in strike of the fracture zones that contain the deposits bear some relation to the differences in the effects of pressure exerted on rocks of different types and powers of resistance.

The country rock at nearly all exposures has been brecciated and in many places has been intensely shattered. The deposits formed in the fracture zones have a composite character. They are made up in part of mineral matter introduced from without, in part of fractured and highly altered country rock which has been incorporated in them. They are termed lodes to distinguish them from veins formed essentially by the deposition of mineral matter as filling in fissures, with or without alteration of the wall rocks. The country rock of the lodes in the different parts of the Grand Reef system varies markedly in chemical composition and other characteristics, yet the chemical composition of all the lodes is in general similar, though local variations have been noted. The chemical composition of the lode matter also differs markedly from that of the unaltered country rock. For these reasons it seems clear that a large part of the mineral matter in the lodes has been introduced from some outside source. On the basis of the mass of evidence accumulated by the study of similar deposits in other regions by many geologists it can be affirmed with confidence that deposits exhibiting such mineral associations as those found in these lodes have derived part of the material composing them from igneous rock. It is highly probable that in this region the magma which formed the granite batholith was the source of mineralization. The contact-metamorphic deposits and the copper deposits of the Fisher prospect, which are even more intimately related to the intrusion, show conclusively that the valuable metals and most of the nonmetallic constituents of the lodes here described were present in the magma from which the granite consolidated. The processes by which the lodes were produced are outlined below. The molten mass that was intruded into the rocks of the crust to form the batholith contained besides the material that consolidated into granite considerable material that did not become solid under the conditions existing when the minerals of the granite crystallized. These volatile constituents were squeezed out of the granite mass as it solidified and were forced into the surrounding rocks. The process was gradual, continuing throughout the period of consolidation of the batholith, which probably occupied a long time measured in terms of human experience. Part of the volatile constituents went to form the contact-metamorphic deposits and those represented by the Fisher prospect, both of which are described below (pp. 63–70). Part of them got farther from their sources and under the lower temperature and pressure there encountered became liquid solutions. The fracture zones on the west side of the Santa Teresa Mountains afforded convenient paths for the ascending solutions, and the deposits were consequently localized along these zones. The fractures may originally have been opened in the course of adjustments in the rocks brought about by the intrusion of the batholith. Movement recurred along them during the mineralization, as is abundantly shown by the brecciation and sheeting in the deposits. Emanations and solutions thus genetically related to igneous rocks are termed hypogene to distinguish them from descending waters containing matter dissolved out of rocks near the surface by processes of weathering, which are termed supergene. These terms are also applied to the deposits thus formed. The material of which the hypogene minerals in these lodes consist came in large part from the ascending solutions, but part of it came from the brecciated rock through which the solutions circulated and which they attacked chemically. The differences in mineral composition in the lodes in the various parts of the system result in part from differences in the composition of the rocks traversed by the solutions. The process of hypogene mineralization probably occupied a considerable time and appears to have been divided into several stages. With the possible exception of some of the minerals in the lodes in limestone the minerals are such as do not require very high temperature for their formation.

In most of the lodes of the Grand Reef system the gangue is quartz and fluorite. In lodes in and near the Tornado limestone chlorite, epidote, actinolite, and small amounts of specularite and calcite have also been found. The hypogene sulphides found are galena, sphalerite, pyrite, chalcopyrite, and argentite. Products of oxidation and secondary deposition from surficial water were noted in most of the deposits.

The dominant alteration in the country rock is silicification. The brecciated rock incorporated in the lodes is largely replaced by quartz and cut by numerous later stringers of the same mineral. Rock at some distance from the lodes is similarly affected but to a less degree. The feldspar of the igneous rocks near the lodes, especially the rhyolite and quartz latite in the vicinity of the Grand Reef and neighboring lodes, is sericitized, but in general sericite is not much more abundant in rock near the lodes than in similar rock at a distance. It is noteworthy that primary ferromagnesian minerals are almost completely absent in the igneous rocks close to the lodes. They have broken down into chlorite and other alteration products.

Quartz is present in irregular masses and distinct veins in the lodes as well as in the replacement deposits already mentioned. The texture displayed by it is various. In the stopes above the adit in the Grand Reef mine gray chert is present in the breccia. On the 100-foot level are irregular masses of white and pink glassy quartz. In several places on this level and above there is medium-grained thin-banded quartz with narrow drusy cavities. Clear quartz forms only a small proportion of the parts of the Grand Reef lode seen during the present investigation, but in most of the other lodes it is more abundant. In some mines and prospects the deposits are essentially quartz veins. The wall rocks are altered and fractured, but fragments of them do not enter into the composition of the vein itself. The veins exposed in the Arizona and Orejana tunnels, near Arivaipa, are examples. In most such veins the quartz is thin banded and contains druses. The banding approximately parallels the sides of the vein and appears to have resulted from shearing of the quartz after deposition. The drusy openings common in the quartz appear to indicate that the pressure existing at the time of formation was moderate, as deposits formed under great pressure do not contain open cavities. This inference is also in accord with the probable depth of the parts of the lodes now exposed at the time mineralization commenced.

Fluorite is widespread in the Grand Reef mine. It has also been noted in some of the others and may be present in a number of places where it was not detected, as it is most inconspicuous. Clear, roughly cubical grains, visible only under the microscope, were found in quartz from the Grand Reef. In the breccia of this reef there are in places numerous small fragments composed of fine-grained fluorite that looks more like chert than like typical fluorite. A veinlet over half an inch wide of similar white fine-grained fluorite cuts galena in one of the Mountain Spring prospect tunnels. The fluorite is cut by tiny stringers of quartz. The veinlet is indistinctly banded by shearing, and the sides of the veinlet and sheared surfaces in it are coated by a thin film of some micaceous mineral.

Galena is as a rule the most abundant of the sulphides. It is of variable texture. Most specimens from the Grand Reef and neighboring lodes show considerable crushing. Specimens of galena from this and a number of other deposits when polished, etched with acid, and examined under the microscope are found to contain blebs of a mineral which appears to be argentite, the sulphide of silver. Probably most of the silver found by assay in the galena ore is in this form, and it is likely that most of the galena in the deposits of the Aravaipa-Stanley region contains argentite. Where exposed in the deposits on Imperial Hill and north of it the galena is coarse and shows little evidence of having been crushed. Sphalerite is associated with the galena in most places but in small amount. Only in the deposits on the north flank of Imperial Hill is it conspicuous. Pyrite is nowhere abundant and in many specimens is absent. Chalcopyrite is of irregular distribution. It is present as microscopic blebs in some sphalerite grains and has also been noted in irregular masses and veinlets cutting galena. The records of the Aravaipa Leasing Co. indicate an apparent increase with depth in the copper content of the ore in the Grand Reef mine.

CONTACT-METAMORPHIC DEPOSITS

There are mineral deposits in nearly all the masses of Tornado limestone scattered over the region. Most of them have the characteristics of contact-metamorphic deposits and will be described in this section. These include the deposits on the Landsman property, at the Cobre Grande mine, and on Satisfaction, Packwood, Limestone, and Copper Reef mountains. Some deposits in limestone form parts of the Grand Reef lode system, already described. Even these have characteristics in common with the contact-metamorphic deposits and form connecting links between them and the lodes. A few deposits, such as those of the Starlight mine and southwest of Rawhide Mountain, are not known to contain contact-metamorphic minerals and are too greatly separated from the lodes of the Grand Reef system to be assigned to that system. When more is learned regarding these deposits it will probably be found that their mode of formation is similar to that of the lode system or the contact-metamorphic deposits. There are certain features of the Starlight mine, however, which suggest that there may be material differences between the method of formation of the deposits here and that of any of the others in the region. In the lack of fuller knowledge these deposits are discussed in the present section.

Contact metamorphism is a process of alteration by which changes are produced in rocks as a result of the intrusion of igneous magma into them. The changes are in part produced by the mechanical disturbance and heating of the rocks, but of much greater importance in connection with ore deposits are the chemical changes produced by the injection of hot fluids, probably largely gaseous, from the cooling magma. Calcareous rocks are affected to a much greater degree by such emanations than others, and ore deposits formed in this way are therefore more likely to be found in such rocks. The name contact metamorphism was given to the process because as a rule the rocks near the contact of the igneous mass that supplies the agents of metamorphism are most intensely altered by it. In many places, however, rocks at considerable distances from known masses of igneous rock show contact-metamorphic changes. It appears that under favorable conditions emanations from the magma can penetrate long distances into the surrounding rocks. The deposits typical of contact metamorphism are produced by rearrangement of the substances present and the introduction of others, forming a new set of minerals in rock already existing, rather than by the deposition of bodies of foreign mineral matter from solution along channels opened in the rocks, as in the vein deposits. The silicate minerals, such as garnet, epidote, and actinolite, are characteristic of contact-metamorphic deposits, although rare in mineral deposits of most other types. The iron oxide minerals magnetite and specularite, the crystalline form of hematite, are frequently found. Pyrite and chalcopyrite are among the common sulphides in such deposits. The texture of most of the deposits is coarse, and some minerals exhibit crystal form. The shape of the deposits depends partly on the ease with which the different rocks that came within the influence of the emanations were attacked by them, and partly on the freedom of access from the igneous rock that was the source of supply. Slight differences in original composition may cause marked differences in the amount of metamorphism. In some deposits the shape can be seen to have resulted from selective replacement along beds of favorable composition. Other deposits have formed where fractures offered convenient paths for the emanations, and such deposits may be intermediate in character between those typical of contact metamorphism and veins.

The following general description and the accounts of individual deposits show that all the deposits in limestone, with such exceptions as have already been noted, are in form, texture, and mineral associations characteristic of contact-metamorphic deposits. They resemble in many respects the contact-metamorphic ore bodies of the Clifton-Morenci district[45] and are of about the same age. Some of them, like those at the Copper Reef mine, are at a distance from outcrops of granitic rock, but all of these are near felsitic porphyry dikes that may have contributed to their formation. Near some dikes there is notable contact metamorphism, and the dike rock itself is partly replaced, but near others there is little alteration in the adjacent limestone. There may be granite below the surface which is nearer to some of these deposits than can be determined from the outcrops of such rock.

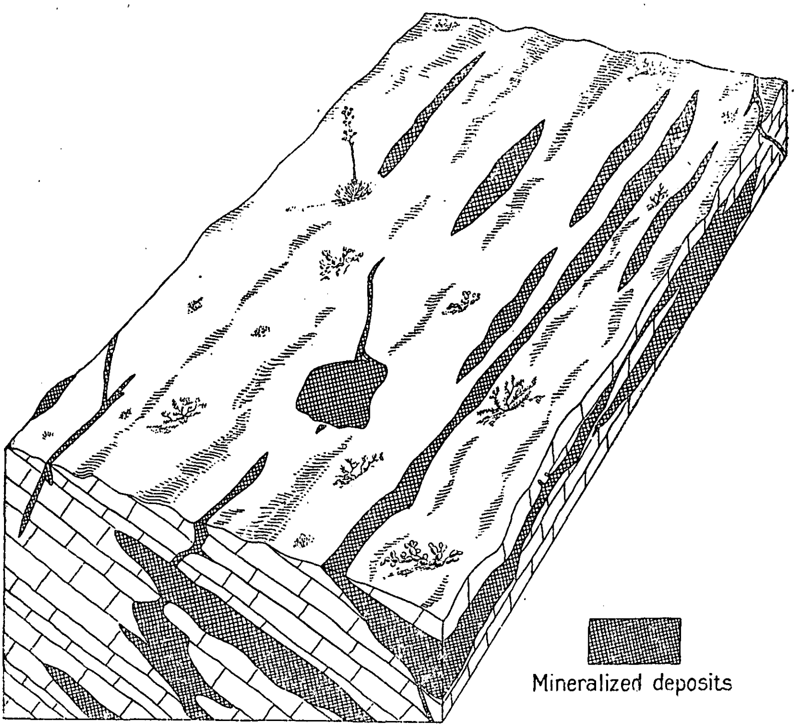


FIGURE 1.—Diagram showing contact-metamorphic deposits in limestone

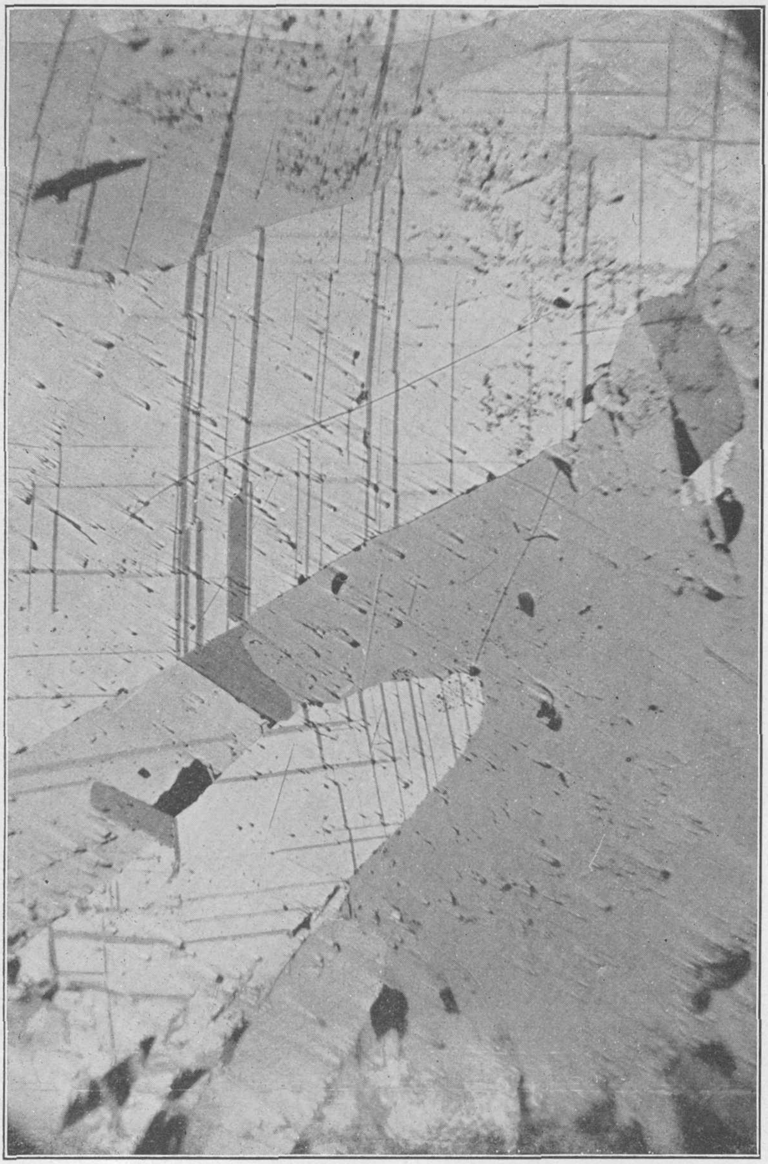
The forms assumed by these deposits are various. Some representative ones are shown diagrammatically in Figure 1. In many deposits the replacement has been guided by the bedding planes in the limestone, and the original sedimentary structure is preserved in the metamorphic rock. Replacement may occur in a number of contiguous strata or may be approximately confined to a single bed. Locally fractures in the rock have furnished channels along which replacement has occurred. Replacement along fissures appears to have produced more irregular, smaller, and less continuous deposits

[45] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, 1905.

than that along the bedding, but there may well be exceptions to this rule. Some of the deposits are most irregular in shape and are independent both of the bedding and of visible fractures. The larger deposits can be traced in places hundreds of feet laterally along the limestone beds. The transition into unaltered limestone is generally rather abrupt, although more gradual transitions were also noted. In places the major part of the limestone exposed over a considerable area has been altered, and there is a progressive decrease in the amount of limestone so affected at increasing distances from this area, although the replacement in the rock that has been affected may be as complete in one place as in the other. These deposits are so irregular in shape and have boundaries so indefinite that it is not safe to predict the continuation of a given deposit far in advance of actual exposures.

The minerals noted in the deposits are quartz, garnet, actinolite, chlorite, epidote, fluorite, barite, calcite, specularite, magnetite, pyrite, chalcopyrite, sphalerite, galena, stibnite, and various oxidized minerals and secondary sulphides. Most of the galena contains tiny blebs that are probably argentite. The proportions of the minerals differ in different places, and in no single deposit have all the minerals listed above been found. Quartz is abundant in a number of exposures, but in some it is inconspicuous. It is clearly of two generations, both later than most of the metallic minerals. There are in a number of places drusy cavities lined with well-formed quartz crystals. The garnet resembles andradite, but its exact composition has not been determined. It occurs in massive form and in crystals projecting into cavities. The quantity of garnet in most of the ore deposits is small, and in many none was found. In the contact-metamorphic rock of Crystal Peak garnet is abundant. Actinolite is locally prominent in masses composed of groups of needles radiating in all directions from common centers. Chlorite is found in masses of flakes of various sizes but is not a conspicuous constituent in much of the ore. Epidote forms small groups of crystals but is nowhere very abundant. It is associated with garnet in most specimens in which it has been identified. Fluorite was found in the deposits on the Landsman property. Crystals of it nestle among the quartz prisms in druses, and it was also noted in massive quartz veinlets. Calcite is present in many of the deposits but everywhere in small amount. Barite was noted only in specimens from the Copper Reef mine.

Specularite and magnetite occur in all the deposits seen. In most specimens the former is the more abundant. The relations of these two minerals to each other are complicated and present many features of interest. Each may replace the other, and it is evident that this reversible chemical process has taken place in both directions in



MAGNETITE IN PROCESS OF REPLACEMENT BY SPECULARITE the deposits of this region. In specimens from the Landsman property magnetite that was formed early in the process of mineralization has been extensively replaced by specularite. Small rounded grains of magnetite penetrated along octahedral partings by specularite and surrounded by that mineral can still be found. (See Pl. XII.) Such relations clearly indicate that the specularite has formed at the expense of the magnetite. The specularite inclosing such residual magnetite grains is irregular in outline, but crystal plates of the mineral project from it into the quartz gangue, in which numerous well-formed specularite plates are embedded. The long axes of the plates have a subparallel arrangement strongly suggestive of flowage. It seems that the specularite formed from the magnetite had so strong a tendency to crystallize that it assumed the plate form characteristic of the mineral. Evidently this took place before complete consolidation of the quartz in which the iron minerals are embedded, for the plates could not have been rearranged along lines of flowage if they had been inclosed in solid material. However, the specularite tends to segregate along lines around quartz grains, proving that part of the quartz had already crystallized before the specularite assumed its present arrangement. These plates are themselves embedded in quartz, which crystallized after they did. Some of the specularite may have originally crystallized as such instead of being derived from magnetite.

Some specimens from the Cobre Grande mine show entirely different conditions. Here there are grains that are composed of magnetite but have the crystal form of specularite. These are clearly pseudomorphs produced by the conversion of original specularite into magnetite. In specimens from the same deposit there are foils of micaceous specularite containing small amounts of magnetite. All the specimens of black iron ore from various parts of the region that have been tested contain both specularite and magnetite, but the visible crystal forms in all of them are those of specularite.

Pyrite is abundant in many specimens of ore. It was one of the first sulphides to form and crystallized in more or less cubical grains, which were later broken apart, shattered, and embedded in gangue minerals or chalcopyrite that subsequently consolidated. Only small quantities of chalcopyrite were noted in any of the deposits except at the Cobre Grande mine. In some of the specimens from this mine the mineral is abundant in structureless masses inclosing pyrite grains. Some specimens contain a few small grains that appear to be sphalerite and galena, but both these minerals are rare in all the contact-metamorphic deposits visited. A few small crystals of stibnite were found in ore specimens from the Cold Spring prospect, but the mineral was not observed elsewhere, and tests on ore specimens from other deposits failed to reveal any antimony.

The distribution of the different minerals within the contact-metamorphic deposits is variable. In places one of the nonvaluable minerals is the most abundant constituent, in others another. Parts of some deposits contain so high a percentage of magnetite and specularite as to constitute iron ore, which might be utilized if it were found in sufficient quantity and if a suitable market for such material were sufficiently convenient. Under present conditions iron ore in this region is of little value. The metallic sulphides are of particularly irregular distribution and make up only a small part of the exposed contact-metamorphic deposits. This is strikingly shown on Crystal Peak, where thousands of tons of intensely contact-metamorphosed limestone is exposed. The only prospect known here is at Cold Spring, on the edge of the contact-metamorphosed mass, and the development work at this prospect appears to have discovered little of value. Elsewhere on Crystal Peak no sulphides or evidences of their former presence appear to have been found. The distribution of minerals in such deposits and the shape and size of the deposits themselves are so diverse that prospecting in them presents even more uncertainties than in veins, but valuable ore bodies occur in other regions under conditions similar to those which exist here, and small amounts of copper ore have been found in contact-metamorphic deposits in so many places in this region as to encourage the hope that deposits of sufficient size and grade to be commercially valuable may be present in the Aravaipa-Stanley region.

As has been mentioned, the Starlight mine presents some features of interest. The rocks in the vicinity of the mine comprise the Tornado limestone, Cambrian quartzite, pre-Cambrian schist, and an altered intrusive rock. The Paleozoic strata are fractured, tilted, and even in part overturned. Schist is exposed under these rocks in Godless Gulch. Just east of the mine is the altered igneous rock, a dark-green fine-grained rock having the composition of an altered soda-rich granodiorite or soda granite that originally consisted of micrographic intergrowths of quartz, alkali feldspar, and plagioclase, and also presumably ferromagnesian minerals, although none now remain. The alteration of this rock produced chlorite, epidote, calcite, and secondary quartz and was probably effected under the influence of moderately heated solutions that seeped up through the rock from below. Some of the original minerals broke down and formed new combinations, and some water, carbon dioxide, and perhaps other things were added. Although the appearance and mineral composition have changed notably, the chemical composition may not be much different from that of the original rock. Such alteration differs markedly from that produced by contact metamorphism. This fact, coupled with the apparent lack of contact-metamorphic minerals in the ore, makes it appear that the deposits of the Starlight mine may differ in origin from most of the ore deposits in limestone in the region.

COPPER DEPOSITS IN THE GRANITE OF THE MAIN BATHOLITH

A curious type of copper deposit in the granite of the main batholith is known only in the Fisher prospect, in the southeastern part of the Turnbull Mountains. The rock here and for 2 miles or more in every direction is granite. Near the prospect are some narrow dikelets of aplite containing abundant micropegmatite. The metallic minerals are irregularly disseminated in the granite. The limits of each deposit are indefinite, but there appear to be a number of disconnected, elongate zones of mineralization. Indefinitely marked slips occur in the mineralized granite in places, but there is no suggestion of the filling of fissures by vein matter or of any definite walls. Chalcopyrite, the only original sulphide found, has crystallized in the granite with only a minor development of gangue minerals foreign to that rock. These are epidote, titanite, apatite, and chlorite, or a similar alteration product. The minerals of the granite are almost perfectly fresh, but some of those near ore minerals are somewhat shattered. There has been some oxidation and a little enrichment.

The striking features of these deposits are the paucity of nonmetallic minerals connected with the metallization, the lack of alteration in the granite, the intimate relations of the chalcopyrite to the minerals of the granite, and the lack of definite form or bounds to the deposits. Clearly the mineralization resulted in impregnation of the granite, not in the formation of veins. The slips mentioned may well have been merely openings along joints formed by contraction during the cooling of the granitic magma. They may have furnished paths of access to the mineralizing agents and thus served to localize the deposits to a certain extent. The mineralization is evidently closely related to the intrusion of the granite. It probably took place during the cooling of the rock, when joints were beginning to form but while the temperature was still high. At this stage in the consolidation of an igneous rock most of the minerals constituting the main mass of the intrusion have crystallized, but some of the most volatile constituents of the original magma have not yet consolidated. Some of these volatile constituents, presumably gaseous, squeezed out from below by the formation of the rock minerals, seeped upward until a favorable combination of conditions of temperature, pressure, and concentration was encountered. Here the emanations attacked the minerals of the granite, replaced them, and deposited chalcopyrite in their stead. Epidote crystallized out later to fill the spaces between the chalcopyrite grains. Thus the deposits appear to fall in the class which Graton and McLaughlin [46] propose to call pneumotectic—that is, they were formed after the strictly magmatic phase of intrusion of molten rock and before the pneumatolytic stage marked by the presence of abundant mineralizers. They were intimately related to the intrusion of the granite magma but were probably formed shortly after the major part of the consolidation of the main mass had taken place. Although formed under the influence of gaseous constituents by replacement of the granite, they can not be called pneumatolytic in the sense in which that term has been restricted by Graton and McLaughlin, for there is little evidence of destructive pneumatolytic action, and none of the characteristic pneumatolytic minerals were found. Each of the nonmetallic minerals formed during the original mineralization is much less abundant than the chalcopyrite. The few prisms of apatite noted are almost negligible, especially as similar tiny crystals were found in thin sections of specimens from distant parts of the batholith. The epidote is thought to have formed in the pneumotectic stage after the deposition of the chalcopyrite, but possibly, as Tolman and Rogers [47] have suggested, it is a result of later hydrothermal alteration. The titanite was probably formed under essentially the same conditions as the epidote. The chlorite is distinctly a later hydrothermal alteration product. It is to be noted that the Fisher prospect is in granite, whereas most of the sulphide deposits in other regions so closely related to magmatic processes are in subsilicic rocks.[48]

The copper minerals present other than the chalcopyrite are all much later in origin. They were formed by processes of oxidation and enrichment similar to those which produced similar minerals in deposits elsewhere in the region.

CALCITE VEINS

There are several veins in the vicinity of Stanley Butte in which calcite is a prominent gangue mineral. This mineral is inconspicuous or absent in the other veins of the region, except where a vein cuts limestone and has derived calcite from it. The mechanism of formation of these veins is similar in some respects to that of the formation of the Grand Reef lode system, already described, but the mineral composition is markedly different. Some of the veins of this type cut Miocene (?) lava, showing clearly that they are at least as young as the lava, and therefore more recent than the major mineralization in the Grand Reef system.

[46] Graton, L. C., and McLaughlin, D. H., Further remarks on the ores of Engels, Calif.: Econ. Geology, vol. 13, p. 85, March, 1918.

[47] Tolman, C. F., and Rogers, A. F., A study of the magmatic sulfid ores: Leland Stanford Junior Univ. Pub., Univ. series, p. 17, 1916.

[48] Idem, p. 70.

The veins in the Tertiary lava are composed very largely of massive, coarsely crystalline calcite containing manganese oxide. A little cherty quartz is present in places, and films of gypsum coat cleavage cracks in the calcite. In chert-lined cavities are tiny crystals of a mineral resembling anatase. Such veins were found in prospect holes on Stanley and Little Stanley buttes. The copper veins of the Friend mine and the zinc and copper veins and shear zones of the Princess Pat mine and its vicinity contain calcite as a prominent constituent of the gangue. These deposits are in volcanic strata believed to be Cretaceous, but Miocene (?) lava overlies the Cretaceous beds a short distance above the deposits, so that possibly the veins originally extended up into the Tertiary (Miocene?) lava before the lava was eroded. The deposits at both localities are therefore tentatively grouped with the Miocene (?) calcite-bearing veins. The veins that the tunnel of the Stanley mine was driven to develop and the veins on Rawhide Mountain regarding which little is known may belong in this group.

The deposits of this group are in part clear-cut veins with definite and regular walls, in part zones of brecciation and shearing. They contain calcite, quartz, chalcopyrite, sphalerite, pyrite, galena, and other metallic minerals produced by oxidation and supergene deposition. The bornite reported from the Friend mine may have been an original constituent of the ore.

BARITE LODES

Near the summit of Stanley Butte on the east side, at the Silver Spar prospect, there are seams in the fractured lava filled with vein matter in which barite is a prominent constituent. These seams may represent a different phase of the mineralization that produced the calcite veins just described, or they may be older or younger than those veins. They are obviously not older than the Miocene (?) lava containing them. Veins containing barite also exist in the complex of pre-Cambrian metamorphic rocks and later intrusive rocks in the vicinity of Kelly Canyon, in the northern part of the Turnbull Mountains. The mineral was also noted in the replacement deposits in limestone at the Copper Reef mine.

At the Silver Spar prospect there are sharply defined but discontinuous seams a few inches wide containing plates of barite and cubes of fluorite in a mosaic of quartz grains. In the vein matter there are irregular aggregates of small black grains of an unidentified silver-lead mineral, and a copper mineral which is probably bornite.

GOLD VEINS

In and near the Santa Teresa Mountains there are a number of quartz veins, some of which contain gold. Prospecting and a little mining for gold have been undertaken in such veins, but none of the mines are reported to be active at present, and, so far as known, all are outside the region mapped in the present investigation. As none of these mines or prospects were visited, no accounts of them can be given in the descriptions of the mining districts. Gash veins filled with massive white quartz were observed in the quartz monzonite on the south side of the Santa Teresa Mountains. All those seen were short lenticular masses, with outcrops only a few feet long. It is probably in such veins that the pockets of gold have been found.

OXIDATION AND ENRICHMENT

The processes of oxidation and enrichment have played a part in the production of most of the mineral deposits of the region, as will be seen from the descriptions of the mines and prospects given below. The conditions believed to have affected the operation of

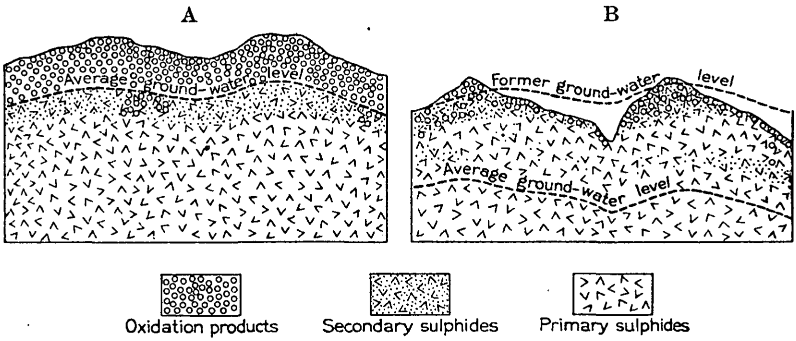


FIGURE 2.—Diagram to illustrate oxidation and enrichment. A, under favorable conditions; B, under accelerated erosion

these processes in this region and inferences drawn from the scanty available data as to what may be expected at depth will next be presented.

The oxidation of mineral deposits is merely a phase of the weathering process that attacks all rocks as soon as they come within its influence. As mineral deposits contain substances that are chemically more active and powerful than those commonly present in rocks, the effects of weathering on such deposits are more rapid and intense. Oxidation starts in a mineral deposit as soon as water percolating downward from the surface and carrying dissolved oxygen and other substances derived from the air and surficial formations comes into contact with it. (See fig. 2.) A great diversity of chemical reactions may take place, the particular reactions depending on the particular set of chemical and physical conditions existing. The results in general are that part of the substances in the deposit are taken into solution and removed, part are converted by solution, precipitation, and chemical interchange into new minerals, and part are attacked so slowly as to remain in their original form for a long time. The probable behavior of the common hypogene metallic minerals present in a region may be summarized as follows. The iron oxides, magnetite and specularite, are attacked slowly and remain essentially unaltered in most outcrops. Galena is readily protected by coatings of its difficultly soluble oxidation products and may remain near the surface after considerable oxidation. A large part of the lead that is dissolved is likely to be reprecipitated promptly as cerusite, anglesite, or some other oxidized mineral. Pyrite and chalcopyrite are both attacked rather readily and would not be expected to crop out where there has been any notable amount of oxidation. Hydrated iron oxides such as limonite are formed as decomposition products of both pyrite and chalcopyrite. Malachite, azurite, chrysocolla, and various copper oxides are formed from chalcopyrite. Lack of visible copper minerals in an oxidized deposit is not, however, proof that none formerly existed, as they may be dissolved and almost completely removed by long-continued oxidation. Sphalerite is readily attacked and is soluble under oxidizing conditions, so that zinc minerals in any quantity are not to be expected close to the surface where there has been much oxidation.

Oxidation may continue to any depth at which the circulating ground water retains any free oxygen. It is usually assumed to cease near the average position of the water table, or ground-water level, and this assumption is probably in general an approximation to the truth. (See fig. 2, A.) The position of the water table is, however, constantly shifting with seasonal fluctuations in precipitation and changes in climatic and physiographic conditions. Oxidation, on the contrary, is persistent but slow. The actual lower limits of oxidation in a given deposit are irregular and dependent on a number of factors. In the Aravaipa-Stanley region it seems to have penetrated to comparatively shallow depths in most deposits, as at present exposed, and many deposits are not greatly affected by it even at the surface.

The water that percolates below the zone of oxidation has lost its power to oxidize but has gained a load of metallic salts. A large part of it usually continues downward in the deposit, coming into contact with the as yet unaltered minerals below. Here the greater part of the dissolved metals may be precipitated as supergene sulphides as a result of direct or indirect chemical reaction between the hypogene sulphides and the salts in the water. The primary sulphides involved in this process will be in part chemically changed and replaced, and some substances will go into solution in exchange for those precipitated, but the net result is a gain in the content of valuable metals in this portion of the deposit, which is therefore termed the zone of enrichment. (See fig. 2, A.) The process seems to be more efficient with copper than with the other metals, and valuable deposits of enriched copper ore are known in many regions. Similar deposits of silver minerals have been found at numerous places, but the process seems to have been in general less effective in enriching silver deposits. Supergene sulphides of lead and zinc are known, but deposits of commercial importance are rare. In the Aravaipa-Stanley region supergene copper sulphides have been found in a number of deposits, but supergene sulphides of other metals have not been proved to be present.

The contacts between oxidized material and supergene sulphides and between these sulphides and the unchanged minerals below are usually irregular. They may be sharp or gradational, according to the existing conditions. In most deposits some supergene sulphides and smaller amounts of hypogene sulphides are found in the oxidized zone, and oxidation products find their way into the enriched zone. Hypogene sulphides are usually found in places in the zone of enrichment, and supergene sulphides may extend in places well below the lower limits of the zone characterized by such minerals. Figure 2, A, shows the relations of the three zones to one another, though the zones as drawn are more sharply defined and regular than they are in most actual deposits.

Oxidation in the exposed parts of the deposits in the Aravaipa-Stanley region is irregular. Most of the deposits show some oxidation on the outcrop, but in a large number original sulphides can be found at the surface, and it is exceptional to find evidence of extensive leaching and removal of metallic constituents from the zone of oxidation. In several places, however, oxidized metallic minerals have been found in such quantity that they have been mined. The ore containing wulfenite, the molybdate of lead, stoped in the Silver Cable and near-by mines is an example. Some of the ore mined at the Grand Reef was partly oxidized to anglesite, cerusite, and other lead minerals, with malachite and chrysocolla in places, but most of this ore contained some unoxidized sulphides, and a large part of the ore in this mine is essentially unaffected by oxidation. The presence of unaltered sphalerite, the sulphide of zinc, only a short distance below the surface shows that oxidation has not been very effective here. On the contrary, strongly oxidized ore, containing, however, some residual sulphides, was encountered on the 300-foot level, the greatest depth to which development has been carried, well below the present water level. It is probable that this oxidation so far below the depth to which the ore body in general has been oxidized has resulted from some circumstance particularly favorable to it, such as the seeping down of oxygen-bearing water from the surface along some fracture that served to facilitate its rapid descent. Partly oxidized ore has been mined at the Tenstrike and other prospects near it and on Imperial Hill. Essentially unoxidized sulphides, including sphalerite, have been found near the surface on the northern flank of Imperial Hill.

In the shaft on No. 1 claim and at several other places near Aravaipa high-grade bodies of cerusite, the carbonate of lead, have been mined. These were produced by concentration within the zone of oxidation, by the deposition in favorable places of lead carbonate from water that had obtained it from oxidized galena ore. Some of these cerusite masses contain so little gangue that the lead content is much higher than that of the original ore. They are, however, small and discontinuous, and there is no means of predicting their location or extent in advance of development.

Oxidized copper ore has been mined at the Copper Reef and Friend mines and elsewhere. The copper minerals in it are principally the carbonates malachite and azurite and the silicate chrysocolla. Limonite and earthy red hematite are present. In partly oxidized copper ore the so-called copper-pitch ore develops around residual cores of chalcopyrite. The copper-pitch ore in this region appears to be an intimate mixture of the black oxide of copper, tenorite, with limonite and the supergene copper sulphide chalcocite. The copper-pitch ore of the contact-metamorphic deposits contains manganese oxide, but the material of similar appearance in the deposits in granite at the Fisher prospect does not appear to contain any manganese.

The supergene copper sulphides chalcocite and covellite have been found in most of the deposits in which copper is present in the unoxidized ore, but at no place in the region are commercially valuable deposits of such sulphides known. Development in most deposits is insufficient to establish the absence of such bodies of sulphides. The chalcocite in the ore of the Fisher prospect and in some of the contact-metamorphic deposits is probably sufficient to raise the copper content appreciably. In those mines in which considerable bodies of original hypogene sulphides have been developed the amount of supergene sulphide present is so small as to be almost negligible.

Supergene silver minerals are present in places. Horn silver is found in the oxidized parts of several deposits. Native silver and supergene silver sulphides are reported from the La Clede mine, but no specimens of such ore were seen during the present investigation. At the Silver Spar prospect there is argentite, but whether it is a product of original deposition or is secondary is uncertain.

The physiography of the region shows that there have been a number of renewals of erosive activity since Pliocene time. During at least the more recent of these the upper parts of the ore deposits have been exposed to attack and portions of them have been removed.

The irregularity and scantiness of the oxidation products in the deposits as now exposed seem to indicate that in geologically recent time erosion has been more active than oxidation. The oxidation products were in most places stripped rapidly away, and the original ore and such supergene sulphides as had formed were exposed to attack. Part of the oxidized copper minerals now present in the deposits have been derived by reoxidation of the copper in supergene sulphides. Figure 2, B, illustrates the effect of accelerated erosion on the oxidized and enriched deposits shown in Figure 2, A. In most of the deposits of this region the process has gone even farther than is shown in the figure, or else the physiographic conditions have been so unstable that no such definite zones as are indicated in Figure 2, A, were ever formed. It must be remembered that few deposits in which copper sulphides and pyrite were abundant as hypogene minerals have yet been developed to any depth by mining in this region. It is possible that such deposits may be found so favorably situated that they include zones of supergene copper enrichment. In deposits in which notable amounts of hypogene sulphides are encountered before bodies of supergene sulphides are found it is unlikely that masses of enriched ore of commercial importance exist at greater depths.

ARAVAIPA MINING DISTRICT

GENERAL FEATURES

Location and extent.—The Aravaipa mining district is in Tps. 5, 6, and 7 S., Rs. 19, 20, and 21 E., only parts of which are surveyed. It lies near the middle of the west border of Graham County and has somewhat irregular and indefinite boundaries. It is bounded on the north by Old Deer Creek, on the west by Arivaipa Creek, and on the south by the valley between the Santa Teresa and Graham mountains. The eastern boundary appears to lie approximately along the divide between streams tributary to Arivaipa Creek and those which flow directly into Gila River. The Cobre Grande mine, on the northeast flank of the mountain of the same name, is considered to be in the Aravaipa district, and John Fisher's prospects, in the southeast end of the Turnbull Mountains, are in the Black Rock mining district. Fisher's prospects are the only ones in the Black Rock district reached during the present investigation, and they are described in the present chapter.

Population.—Klondyke, which consists of a store and post office, a school, a church, and a dwelling house, is the distributing point for the district. A number of small ranches lie in Arivaipa Valley in the vicinity of Klondyke. Most of those north of Klondyke are shown on the map (Pl. I), but some of those south of it are omitted.

Arivaipa, about 10 miles from Klondyke, is the center of population for the northern part of the district. It consists of a post office and several buildings, one of which is occupied. When the Aravaipa Mining Co. was operating, there were as many as 60 people here. According to the census of 1920, Klondyke precinct had a population of 461. In 1910 the population was 334.

Roads.—Klondyke is accessible from Willcox, on the main line of the Southern Pacific Railroad, by a wagon road about 60 miles long, and from Glenbar, on the Arizona Eastern Railroad, by a road about 36 miles long. Safford, the largest town in that part of the valley of Gila River, is about 10 miles southeast of Glenbar. Both roads are good "natural" roads and passable for automobiles. The Willcox road has fewer and lower grades than that to Glenbar but gives some trouble from mud in wet weather. There is at present no road connecting the Aravaipa and Stanley districts, but the gap of about 3 miles between Arivaipa and the Princess Pat mine could easily be closed, the only obstacle of any moment being the canyon of Old Deer Creek. There is talk of the construction of a road by Graham County to connect with one to be built by Pinal County which would pass from Klondyke either through Arivaipa, across Lone Cedar Mesa into Hawk Canyon, and thence over the divide westward into the head of the valley of Deer Creek, or else through Arivaipa Box. Such a road would aid greatly in the development of the district, but its growth will continue to be handicapped until better railroad facilities are available. It would not be difficult to construct a railroad line between Willcox and Klondyke, but the present production of the district is not sufficient to warrant the necessary outlay. This lack of adequate transportation has hampered the district from the outset and is one of the principal reasons for a total production of less than 35,000 tons of ore in more than 40 years of mining. The hope for future growth of the district seems to lie in its mining rather than in its other industries, important though they will be as aids. This hope can be realized only if some company, backed by adequate capital, should be successful in proving the presence of such large ore bodies of workable grade somewhere in the district as to induce it or others to provide modern transportation. As will be seen from the descriptions of the several properties given below, there are a number of mineral deposits whose appearance warrants hope of the presence of good-sized bodies of ore, but on few has there been any systematic attempt at development, and on none has development been carried far enough to establish the presence or absence of really large ore bodies.

The ranches along Arivaipa Creek and the principal mines of the district are all connected with Klondyke by "natural" roads that present few difficulties to wagons. Some of those leading to mines where little work has been done of late years are scarcely passable for automobiles but could be made so with little work. One road leads from Klondyke 3 miles east to the Silver Coin mine, with a branch to the La Clede mine. Another leads southwest up Fourmile Creek. Another trends northwest, with a branch leading to the Grand Reef mine about 4 miles from Klondyke and short branches to ranches in the valley. At the head of the box canyon the road splits, one branch going down the canyon and the other into the side valley where the Dowdle ranches are. About 5 miles below this fork the road down the canyon forks again, one branch continuing a short distance farther down the main canyon, the other leading to a goat ranch on Turkey Creek. The road up the side valley has branches leading to the Tenstrike mine, the Bullis property, and the several ranches, and, after climbing out of the valley, to the Royal Tinto property, and ends at Arivaipa, nearly 11 miles from Klondyke. It formerly extended somewhat less than a mile farther, to the Arizona mine. From this mine to the end of the road from San Carlos at the Princess Pat mine the distance is only a little over 2 miles. If this short gap were closed by building a road, communication between the Aravaipa and Stanley districts by vehicle would become possible and the Aravaipa district would have another outlet to the railroad.

Plan of descriptions of deposits.—The descriptions of the mines and prospects in both the Aravaipa and Stanley districts are grouped in accordance with the mode of origin and location. In several of the groups there are deposits on which more development work has been done, and these are described first. The groups are described in order from south to north in each district. General notes on the types of deposits and modes of origin have already been given. In this part of the report the known facts regarding the individual deposits are stated. Plate XI shows all the mining claims whose positions are known, including all the patented claims and most of the unpatented ones. For some of the claims no data by which they could be plotted are available, and only the approximate position of the prospects could be shown. A few groups of claims, for lack of information, could not be shown at all, but these are all groups on which little work has been done.

MINES AND PROSPECTS

ARAVAIPA LEASING CO.

Property.—The Aravaipa Leasing Co., of Boston, Mass., owns the Grand Reef mine, the principal producer of lead-silver ore in the Aravaipa district, and several smaller mines and prospects. The mill and principal workings of this company are in Laurel Canyon, on the west flank of the Santa Teresa Mountains, about 3½ miles from

Klondyke, the supply point for the vicinity. The property comprises seven patented and eighteen unpatented claims stretching north and south from the main camp. Their location is shown on Plate XI. There are also two mill-site claims in Laurel Canyon, and 160 acres of land in Arivaipa Valley. Thomas Finnegan has one-third interest in one of the unpatented claims. In Laurel Canyon there are a small ore-dressing mill, now partly dismantled, a blacksmith shop, an engine house, a boarding house, a school, and other buildings. In Silver Cable Canyon, half a mile to the south, there are also small buildings.

The deposits have been prospected by means of a number of tunnels, pits, and small shafts. The principal workings are in the Grand Reef claim, in Laurel Canyon, the Dogwater and Silver Cable claims, in Silver Cable Canyon, and the Aravaipa claim, 1½ miles north of the main camp. The Grand Reef workings consist of an adit some 1,400 feet long, with crosscuts off it and stopes above it, a winze extending 300 feet below the adit level, and levels leading off from the winze at intervals of 100 feet below the adit, making a total of over 4,000 feet. The principal workings are shown in Figure 3. On the top of the ridge on the north side of Laurel Canyon is a shallow shaft, known as No. 4 shaft, not shown in the sketches. On the Mountain Spring claim there are two short tunnels. On the Silver Cable claim is a tunnel a few hundred feet long with stopes above. On the Dogwater claim is a tunnel about 140 feet long, a little over 100 feet from the mouth is a stope that extends up to the surface, and just beyond is a short winze off which a little work has been done. (See fig. 4.) On the Aravaipa claim is a shaft somewhat less than 100 feet deep off which about 500 feet of drifting and some stoping has been done. These workings are shown in Figure 5. They connect underground with workings on the Tenstrike group, and such data as are available regarding the mineralization at the Aravaipa mine are given in the description of the Tenstrike mine.

History.[49]—The principal claims of the group were purchased by John W. Mackay from the locators in the nineties. He carried development at the Grand Reef to a depth of 300 feet, did considerable other work on the property, and planned extensive exploration, which was terminated by his death in 1902. No further work was done until 1915, when a lease was obtained by local people, who erected a small mill and shipped most of the ore and concentrates that had been produced from the property. After about four years of activity their operations ceased because of litigation, in June, 1919. At this time the property was taken over by the Aravaipa Leasing Co., first under lease and later by purchase. In 1919 and 1920 this company unwatered the Grand Reef mine, sampled it, did

[49] Most of this section is based on notes by C. E. Minor, who was superintendent in 1920 and 1921 at the Grand Reef for the Aravaipa Leasing Co.

considerable exploration work on this and on other properties in the district, and mined, concentrated, and shipped some ore. The major efforts of the company during this period were directed rather to exploration than to mining ore; consequently the total of the shipments, as shown in the table below, was not large.

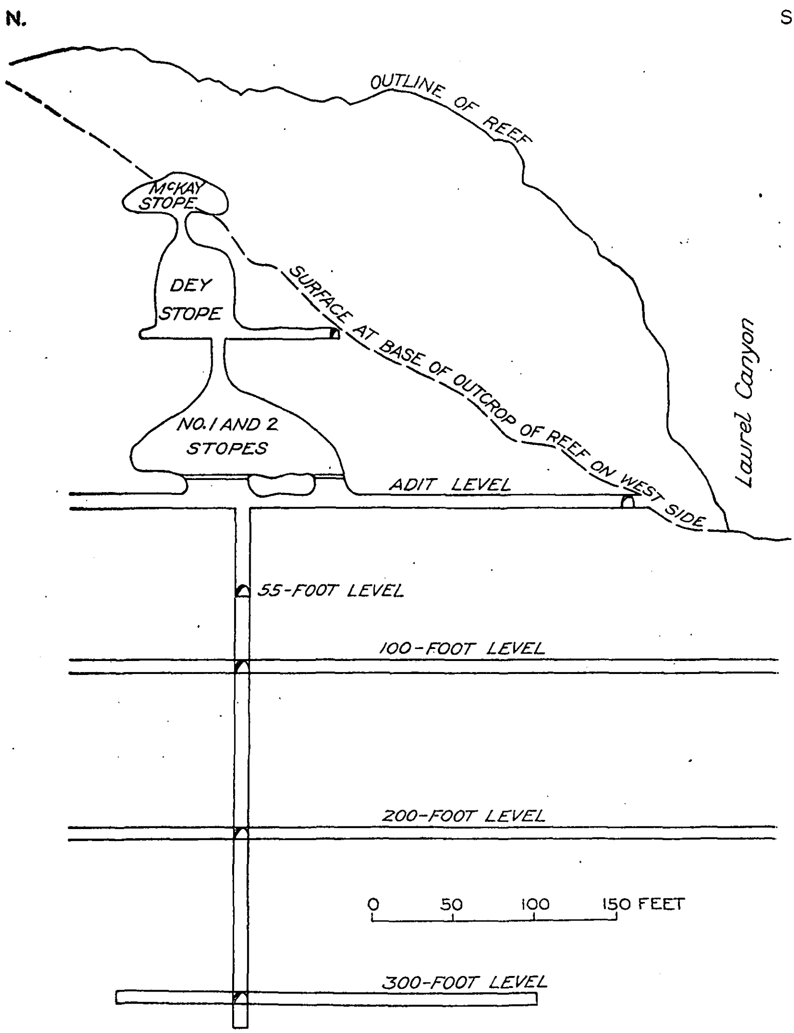


FIGURE 3.—Section through principal workings at the Grand Reef mine. From sketch furnished by Aravaipa Leasing Co.

The company suspended operations late in 1920, and the mines were closed down and left in charge of a watchman early in 1921. The shutdown was the result of general business conditions in the United States, which, in the opinion of the company's officials, made it inadvisable to continue work. It is expected that operations will be resumed when conditions become more favorable.

Production.—If any ore shipments were made prior to 1915, no records of them are now available. Below is given a table showing the amount of ore and concentrates shipped from the several mines of the group from 1915 to 1920. The table is compiled from data assembled by C. E. Minor from the records of the Aravaipa Leasing Co. It has been estimated that the total ore mined is about 30,000 tons.[50] This small tonnage by no means represents the capacity of the mine, for no systematic campaign of development and mining backed by adequate capital has yet been undertaken. It is to be hoped that as soon as favorable business conditions return the present owners will continue their development of the property and give the mine a thorough test.

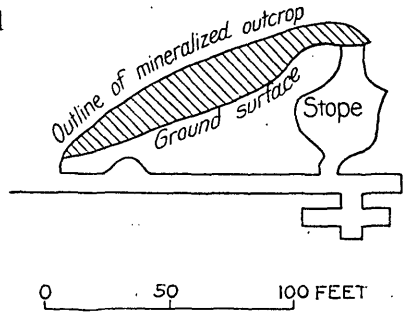


FIGURE 4.—Section through Dogwater mine. From sketch furnished by Aravaipa Leasing Co.

Ore and concentrates shipped from the Grand Reef group, 1915–1920, in dry tons

Year	Ore from Grand Reef mine	Mixed ore from Grand Reef, Aravaipa, and Dogwater mines	Concentrate: Grand Reef mine	Concentrate: Aravaipa mine	Concentrate: Dogwater mine
1915	61		110		
1916	247		392		
1917	423		841		
1918	341		885		
1919	242		385		
1920	75	117		89	160
	1,389	117	2,613	89	160

Total ore, 1,506 tons; total concentrate, 2,862 tons.

Character of the deposits.—The Grand Reef mine takes its name from the remarkable outcrop of the lode. In Laurel Canyon, where the reef is most prominently exposed, it is indeed a grand and impressive sight. It is a great mass of iron-stained rock composed of brecciated and silicified igneous rock and vein material cemented with quartz and other vein minerals. Plate X gives some idea of the way in which it towers above the softer rocks on either side of it. The exposure of the reef along the stream bed in Laurel Canyon is 200 feet wide. This is about the maximum width, but the outcrop is over 100 feet wide for a considerable distance on either side of the stream. The average strike is approximately N. 12° W., and the dip

[50] Weed, W. H., Mines Handbook, vol. 15, p. 197, 1922.

ranges from about 70° W. to vertical. To the south the reef splits up into several smaller and less conspicuous lodes. The Mountain Spring, Silver Cable, and Dogwater mines and prospects are on such extensions of the main reef. Southeast of these there is a group of four claims on similar deposits. The country rock of the Grand Reef and the deposits near it belongs for the most part to what has been here termed the intrusive rhyolite. Some of it has the composition of quartz latite and is very fine grained. The rock near the lodes, especially west of the main reef, is sufficiently altered to make accurate determination of its original characteristics difficult. Just east of the Grand Reef is the granite of the main batholith, which here clearly intrudes the rhyolite porphyry. The porphyry east of the reef seems coarser and is somewhat darker than that west of it, but this difference is thought to have resulted from differences in hydrothermal alteration. On the 300-foot level of the Grand Reef

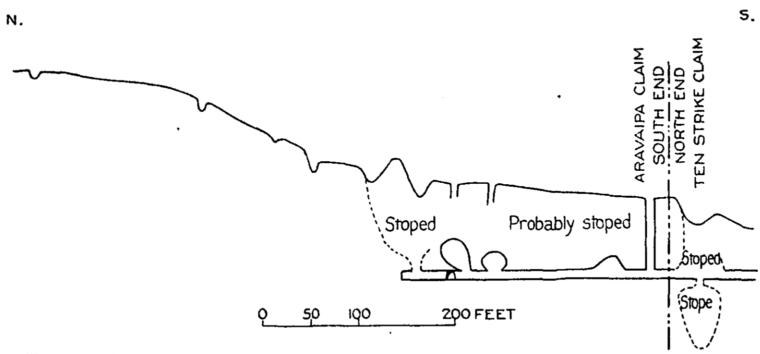


FIGURE 5.—Section through Aravaipa mine. From sketch furnished by Aravaipa Leasing Co.

mine just east of the footwall of the lode diabase is reported[51] to have been encountered. A short distance farther east the diabase is in contact with granite. The contact strikes approximately parallel to the vein and dips 70° W.

The adit level, parts of the stopes above it, the first 100 feet of the winze, and part of the 100-foot level were the only portions of the Grand Reef mine accessible at the time of visit. Water stood in the winze 30 or 40 feet below the 100-foot level, but at most seasons the water is reported to stand above that level.

The following data regarding the ore shoots are abstracted from records furnished by H. A. Wentworth, the president of the Aravaipa Leasing Co. The principal known ore shoot is the one in which the winze is sunk. Stoping has been done on this shoot from the adit level up into the portion of the reef that projects above the surface of the ground (fig. 3), and ore has been found vertically

[51] Wentworth, H. A., letter of Feb. 2, 1923.

below these stopes as far as development has gone. On the adit level the ore shoot has a stope length of more than 120 feet and a width ranging from 15 feet to considerably more than 30 feet.

Besides the principal ore shoot described above, several smaller ones have been found. West of the principal shoot and separated from it by about 10 feet of barren material is the hanging-wall or No. 3 ore shoot. It has been stoped and back-filled from the adit level down about 30 feet and up nearly to the surface; the stope length is about 60 feet and the width of the shoot about 3 feet. The outcrop above this stope shows mineralization. No. 4 shoot is developed by a shallow shaft on the top of the ridge 600 feet north of the Dey stope, and what is believed by company officials to be the same shoot has been encountered at the adit level vertically below this shaft. Ore is also reported to have been found in the adit north of this shoot. On the 200-foot level a body of soft ore was encountered south of the main ore shoot.

Most of the ore mined in the Grand Reef mine has come from the stopes in the principal ore shoot and the hanging-wall shoot above the adit level, so that the table below showing the average content of the crude ore shipped will serve to give an idea of the character of the ore of shipping grade found in the upper 200 feet of these shoots.

Assays of crude ore shipped from Grand Reef mine, 1915–1920

Year	Ore (dry tons)	Gold [a] (ounce per ton)	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	Insoluble (per cent)	Iron (per cent)	Lime [a] (per cent)	Zinc [a] (per cent)	Sulphur (per cent)
1915	61	0.01	17.3	52.9	2.06	20.3	1.2	4.7	1.7	6.5
1916	247	.01	19.2	46.1	2.12	21.3	2.8	3.5	1.9	5.8
1917	423	.01	23.9	40.4	3.21	37.4	3.0	2.2	1.8	7.4
1918	341	.01	21.9	40.3	2.85	32.0	1.9	4.5	1.2	6.6
1919	242		13.4	34.8	3.56	36.9	2.2	3.0	.9	5.5
1920	75		15.4	37.0	1.15	33.9	1.8	.9	.6	4.3
	1,389	.01	20.0	40.9	2.83	32.3	2.4	3.1	1.4	6.4

[a] Not reported in all assays.

A large part of the ore is of sufficiently low grade to require concentration before shipping. The company estimates that it has 90,000 tons of ore reserves.[52] The computations of the company's engineers [53] indicate that the ore in No. 1 shoot between the adit and 100-foot levels, estimated to be 43,000 tons, averages 7.0 ounces of silver to the ton, 1.5 per cent of copper, and 8.8 per cent of lead; this gives an idea of the tenor of the average ore in the mine.

It has already been stated that the country rock on the hanging-wall side of the lode is hydrothermally altered. In places on the

[52] Weed, W. H., Mines Handbook, vol. 15, p. 197, 1922.

[53] Wentworth, H. A., letter of Feb. 2, 1923.

hanging wall there is reported to be a distinct gouge. No gouge has been found on the footwall, and on that side on the 300-foot level both the diabase and the granite beyond it are iron stained and contain pyrite and a little chalcopyrite.

Most of the deposit is a breccia composed of angular fragments many of which are less than an inch in greatest dimension. The fragments are in part silicified and otherwise altered wall rock, in part vein minerals. A large number of the light-colored fragments abundant in parts of the deposits are fine-grained fluorite. Many of the fluorite fragments are white; others have pinkish or violet casts. Some of them show distinct banding. Their appearance more closely resembles that of chert than of the commonly observed forms of fluorite. The matrix of the breccia in most places is a dark-purplish mass composed principally of fine-grained quartz in which comparatively large clear grains of fluorite are embedded. In places tiny flakes of chlorite are scattered through the matrix. Some of the fragments are green with chlorite, and a few are entirely composed of that mineral.

Quartz is the most abundant of the gangue minerals and occurs in various forms. The fine-grained quartzose matrix of the breccia has already been mentioned. Brecciated ore from the large stope above the adit is cut by irregular bands of light-gray chert which have themselves been fractured. Here and in the small opening at the 55-foot level are narrow quartz veinlets with comb structure and drusy cavities, which were apparently the latest products of hypogene mineralization. On the 100-foot level the ore in places is sheeted and banded rather than brecciated, and there is considerable clear massive quartz which is in part white, in part pink and vitreous. Adjoining such banded ore is breccia like that elsewhere, containing little sulphide.

Galena is the most abundant sulphide. It is of variable texture. In places it occurs in irregular curved bands, but in probably most of the ore it shows marked evidence of having been brecciated. Argentite in tiny blebs is present in much of the galena. Veinlets and small irregular masses of chalcopyrite are prominent in some specimens. Sphalerite is associated with the galena but in subordinate amount. A little pyrite was noted, but it is nowhere abundant. In the floor of the main adit near the north end there is reported to have been found a hard black mineral resembling tetrahedrite. C. E. Minor states that a specimen of this ore given to him was found to assay 7 ounces of silver to the ton and 5.1 per cent of copper.

Films of the supergene copper sulphide covellite were noted on chalcopyrite in specimens from the large stope above the adit and from the 55-foot level. No chalcocite was found.

The ore in the large stope above the adit and that visible on the 55 and 100 foot levels showed no evidence of oxidation except superficially. Within 50 feet or less of the surface in the upper stopes there is unaltered galena, and chalcopyrite is reported to occur also, but much of the ore in these stopes is oxidized. Cerusite, anglesite, and probably other sulphates of lead are present. The copper carbonates, malachite and azurite, and the silicate, chrysocolla, are also found. Limonite occurs in places in the ore and stains the outcrops of the reef but is nowhere present in great quantity. On the 300-foot level there is reported to be a mass of highly oxidized ore.

The short tunnels on the Mountain Spring claim penetrate an outcrop of breccia similar to and in line with the Grand Reef but much smaller. A small amount of ore has been found here.

The tunnel on the Silver Cable claim is in shattered igneous rock, most of which is altered beyond recognition. It is thoroughly silicified, and the feldspars that remain are clouded with alteration products. No ferromagnesian minerals were noted in it. Near the tunnel mouth there are several slips. Most of the tunnel follows a fairly well defined lead that strikes about N. 30° W. and dips steeply to the east. It is composed of sheared and altered rock and ribbon-banded and drusy quartz. The stope above is reported[54] to have been opened in mining oxidized ore supposed to contain lead vanadate, for a mill test in 1915 or 1916. The so-called vanadate was probably the molybdate wulfenite, such as occurs at the Dogwater and Silver Coin mines.

The lode in the Dogwater tunnel is doubtless similar to that in the Silver Cable. The only place where ore was noted was in the face of the tunnel, that in the back having been stoped out. At the face there is a mineralized zone 2 or 3 feet wide which contains wulfenite and some galena. The ore mined is reported[55] to have contained cerusite, galena, wulfenite, and a small amount of argentite. There was considerable fluorspar in the gangue. The galena was found to contain silver, which was doubtless in the form of invisible blebs of argentite. The ore from this mine carried considerable silver and lead. High-grade ore is reported to have been found in the shallow shaft in the gulch below the Dogwater tunnel.

Little development work has been done on the claims in the southeast end of the group owned by the Aravaipa Leasing Co. On the Junction and Varick claims is a reef similar to and almost as impressive as that at the Grand Reef mine. In places on this reef ore containing galena and assaying well in lead and silver is reported to crop out. On the west side the wall rock is rhyolitic porphyry. On the east a large part of the wall is pre-Cambrian schist, although

[54] Wentworth, H. A., letter of Dec. 1, 1922.

[55] Minor, C. E., notes furnished by H. A. Wentworth.

porphyry is also present, and the granite is close at hand. The Blank and Conundrum claims were not examined during the present investigation but are reported by Mr. Minor to follow the outcrops of a lode striking approximately east.

PROSPECTS SOUTH OF THE ARAVAIPA LEASING CO.'S PROPERTY

From the Aravaipa Leasing Co.'s property south to the Tertiary beds near the Safford road a considerable number of claims have been staked, but on many of them no work has ever been done.[56] Some shallow workings were noted during the present investigation, but no prospects of any consequence were found here except the La Clede and Silver Coin mines, described below. Most of such deposits as exist in this part of the district are probably of the same general type as those just described. In the vicinity of Oak Canyon there is in places considerable micaceous specularite along partings in the schist. This indicates a concentration of iron by hydrothermal processes but may have no relation to the formation of ore deposits.

LA CLEDE MINE

The La Clede mine, owned by James Quinn, of Klondyke, is in a narrow gulch southwest of the Santa Teresa Mountains and about 2½ miles east of Klondyke, with which it is connected by a road. The property comprises about five unpatented claims. There is a shallow shaft in the side of the gulch and a tunnel entering near stream level. Mr. Quinn states that he has shipped about three carloads of ore in 12 years of operation.

The country rock is a bluish-purple fine-grained porphyry, which has been fractured, silicified, and altered even at some distance from the vein. The rock is highly silicified but contains microcline and sodic plagioclase, which are probably hypogene. Some of the quartz may also be hypogene. The rock may have been a latite, but whether it is related to the intrusive rhyolite or to the later volcanic rocks is conjectural. Sparingly disseminated through it are tiny black grains, which are in part specularite. Small areas of later albite have formed by replacement of the rock.

The vein strikes nearly east and stands almost vertical. Assessment work was in progress when the mine was visited, but most of the workings were inaccessible. Near the surface there appears to be considerable oxidation in the vein and its wall rocks, with the development of limonite, some malachite, and other oxidation products. The owner reports that native silver has been found here and that some of the ore assays very high in silver.

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[56] Koch, A. W., letter of Jan. 24, 1923.

SILVER COIN MINE

The Silver Coin mine is in the gulch immediately south of the one in which the La Clede mine is situated, about 3 miles east of Klondyke, with which it is connected by a road. The property comprises five unpatented claims owned by Ted Quinn, who resides on it with his family. The position of the group is only approximately shown on Plate XI, but the relations of the claims to one another are essentially as there shown.

The developments consist of a tunnel 180 feet long with short crosscuts off it, a winze about 50 feet deep at the end of the tunnel, and a shaft more than 200 feet deep which passes at one side of the winze and is connected with it. Part of this work was done by the Aravaipa Leasing Co. when it had the property under lease. The workings are shown in Figure 6 as they were in July, 1919, when the Aravaipa Leasing Co. ceased work. The winze and probably also the shaft have been deepened since then. Small lots of ore have been shipped at different times.

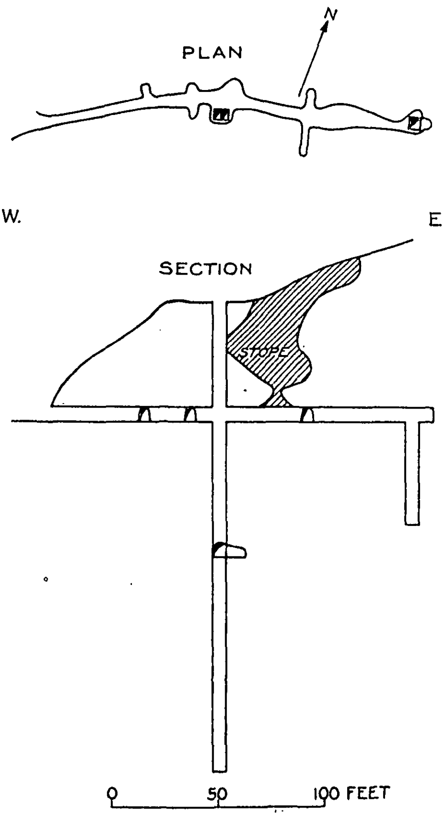

FIGURE 6.—Workings of Silver Coin Mine. From sketch furnished by Aravaipa Leasing Co.

The country rock is a highly altered and weathered light-colored igneous rock, which may have been a fine-grained granite. It contained some original quartz and alkali feldspar, a few flakes of bleached biotite and chlorite, and much secondary quartz both in veinlets and as fine-grained aggregates replacing original minerals. The lode is made up of brecciated rock of this character and quartz. The average strike is nearly east, and the dip is steep to the north. Wulfenite and other oxidized minerals are present in the lode and also in the altered igneous rock at some distance from the lode, but the most valuable ore is that containing unoxidized galena. The distribution of the galena is irregular, but in places it is reported to have been found in sufficient abundance to make ore with a good content of silver and lead.

TENSTRIKE GROUP

The four unpatented claims comprising the Tenstrike group, owned by James Quinn, of Klondyke, stretch between the north end of the main group of claims owned by the Aravaipa Leasing Co. and the Aravaipa claim of the same company. (See Pl. XI.) The property was formerly connected with Klondyke by a wagon road forking off the main road a short distance above the upstream end of the Arivaipa box canyon. This road has been out of use so long that repairs are needed to make it available for vehicles. There is a cabin on the Tenstrike claim, and considerable underground development work has been done on this and the other claims of the group. A tunnel on the Tenstrike extends north into the Aravaipa claim. Ore has been stoped from this and other workings on the property, and probably a few carloads have been shipped.

These claims are evidently on a northward extension of the Grand Reef vein, and the deposits in them, like those of the Grand Reef mine, are in brecciated and mineralized rhyolite. The rock is silicified and shot through with numerous narrow quartz stringers, most of them distinctly banded. There are small druses with well-developed quartz crystals. Narrow seams of calcite were noted, but these may be of supergene origin. The hypogene metallic minerals are galena, pyrite, sphalerite, and chalcopyrite, of which the galena is much the most abundant. The galena occurs in coarsely crystalline masses; the other sulphides in small individual grains irregularly disseminated in the quartz. Supergene chalcocite is a prominent constituent of some specimens. Galena has oxidized to anglesite and cerusite. There is a small amount of linarite, a basic sulphate of lead and copper, but, except for occasional slight stains, other oxidized copper minerals were not noted.

FINNEGAN GROUP

Thomas Finnegan, of Klondyke, owns four unpatented claims just south of the Bullis property and a third of the Blevin claim, at the north end of the Grand Reef group. These are on the northern part of the Grand Reef vein and have outcrops of iron-stained, silicified, brecciated rhyolite like that at the Grand Reef mine, but smaller. The deposits have been prospected by means of tunnels.

BULLIS GROUP

Property.—The Bullis group consists of 9 patented and 19 unpatented claims on Imperial Hill, shown on Plate XI. The northern part of the group is little more than a mile southeast of Arivaipa, but the intervention of the steep-walled Tule Canyon makes it inaccessible from that side. The property is reached from the southwest by a road from the valley containing the Dowdle ranches. The two shacks on the south side of Imperial Hill, the only buildings on the property, are nearly 9 miles from Klondyke by this road.

A considerable amount of miscellaneous development work has been done in various places on this property, principally in the course of annual assessment work. There has been more systematic work done in the Windsor workings, shown in Figure 7, than elsewhere. These workings, which aggregate over 1,100 feet, consist of an inclined shaft and drifts and crosscuts at the 60 and 200 foot levels connecting with the surface by an adit at the lower level. The shaft reaches a depth of 190 feet vertically below the collar. Besides the Windsor workings there is a shaft farther down the hill to the east and tunnels, cuts, pits, and small shafts scattered over the property.

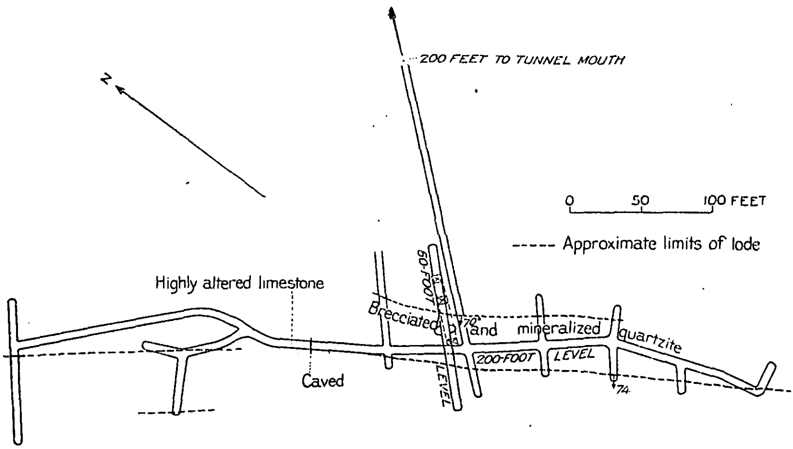

FIGURE 7.—Composite level map of Windsor mine. From sketch furnished by Aravaipa Leasing Co.

History.—The deposits on Imperial Hill are reported to have been found in the early seventies, but little work appears to have been done on them until 20 years later, when Gen. J. L. Bullis began to acquire the group of claims now owned by his estate. Under his direction all parts of the property were prospected, but little development work was done, and little or no ore was shipped. At the time of his death, about 10 years ago, he is reported to have been planning more intensive development. For some years after his death little was done. The Aravaipa Leasing Co. had a lease on the property in 1918 and 1919 and did some development work on the Windsor and on several other claims. Since this company's operations ceased nothing beyond annual assessment work has been done, except that in 1922 the Windsor workings were sampled by E. H. Bachman, of Globe, Ariz. He and his associates hope to develop this part of the property under lease and to erect a cyanide mill of some 20 to 30 tons daily capacity to treat the ore mined.

Character of the deposits.—The greater part of Imperial Hill is composed of intrusive rhyolite. The contact between it and the granite to the east is gradational, and numerous dikes and irregular masses of granite cut the rhyolite. On the northeast flank of the hill are blocks of Paleozoic limestone and quartzite inclosed in the rhyolite. The presence of these rocks is indicated diagrammatically on Plate I, but the strata are actually more broken and scattered about in smaller blocks than it was possible to show on the map. Less limestone than quartzite is exposed.

Several lodes crop out on the property. According to Thomas Finnegan, who has charge of the annual assessment work, there are four principal lodes. The exposures of mineralized rock have not been mapped, but in a broad way it may be said that there is a group of veins and zones of mineralization outcropping over a broad area on the east side of Imperial Hill. The strikes measured at different exposures range from N. 40° W. to almost N. 40° E., but the average is somewhat west of north. The lodes cut representatives of all the rocks mentioned in the last paragraph. The quartzite, rhyolite, and granite are cut by quartz stringers, brecciated, and somewhat altered and replaced. The limestone has locally been permeated with mineralizing solutions, and small portions of it have been thoroughly altered. The igneous rocks in the vicinity of the deposits are somewhat chloritized and fractured, but the feldspars in them seem as fresh as in similar rocks that have not been exposed to mineralization. In some exposures the brecciated quartzite or rhyolite is permeated irregularly with quartz. Elsewhere there are distinct veins of quartz, which in places are sheeted. The quartz in most exposures has drusy cavities lined with well-developed quartz crystals. The deposits contain lead, copper, and silver both as sulphides and in oxidized minerals. The exposures seen during the present investigation showed only small amounts of metallic minerals. Samples taken by E. H. Bachman, of Globe, at 5-foot intervals down the Windsor shaft contained, according to Mr. Bachman, both lead and silver. One of these samples assayed slightly over 100 ounces in silver, but the average of the assays is less than 15 ounces. The lead content of the samples ranged from a few tenths of 1 per cent to more than 9 per cent. The distribution of both lead and silver is irregular and appears to bear no relation to depth. Assays from the 60 and 200 foot levels also show some lead and silver, but the average amount is small. A composite sample from the shaft contained 0.14 per cent of copper. Copper is present in spots on the 200-foot level, one assay of 1.5 per cent and several of less amounts being reported, but the average amount is small, and in places, notably in the crosscut where the ore carrying the most silver found on the level is exposed, no copper is present. The drift on the lower level south of the adit is in brecciated quartzite that shows a little mineralization. Mr. Bachman's assays show from 0.94 to 2.42 ounces of silver to the ton in this part of the mine. A short distance north of the adit there is broken ground and the drift has caved in. According to the map prepared by the Aravaipa Leasing Co.'s engineers there is a fault here which shifts the lode westward about 40 feet, as indicated in Figure 7. A green fine-grained rock collected at the point where the drift is caved proved on examination to be quartzite containing a little feldspar and partly replaced by calcite and chlorite. The map just referred to shows limestone in this drift beyond the caved portion, and the calcite in the altered quartzite may be derived from this rock. The same map indicates that rhyolite forms the hanging wall south of the adit and that there is porphyry in the north end of the mine beyond the limestone.

The quartzite at the mouth of the Windsor shaft contains small amounts of horn silver, malachite, copper pitch, covellite, and chalcocite. The two sulphides occur together in small black blebs. They carry silver, perhaps in solid solution as sulphide.

The shaft east of and down the hill from the Windsor is in coarse porphyritic granite, which has been somewhat crushed. The biotite in it is chloritized, and quartz has been introduced since the formation of the rock. Ore containing 4 or 5 per cent of copper is reported to have been found in the shaft, and a number of pieces containing malachite and azurite were noted on the dump. If any considerable quantity of ore was taken out, it has since been removed.

BULLIS-LANDSMAN GROUP

There are nine unpatented claims which adjoin the Bullis property on the northwest and the Norton group on the south. (See Pl. XI.) These may be called the Bullis-Landsman group, as Mrs. J. L. Bullis and Frank Landsman hold them in common. They are developed by several branching tunnels. Part of the work was done by the Aravaipa Leasing Co. when it leased the claims in 1919.

The country rock is largely intrusive rhyolite, but there is also a little limestone which is cut by dikes of the rhyolitic rock and of a dark trap. Streaks of copper sulphide are reported to have been found in dike rock of both these types. On these claims there are several lodes, which in general strike west of north and have a nearly vertical dip. In the rhyolite there are iron-stained outcrops which resemble the Grand Reef in miniature. Underground stringers of sulphides and specularite are found on small slips in the brecciated rock. Galena, pyrite, and chalcopyrite are found, but if sphalerite is present it is in small amount. The galena here, as elsewhere, doubtless contains argentite. In the limestone, which is brecciated and partly silicified, the ore is in irregular stringers and small masses. The gangue minerals are quartz, actinolite, specularite, calcite, and chlorite. The only sulphides noted are galena and sphalerite. The quartz, which is the most abundant gangue mineral, varies in texture from cherty rims around sulphide grains to rather coarsely crystalline masses, with drusy cavities. The actinolite masses are made up of small bunches of radiating needles. Specularite, which is not abundant, is in scattered flakes and fine-grained aggregates. There is only a little calcite. The sulphides are in part in fine-grained aggregates, in part in scattered grains, some of which are an inch wide. They show almost no oxidation.

ROYAL TINTO MINING & SMELTING CO.

Property.—The property of the Royal Tinto Mining & Smelting Co., of New York, consists of 22 patented and 10 unpatented claims on Tule and Copper Bar gulches 2 miles east of Arivaipa. (See Pl. XI.) Except for a shaft house on the Copper Bar claim, there are no buildings on the property.

The principal underground workings are the Sam Jones and Copper Bar tunnels, named from the claims in which they start. They are shown in Figure 8. There is also a shaft near the mouth of the Copper Bar tunnel, reported to be 100 feet deep; other shafts on the Tinto claim, one of which is reported to have been 100 feet deep; and several excavations, mostly small and shallow, on the other claims. At the time of visit it was possible to get underground only in the two tunnels.

History.[57]—The ore deposits of this group have been known for at least 20 years. In 1902 Frank Landsman had a lease on the New York claim and shipped 15 tons of carefully picked chalcocite ore reported to have assayed 29.7 per cent of copper and several dollars' worth of gold and silver to the ton. This seems to be the only ore that has been shipped from the property. In 1905 the Royal Tinto Mining & Smelting Co., the present owner, was organized under the laws of New Jersey. Most of the work was done in 1906 and 1907, and, except for annual assessment work, little has been done since then.

Character of the deposits.—The deposits lie in a complex of fault blocks of pre-Cambrian schist and Paleozoic sedimentary strata, bordered on the south and east by the granite batholith and cut by rhyolitic apophyses of the granite. There are numerous faults, most of them small. Many strike northwest, but some trend in other directions. An idea of the extent to which the rocks have been shat-

[57] From H. W. Darling's report on the property of the Royal Tinto Mining & Smelting Co., supplemented by information furnished by Charles Firth, of Arivaipa.

tered and broken into small blocks can be gained from Figure 8. This sketch, showing the geologic features exposed in the two tunnels, is copied from a report on the property made for the company by C. F. Tolman, from which some of the facts given below are taken. The

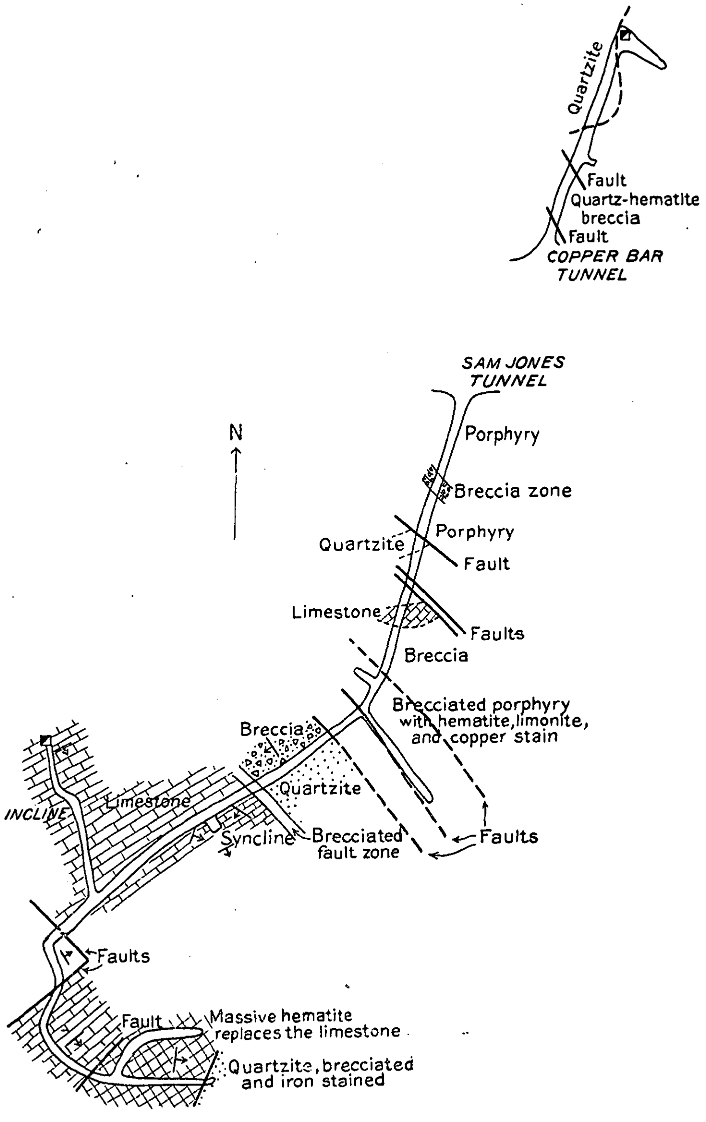

FIGURE 8.—Geologic sketch map of Sam Jones and Copper Bar tunnels. After C. F. Tolman. Scale, 1 inch=200 feet

deposits are on fracture zones that cut altered rhyolitic facies of the granite along the contact and extend northward beyond the igneous rock into the quartzite and limestone. The zones fork and pinch out in irregular fashion, but the resultant trend of the group of zones is to the northeast. The mineralized outcrops are in most places inconspicuous features on the brush-covered hillsides, but in some places, notably at the mouth of the Copper Bar tunnel, there are prominent exposures of iron-stained siliceous breccia. Mineralization can be traced on the surface for an air-line distance of over a mile on the property, and according to Tolman the outcrops of the zones range in width from about 8 feet on the New York claim to 300 feet on the Copper Spar claim.

The rock along the zones has been sheared, brecciated, and replaced by chlorite, hematite, quartz, pyrite, chalcopyrite, and products of oxidation and supergene deposition. In some places the original rocks have been completely replaced; elsewhere there has been sufficient alteration to make it difficult to recognize the rock. The wall rocks were altered to some distance beyond the fracture zones in places, but this alteration is irregular, and so far as can be judged from the exposures in the two tunnels the amount of metallic minerals deposited is small, with the exception of some small irregular bodies in limestone. No primary copper minerals were observed during the present investigation, but chalcopyrite is reported to have been found in the bottom of the shaft at the mouth of the Copper Bar tunnel, and Tolman noted small quantities of the mineral in some of the surface cuts. Copper oxidation products and supergene sulphides exist in a number of places, proving the original presence of hypogene copper minerals in the deposits. The amount of copper originally formed in parts of the deposits was negligible, but it may well be that in places ore shoots containing considerable copper were produced. Chlorite is one of the most abundant minerals in the deposits exposed in the Copper Bar tunnel. Intimately mixed with it are seams and aggregates of quartz, hematite in fine disseminated flakes and aggregates, and pyrite in streaks and irregular groups of small cubes disseminated in the masses of chlorite and hematite. Elsewhere chlorite is not so abundantly exposed. In places reticulating veinlets of hematite are the only evidence of hypogene mineralization.

The outcrops of the mineralized rocks all show weathering, but the oxidation is neither intense nor deep. Limonite occurs only in superficial stains and small masses. Malachite, azurite, cuprite, and copper pitch are found on the Tinto and New York claims and have also been reported on the Newark, but the amount at all exposures is small. In the Copper Bar tunnel the pyrite has been tarnished and loosened by leaching and there is an efflorescence of hydrous iron sulphate on the walls. The end of this tunnel is about 100 feet below the surface, which is the greatest depth at which the deposits are now exposed. From this it appears that incipient oxidation reached depths as great as 100 feet, but that its effects were slight. The supergene sulphides, chalcocite and covellite, are present in varying amount in many of the exposures of mineralized rock, although in some the amount is so small that it can not be seen. A little massive chalcocite can still be found on the Tinto dump. It evidently formed veinlets and irregular masses in the altered and brecciated rock. Chalcocite ore is also reported to have been found in the shaft at the mouth of the Copper Bar tunnel. For the first 25 feet this shaft is reported to be in mineralized rock like that exposed in the tunnel except that considerable chalcocite was noted. Below this the rock penetrated is reported to be barren except at the bottom, at a depth of about 100 feet, where chalcopyrite was found. The small amount of copper found by chemical tests in specimens from the Copper Bar tunnel is probably present as films of chalcocite and perhaps also covellite on the pyrite. Specks of covellite were noted by Tolman on the New York claim, and it is probably also present elsewhere. H. W. Darling, in the course of an examination of the property for its owners in 1918, took several grab samples for assay, and the results show that copper is present in a number of places. Part of the copper is in the form of carbonates and oxides, and a little may be in hypogene chalcopyrite, but much of it is probably in supergene sulphides. In some of the places where he sampled such sulphides are visible. In others there is no visible copper mineral, and the copper is probably in films of supergene sulphides, a form in which it is less conspicuous than in either hypogene sulphides or oxidation products.

C. A. FIRTH GROUP

Charles A. Firth has four unpatented claims adjoining the property of the Royal Tinto Mining & Smelting Co. As is shown on Plate XI, two of these claims are south of that property, and the other two are northwest of it. Only a little development work has been done on these claims. Presumably the deposits here are similar to those on the Royal Tinto ground.

ARAVAIPA MINING CO.

Property.—The property of the Aravaipa Mining Co., of New York, consists of 19 patented and 5 unpatented claims. These claims, on which mining for lead-silver and copper ores has been carried on intermittently for many years, extend from Arivaipa north to Deer Creek. They are shown on Plate XI. There is an engine house at the Arizona shaft and about eight buildings at Arivaipa, including the residence of H. T. Firth, superintendent, the post office, the houses used by the workmen when the mines were running, and outbuildings.

The principal workings of this company are on the Arizona, No. 1, and Orejana claims. No maps of these workings are available, and considerable parts of them are now inaccessible, so that only approximate data can be given.

At the Arizona mine there is a shaft about 580 feet deep. The lower part of this shaft is now full of water, and the whole was inaccessible at the time of visit. The deposit is also developed by means of a tunnel entering farther down the hillside, which encountered the vein about 200 feet from its mouth. The tunnel was continued about 500 feet farther without cutting any more veins. From the point where the vein was cut drifts were run on it about 400 feet in a southerly and 700 feet in a northerly direction. The north end of the north drift is close to the shaft, at a depth estimated by Mr. Firth as 125 feet below the collar.

On the Orejana claim a tunnel about 700 feet long follows another vein. On the No. 1 there is a shaft a few hundred feet deep and a short tunnel connected with it. There has been some stoping and a little drifting off this shaft, which was inaccessible at the time of visit. Other workings on the company's claims include a tunnel several hundred feet long on the Gordon, irregular tunnels on the Grand Central and Head Center, and tunnels and pits on the Iron Cap and elsewhere.

History.—The principal deposits have been known for nearly 50 years. Among the early locators were W. C. Bridwell, Charles Cunningham, the Dunlap brothers, John Harr, and Charles McGeary. Col. W. C. Bridwell had a smelter near Arivaipa in the late seventies in which he treated ore from these deposits. In 1889 the deposits were acquired by a group of men who formed the present Aravaipa Mining Co. At one time this organization was known as the Aravaipa Leasing Co., a name that has since been adopted by the company which owns the Grand Reef group. The Aravaipa Mining Co. operated from 1890 to 1895 and is reported to have shipped two cars of ore obtained from different places on the property for the purpose of a mill test. In 1916 John Gleason and T. C. Parker leased the No. 1 claim and are reported to have shipped lead carbonate ore of a gross value of about $90,000. No other work except the annual assessment work on the unpatented claims has been done on the property.

Character of the deposits.—The rocks that crop out on the Aravaipa Mining Co.'s property comprise fault blocks of Paleozoic quartzite and limestone cut by a number of dikes and irregular intrusive masses of felsite, andesite, and basalt. Several veins crop out on the property but are probably all parts of the same vein system. One group of mineralized outcrops extends northward from Arivaipa through the Arizona claim to Gordon Canyon and beyond, on Abe Reed's claims, as far as Old Deer Creek. Another line of outcrops lies to the west on the Standish, Orejana, and Winthrop claims. These two groups are principally in quartzite and felsite with limestone in the vicinity of Arivaipa. To the east, on the Grand Central and neighboring claims, there are deposits in limestone. The line of claims from Imperial Hill through Arivaipa to Old Deer Creek is over 3 miles long. The principal workings of the Aravaipa Mining Co. are in this group, and most of the claims are held by the company. Mineralized outcrops are found at short intervals on these claims, but the exposures are by no means continuous. It is probable that there is a zone of mineralization made up of a series of genetically related lodes, which may be connected with one another at depth. The deposits on the Orejana group are similar and related to the deposits of this zone but lie somewhat to the west. The deposits in quartzite are veins with definite walls and approximately constant strikes which range from north to about N. 20° W., but those in limestone are more irregular, and the strikes of the mineralized fractures vary widely.

The vein exposed in the drift off the tunnel at the Arizona mine is in an altered fine-grained porphyry. It strikes about N. 20° W. and dips steeply west. The maximum exposed width is over 10 feet. The vein filling is banded quartz with quartz crystals on partings and in vugs. Galena is present in the quartz at the north end of the drift. Cerusite is irregularly distributed along the vein in streaks and bunches. The quartz is impregnated with manganese oxide in places. Mr. Firth states that the ore in the drift has an average content of 12 to 15 ounces of silver to the ton, 10 to 15 per cent of lead, and a little gold. The shaft is said to have passed through broken ground containing fragments of limestone between depths of 450 and 500 feet. On the dump is sulphide ore reported to have come from a depth of 560 feet. This ore contains galena, argentite, sphalerite, pyrite, chalcopyrite, quartz, and calcite. Other specimens on the dump consist largely of calcite and quartz stained dark red with hematite. In this fine-grained mass are small aggregates of pyrite and grains of sphalerite speckled with chalcopyrite. The rock is reticulated with tiny branching veinlets and irregular masses of earthy hematite. It is probable that these specimens represent silicified and mineralized limestone and therefore that the vein intersects a fault block of limestone at a depth of about 560 feet. Mr. Firth is authority for the statement that no ore was encountered in the shaft until this depth was attained and that all the mineralized rock on the shaft dump came from this depth. This is the greatest depth so far reached by mine workings in the Aravaipa district, and the presence of products of oxidation in rock found near the bottom of the shaft is interesting as indicating the depth to which oxidation has extended. Water was encountered in this shaft at a depth of 500 feet in sufficient quantity to be a handicap in sinking the shaft deeper. Work finally ceased in May, 1895, when the shaft was down about 580 feet.

The ore found on the No. 1 claim is cerusite, which was found in irregular masses in the limestone. Most of it so far discovered is reported to have been stoped out, but other bodies may well be found if development work is carried farther. No sulphides appear to have been encountered. Near by the limestone is silicified and replaced by actinolite in places.

The tunnel on the Orejana claim is in quartzite with a dike of altered trap showing near the mouth. The tunnel follows a vein striking approximately N. 15° W. and ranging in width from a few inches to 2 feet. The vein filling is ribbon-banded quartz, in places with coarse galena. The galena is altering to anglesite and cerusite. Both the chloride and the bromide of silver are reported to have been found. The highest silver assays are obtained from narrow streaks of soft material on the vein walls. Small amounts of ore containing as much as 300 ounces of silver to the ton are reported to have been shipped.

The other workings on the claims of the Aravaipa Mining Co. do not appear to have developed ore bodies of commercial importance. On the Grand Central and Head Center sulphides occur along irregular slips in limestone exposed in short tunnels and pits. The Iron Cap and adjoining claims were not visited, but the development work on them is reported to be small. The limestone is somewhat mineralized, but valuable ore bodies have not been discovered. A long tunnel on the Gordon claim disclosed nothing of value.

MOLTKE GROUP

The Moltke group consists of four unpatented claims owned by Mrs. H. T. Firth and Frank Landsman. It is on the road between Arivaipa and Tule Spring, about a mile from Arivaipa. There are some short tunnels on the property on slips in the altered rock. Most of the rock in this vicinity appears to be related to the intrusive rhyolite, but pre-Cambrian schistose rocks are also present.

NORTON GROUP

The Norton group consists of four unpatented claims owned by Mrs. H. T. Firth and C. A. Firth. They border the south end of the Aravaipa Mining Co.'s property on the east, near Arivaipa, and contain principally Paleozoic sedimentary strata that show brecciation and some mineralization. The development work on these claims is small.

There is an unpatented claim north of this group which appears to belong to H. T. Firth.

H. T. AND C. A. FIRTH GROUP

A group of six unpatented claims belonging to H. T. and C. A. Firth lies north of Arivaipa, bordering the principal group of claims belonging to the Aravaipa Mining Co. on the west. Little work has been done on these claims.

TOLMAN-BABCOCK GROUP

The six unpatented claims that constitute the Tolman-Babcock group lie east of the Arizona mine and about a mile north of Arivaipa. They are owned by Mrs. H. T. Firth, of Arivaipa. Two or three cars of cerusite ore have been shipped from this property. There is a short tunnel and a 75-foot winze on the Babcock claim, a shallow shaft on the La Sorilla claim from which 55 tons of cerusite ore has been stoped, and other workings elsewhere.

The workings on the Babcock and La Sorilla claims of this group were the only ones examined. At the Babcock there is a zone about 3½ to 5 feet wide without definite walls composed of brecciated and altered fine-grained porphyry. It strikes northwest and dips about 60° W. The ore is reported to assay about 10 per cent of lead and 5 ounces of silver to the ton. The rock of the brecciated zone contains somewhat crushed and altered phenocrysts of alkali feldspar, quartz, and chloritized biotite in a groundmass so fine that it can not be satisfactorily resolved even under the microscope. It is cut by stringers of vein quartz. The rock is too much altered and too fine grained for exact determination. In the hand specimen it is of a dirty heliotrope color dotted with white specks of feldspar and green chlorite patches. In the field it was thought to be an altered variety of the intrusive rhyolite, but the composition appears to be too calcic. It might be related to either the Miocene(?) or the Cretaceous volcanism.

At the La Sorilla claim there is glassy vein quartz in a brecciated and altered porphyry, which in the hand specimen resembles intrusive rhyolite. A basalt dike cuts the brecciated porphyry and the vein matter. There was renewed brecciation and deposition after the basalt intrusion. The zones along which both the original and the postbasalt fracturing and mineralization took place strike in about the same direction, somewhat west of north. The lode now consists of fragments of porphyry, quartz vein matter, and basalt. The basalt has been markedly altered, the original augite and olivine being almost completely converted to chlorite, epidote, and iron-oxide dust. The groundmass is composed of feldspar microliths with flow structure. About 55 tons of cerusite ore has been mined from a pocket in this lode.

BRYCE-MERRILL PROSPECT

E. W. Bryce and W. P. Merrill have some unpatented claims in Williamson Canyon east of the Arizona mine and about a mile north of Arivaipa. A shaft about 50 feet deep has been sunk on one of the veins belonging to the zone of mineralization that extends through this part of the district.

SINN FEIN PROSPECT

The Sinn Fein prospect is owned by James Quinn and Thomas Finnegan, of Klondyke. It is on the north side of Williamson Canyon, west of the Head Center claim of the Aravaipa Mining Co. and somewhat over a mile northeast of Arivaipa. It is developed by an irregular tunnel that begins a short distance above the level of the stream bed. This prospect was formerly owned by H. T. Firth, of Arivaipa, who shipped one carload of ore. The present owners have shipped two carloads. About half a mile east of this prospect, on the west slope of Satisfaction Mountain, are some pits and shallow cuts. These are reported to be on claims belonging to the owners of the Sinn Fein.

The Sinn Fein tunnel is in Tornado limestone and follows a mineralized shear zone that strikes north and dips 60°–70° E. The ore contains galena and sphalerite in good-sized crystals and some cerusite.

The pits on Satisfaction Mountain are also in Tornado limestone. They are sunk on irregular masses of rather coarsely crystalline calcite and quartz impregnated with iron and manganese oxides. A little copper stain was noted, and specularite is present in small flakes.

RAWHIDE GROUP

Between the north end of the Aravaipa Mining Co.'s property and Old Deer Creek are four unpatented claims known as the Rawhide group and owned by Abe Reed, of Stanley. On this group there is reported to be a tunnel about 300 feet long and another about 50 feet long which expose a vein carrying lead and silver in Paleozoic strata.

WARM SPRING PROSPECT

Warm Spring is in the bed of Old Deer Creek on the trail between Arivaipa and Stanley 2 miles north of Arivaipa. There are corrals and a cabin here and a fenced pasture near by. The Old Rawhide Development Co. owns one or more unpatented mining claims at this locality. There is a short tunnel on the north side of the stream just below the spring.

A small block of Tornado limestone is inclosed in the rhyolitic rock. The tunnel follows slips in the limestone. It has caved and been partly reopened. Little evidence of mineralization could be seen in the part now accessible.

LANDSMAN GROUP

Property.—The compact group of 37 unpatented claims which lie on the slopes southwest of Cobre Grande Mountain has for a number of years been controlled by Frank Landsman and may be termed the Landsman group. He has from time to time shared his interest in them with different partners. The location of the claims is shown on Plate XI. The only buildings on the property are the tent house and cabin at Lawrence Spring where Mr. Landsman lives.

There are a considerable number of shallow holes on the claims, also several short tunnels, most of which were caved and inaccessible at the time of visit. No developments beyond the required annual assessment work have been attempted, and the excavations serve principally to give fresh exposures of the rocks that crop out at the surface. No ore has been shipped.

Character of the deposits.—Most of the mineralization on the Landsman group is in the Tornado limestone, which is cut by a number of rhyolite dikes that are in places themselves mineralized. These dikes are similar to the rhyolite associated with the main granite batholith and are probably related to it. There is also some mineralization in the schist. The mineralization in the limestone in part conforms to the bedding, in part forms irregular masses of indefinite extent, and in part follows lines of fracturing transverse to the bedding, most of which strike west of north and dip west. In several places rhyolitic dikes cut the replacement bodies and have been shattered and partly replaced, but not so completely as the limestone. The metamorphic rocks also are less thoroughly replaced than the limestone. Replacement in limestone is conspicuous over hundreds of square feet of the lower slopes of Lime Hill. In places the ore minerals have been almost completely substituted for those of the original rock over a considerable area of outcrop. In many of the irregular replacement deposits specularite predominates, but in those that accord with the bedding silicate minerals are more abundant.

The minerals formed by hypogene deposition are specularite, magnetite, pyrite, chalcopyrite, quartz, fluorite, actinolite, epidote, and garnet. Oxidation has produced copper pitch, cuprite, malachite, and manganese and iron oxides. The supergene sulphides, chalcocite and covellite, are also present, principally in association with the oxidized copper minerals. In many outcrops specularite is one of the most abundant minerals. It occurs in the limestone in aggregates of shining plates, intermingled in places with silicate minerals, and in the other rocks in fine-grained intersecting stringers. There are cavities in rhyolite in which thin bands of specularite cover the walls and into which crystals of quartz and fluorite project from the specularite. A small quantity of magnetite is almost invariably found associated with the specularite. Sulphides are not abundant in any of the exposures. They are most conspicuous where there are veinlets or irregular masses of quartz. Actinolite is abundant in places, parts of some limestone beds being almost completely replaced by this mineral, but it is less widespread than specularite. Garnet and epidote were noted in a number of places, but they are not abundant in most exposures. The oxidized minerals are irregularly and rather widely distributed but are nowhere abundant. Assays as high as 1 per cent of copper and a little gold are reported to have been obtained from specimens of specularite containing no visible copper minerals. Microscopic examination of such a specimen revealed small quantities of chalcocite. This mineral associated with copper pitch ore and a little covellite is also found around residual cores of chalcopyrite, but in most specimens the quantity of chalcocite is so small that it can not be distinguished with the unaided eye.

COBRE GRANDE MINE

The Cobre Grande mine lies on the northeast slope of the mountain of the same name. It is 4 miles northeast of Arivaipa and 6 miles southeast of Stanley, measured in straight lines, and is accessible only by steep trails. The camp of the miners consisted of several tent houses and cabins about half a mile south of the main workings, at a place where there was formerly a good spring. The camp has been uninhabited for several years. The Cowboy tunnel, in which most of the ore has been found, winds around in an irregular curve a few hundred feet long; short drifts lead off it, and near the end stopes have been opened above and a winze about 40 feet deep below. Another tunnel near by cut ore also. A short distance down the slope is a caved tunnel reported to have been over 600 feet long but to have encountered no ore. A few hundred yards to the west, on the other side of the mountain spur, is a shaft reported to have been 160 feet deep in which some ore was found. On the trail to the old camp is a partly caved tunnel reported to have been over 700 feet long. There are doubtless other excavations, but those enumerated are the principal ones.

The deposits appear to have been first located in 1905 by Julius Riser and W. A. Clark.[58] In recent years the owners have been Messrs. Snell, Elliot, Fisk, and Alderman, of Globe, Ariz. Location

[58] Historical data have been furnished by Frank Landsman, of Arivaipa, who acted as guide to this and other properties.

notices of J. C. Sayers dated January 3, 1922, were posted on the property when it was visited. A carload of ore running about 8 per cent of copper is reported to have been shipped to the Old Dominion smelter at Globe some years ago. Most of this ore came from the Cowboy tunnel.

The Cowboy tunnel and the workings near it are all in the Tornado limestone. The accessible part of the tunnel on the trail to the camp is in an altered fine-grained igneous rock, but the face is reported to have been in limestone. In the Cowboy tunnel, which is the only one where ore in place was accessible at the time of visit, the ore is in irregular bodies in the limestone. In general the replacement followed the bedding. The gangue minerals include quartz, calcite, chlorite, epidote, garnet, specularite, and magnetite. The hypogene sulphides are pyrite, chalcopyrite, and a little galena. A little chalcocite is also present. There is scant evidence of oxidation in any of the ore.

FISHER PROSPECT

Location.—John Fisher's copper prospect is in a rugged canyon in the southeast end of the Turnbull Mountains, in the Black Rock mining district. It is about 25 miles from Fort Thomas, on the Arizona Eastern Railroad, but there are ranches along Black Rock Wash within a few miles of Fisher's cabin.

Ore.—The prospect has been developed by means of a number of pits and short irregular tunnels. The outcrops and tunnels are scattered around near the head of a short canyon, principally on the west side. They are not connected but show the presence of several mineralized masses. The rocks here are almost free from soil, but the surface evidences of mineralization are small and rather inconspicuous. No large amount of ore has yet been developed, but the underground work done so far is small and scattered. A few tons of rock, some of which contains several per cent of copper, has been mined, but none has yet been shipped.

Character of the deposits.—The prospect is in the midst of the granitic batholith, probably 2 miles or more from the nearest boundary of the intrusive mass as at present exposed. The east boundary of the batholith was not reached during the present investigation, but the characteristic erosion forms of the granite are clearly visible for a considerable distance beyond the area mapped. (See Pl. IX, *B*.) In the vicinity of the prospect are a number of aplitic dikes rich in micropegmatite. Many of them are less than a foot in width. Such dikes are rare in other parts of the batholith. The metallic minerals are irregularly disseminated in the granite. Indefinitely marked slips were noted in the mineralized granite in some of the tunnels. Much of the rock exposed by the tunnels is colored green by chrysocolla. Some of the rock originally contained a considerable amount of chalcopyrite, but this appears to have been concentrated in small irregular bunches. The tunnels twist and branch, following the zones of mineralization. There seems to be some tendency for these zones to be elongated in form, but the limits are indefinite and irregular. There is no suggestion of vein filling or of any definite walls.

The only original sulphide that was found is chalcopyrite. Later processes have produced copper pitch ore, chalcocite, covellite, and chrysocolla. The only gangue minerals besides those of the original granite are epidote and minor amounts of titanite, apatite, and chlorite or a similar alteration product. Like most of the rock of this batholith, the granite contains quartz, orthoclase, microperthite, albite, oligoclase, microcline, and biotite. The rock shows less alteration than most of the specimens from other parts of the batholith. Thin sections cut from specimens of ore contain almost perfectly fresh feldspars, but some of them, especially near ore minerals, are somewhat shattered. In a section cut from a specimen free from sulphide the feldspars are slightly clouded with alteration products. The chalcopyrite, which is the original ore mineral, is so greatly altered by oxidation that its relations to the minerals of the granite are somewhat obscure, but there can be little doubt that it was formed by replacement of the rock minerals. Epidote occurs in grains nearly 2 millimeters in the greatest dimension, some of which have crystal form, and in finer granular aggregates. Some of the grains are clouded with alteration, and most of them show cracks produced by weathering. The epidote seems later than the chalcopyrite. The large crystals appear in places to be molded on chalcopyrite grains, and finer aggregates probably filled cracks in the sulphide. Here also the oxide minerals obscure the relations somewhat. It is rare to find epidote in actual contact with sulphide. Many of the grains are embedded in copper pitch. Probably most of the epidote is in contact with feldspar, which it replaces, and not with any metallic mineral. All of it, however, is in the vicinity of such minerals. None is found in the granite that was not impregnated with chalcopyrite. Titanite is not abundant. It occurs here and there in granular aggregates, certainly later than the feldspar and perhaps later than the epidote. It was not noted in the unaltered granite. A few tiny prisms of apatite were noted near the epidote grains. Similar prisms were found in small amounts in some of the thin sections of specimens from other parts of the batholith, and it is possible that the apatite is to be considered an original constituent of the granite, although its association with epidote in the ore leads to the suggestion that it may have been introduced during the mineralization.

The chalcopyrite grains have been in large part replaced by an assemblage of supergene minerals. These are copper pitch ore and chrysocolla formed by weathering of the sulphides, with small amounts of the supergene sulphides chalcocite and covellite. The copper pitch in this ore is an indefinite mixture of hydrous oxides of copper and iron without manganese. The small cores which are all that remain of the chalcopyrite grains are embedded in the copper pitch. The latter has not wandered far from its place of origin, although, besides replacing chalcopyrite, it has reached out into the feldspar to some extent, especially along cracks. The chrysocolla is more widely diffused than the copper pitch ore. Much of it is so finely disseminated through the granite in the vicinity of the ore minerals that it can not be resolved even under the microscope, and its presence is determined only from the slightly bluish-green color which suffuses the rock. Here and there, however, along tiny cracks are knots of the mineral, some of them large enough to be seen with the unaided eye. Some of the chalcopyrite cores have narrow rims of chalcocite with a little associated covellite. The total quantity of such supergene sulphides visible even under high magnifications is small. They were formed by downward enrichment, apparently after the original chalcopyrite had been attacked by oxidation, with the formation of copper pitch ore.

STANLEY MINING DISTRICT

GENERAL FEATURES

Location and extent.—The Stanley mining district lies approximately in unsurveyed Tps. 4 and 5 S., Rs. 19 and 20 E., in Graham County just north of the middle of the west border of the county. It is bounded on the north by the south border of the San Carlos Indian Reservation, on the west by the Pinal County boundary, and on the south by Old Deer Creek. The eastern boundary, which is somewhat irregular and indefinite, corresponds in part with the west border of the Turnbull mining district and for the purposes of this report may be taken as a line along Kelly and Rustler Park gulches to the head of the latter and thence west and south along the ridge tops to the head of Old Deer Creek.

Population.—The old settlement of Stanley is the center of population for the district. It is a collection of houses and shacks all but one of which are now abandoned. The sole remaining resident is J. Flaherty, a veteran prospector whose success in raising vegetables on the patches of soil in the rocky streamway that passes by Stanley has resulted in the streamway being known as Garden Gulch. The post office of Stanley has recently been moved to the assistant postmaster's house, about half a mile south of the old settlement. According to the census of 1920 Stanley precinct, which doubtless comprises the whole of the district, has a population of 54. This is made up of stockmen, prospectors, and miners scattered over the district, there being nowhere more than a single family or group of a few men at any one place. In 1910 the population, according to the census, was 139.

Roads.—Stanley is over 15 miles by road from San Carlos, which is the supply point for the district. This road is in poor repair but is practicable for a wagon, and most of it can be traversed by an automobile. Beyond Stanley the road continues nearly 4 miles farther to the Princess Pat mine but has been little traveled since that mine shut down in 1918. The whole of this road could be made passable for automobiles with a small amount of work, but unless considerable surfacing and grading were done it could hardly be made into a good automobile road. Another road extends from San Carlos to the Copper Reef mine, and a branch of it goes up Hawk Canyon to the Webster ranch, near its head. The road to the mine is in fair shape, but that up Hawk Canyon is washed out in places and very rough. The other parts of the district are accessible only by trail.

MINES AND PROSPECTS

PRINCESS PAT MINE

Property.—The Princess Pat group consists of 44 unpatented claims, which were bonded to the Princess Pat Mining Co., of New York, by the Allison brothers. The claims are on Old Deer Creek just south of Stanley Butte, most of them on the north side of the stream. The company built a number of tent houses and shacks on a patch of level ground on Old Deer Creek and installed a compressor and other machinery at the tunnel mouth. The cabin of the late J. S. Allison is a short distance farther upstream. The camp is about 4 miles from Stanley by a road which, considering that it has not been repaired since 1918, is in fairly good condition.

The principal underground development work on the property is that done by the Princess Pat Mining Co., which opened a tunnel reported to be 870 feet long, with a trend of N. 10° W. There are two crosscuts on the west side, each about 120 feet long, and one on the east about 70 feet long. Other workings of small extent resulting from annual assessment work are scattered over the property.

History.—The presence of mineralized outcrops here has been known since the early days of prospecting in the region, and some work was done on them long ago. About the beginning of the present century the ground was located by members of the Allison family, and since then it has been held by Messrs. Grant, G. M., O. W., and J. S. Allison, the last two of whom are dead. Many of the data given here were kindly furnished by G. M. Allison, who acted as guide in this part of the region. About a ton of oxidized copper ore was shipped by the Allisons from workings near the northwest corner of the property. In 1916 the property was bonded to the Princess Pat Mining Co., which gave the present name to the group. The claims had previously been known as the Butte & Arizona and Palo Alto groups. The company drove the tunnel and crosscuts already described but shipped no ore and in December, 1918, suspended operations. Since then little has been done. The tunnel now contains considerable water and is beginning to cave.

Character of the deposits.—The rocks on the property consist of Cretaceous and Miocene (?) beds and rhyolitic intrusive rock. The Cretaceous beds are principally andesite and andesitic breccia, but sandstone and shale, in part carbonaceous, are also present. The rocks strike about N. 45° W. and dip 30°–45° SW. They are cut by contemporaneous andesitic dikes. The Tertiary lava overlying the Cretaceous rocks on the west is principally glassy quartz latite.

The deposit which the tunnel was intended to open up shows on the slope above as a rusty and silicified shear zone in andesite. The only mineralized rock reported to have been found underground is in a zone about 7 feet wide in a crosscut to the west about 320 feet from the portal. Apparently this rock does not crop out. Specimens from this zone on the tunnel dump consist of light-green brecciated and chloritized andesite, softened by weathering. The most abundant metallic mineral is sphalerite. Pyrite in cubes and irregular grains, a little chalcopyrite, and probably some galena are also present. The rock is shot through with calcite, part of it in crystal form, and quartz has also been developed in it.

A few hundred feet west of the tunnel is a body of rhyolite which appears to be a continuation of the intrusive mass to the south, although differing somwhat from the typical intrusive rhyolite. It contains phenocrysts of quartz and alkali feldspar in a rather fine grained groundmass of alkali feldspar and quarts intimately intergrown somewhat after the manner of micropegmatite. This rock in places is altered, iron stained, and broken by small slips. The slips are more iron stained than the surrounding rock and show chrysocolla and malachite in places. Some of the slip surfaces are coated with quartz. Casts of pyrite crystals partly filled with limonite are sparsely disseminated in the rhyolite. In shallow workings near the stream stringers of chalcocite are reported to have been found.

COPPER DIKE GROUP

The Copper Dike group consists of 14 unpatented claims on the south slope of Stanley Butte, adjoining the Princess Pat group on the north. Only a little shallow underground development work has been done on this property, to meet assessment requirements.

This group is a part of the Allison property which was retained when the Butte & Arizona and Palo Alto groups were bonded to the Princess Pat Copper Mining Co. The early history is given in the description of the Princess Pat mine. In recent years very little has been done on the Copper Dike group.

There are on these claims two shear zones in andesite breccia. The rock of these zones is silicified and rusty and in places contains azurite. The zones strike about N. 15° W. and appear to dip steeply east.

COLD SPRING PROSPECT

The Cold Spring prospect, owned by Martin Flaherty, of Stanley, is near the head of Garden Gulch, somewhat less than 3 miles southeast of Stanley. There is a tunnel opening a few feet above the stream bed from which issues the water that gives the place its name. The water is piped into a trough in a small corral at the tunnel mouth, and the corral is closed with a gate. The place is now used for watering cattle, and no mining appears to have been done for some time.

The tunnel is in the Tornado limestone near the southwest border of the metamorphosed phase of that formation which forms Crystal Peak. Near the tunnel some beds are thoroughly altered, but some are little affected by the metamorphism. Some of the limestone on the dump contains masses of recrystallized calcite with abundant cubical crystals and small amounts of stibnite, sphalerite, chalcopyrite, and perhaps supergene copper sulphides.

SOLDIER PROSPECT

The Soldier prospect is on the west slope of Limestone Mountain about a mile east of Stanley. It is owned by P. T. McCulley, assistant postmaster of Stanley. The development consists of an inclined shaft and a tunnel more than 1,000 feet long, starting a few hundred feet down the slope, which was intended to cut at depth the slip on which the inclined shaft was sunk.

The country rock of the workings is the Tornado limestone, which is cut by quartz porphyry dikes near by. Some of the limestone beds contain actinolite, garnet, specularite, and quartz, but most of them show little metamorphism of this type. On the slip at the shaft there is a little specularite and some copper stain. Near the mouth of the tunnel the rock is slightly mineralized, and at its face the limestone shows some replacement by garnet and similar minerals.

COPPER BELLE MINE

The Copper Belle mine, owned by Martin Flaherty, is a short distance west of Stanley. It has been developed by several shafts, none of them deep. It was first located in 1883, and two partial carloads of ore have been shipped from it.

The deposits are in highly faulted Tornado limestone. The mineralized rock is in irregular seams and contains specularite, calcite. pyrite, and chalcopyrite.

SILVER SPAR PROSPECT

The Silver Spar prospect, owned by Joe Stewart, is on the west side of Stanley Butte near the summit. A short tunnel, a shallow shaft, and perhaps other cuts have been opened on the property.

The country rock is a dark latite or andesite breccia. The ore is in irregular seams and has a gangue of quartz, barite, and fluorite. The metallic minerals are in aggregates of tiny dark grains, on some of which there is a little malachite. Under the microscope three metallic minerals can be seen, but the quantity of each is so small that positive identification was not made. There are specks of some mineral that has the appearance of bornite. It is tentatively considered to be that mineral and to be the source of the malachite noted. A bright silvery mineral, very soft and sectile, is present in somewhat greater amount. The bright grains are rimmed with a soft gray material, evidently an alteration product. The microchemical reactions observed on these two minerals do not seem to accord with any of the minerals listed by Davy and Farnham.[59] It was thought that the bright mineral might be a telluride, but chemical tests failed to confirm this conjecture. The material contains lead, silver, and probably antimony. Small quantities of a mineral resembling horn silver were noted in the specimens.

STANLEY MINE

The Stanley mine or prospect is on the northeast side of Little Stanley Butte, on a tributary of Garden Gulch a little over a mile in a straight line west of Stanley. It was worked by Martin Davis a few years ago. He lived in a house near the mouth of the tunnel, which is the principal underground working on the property. It is now caved but is reported to have been 1,200 feet long.

The tunnel is in red Cretaceous sandstone striking N. 15° W. and dipping 20° W. It is reported to have been driven to cut leads found on the slopes above but does not appear to have done so.

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[59] Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals. 1920.

FRIEND MINE

Property.—The Friend mine comprises the principal development on the Copper Range group of claims, owned by the Stanley Peak Mining Co. It is on the north side of Little Stanley Butte 1½ miles west of Stanley. The house where the miners live is near Garden Gulch, a short distance downhill from the mouth of the principal tunnel.

There are reported to be about 2,000 feet of underground workings on the property. The principal opening is a tunnel about 1,400 feet long, now largely caved. Above this are some short tunnels and shafts.

History.—The deposits were known in the early eighties and held for a time by a half-breed Indian named Bob McIntosh, who took a negro and later a white man called James Stevens as partners. They sold the property to John Blake and Albert Warren in the nineties. Most of the development work is reported to have been done from 1870 to 1907. About three years ago the present company was organized. Only one carload and a few small lots of ore have been shipped from the property. The carload was copper carbonate ore. At present the principal tunnel is being reopened. The company plans to clean it out and timber it to the point where the vein was intersected, about 1,100 feet from the tunnel mouth, and then to drift on the vein. The work is in charge of J. C. Anglin. He and Martin Flaherty, of Stanley, furnished the historical information here given.

Character of the deposits.—The rocks on the property all belong to the Cretaceous system. Sandstone, shale, and andesite are exposed in the tunnel and crop out near by. The visible portions of the veins are in andesite, and the wall rock of the vein in the tunnel is reported to have been similar. At the top of a shaft on the hillside above the principal tunnel the intersection of two veins is exposed. These dip very steeply and at the intersection strike N. 20° W. and N. 20° E. The principal gangue mineral in the portions of the veins visible in the upper workings is calcite. They contain azurite, malachite, cuprite, and hematite, with some bornite, chalcocite, and chalcopyrite in places. Ore containing as much as 20 to 30 per cent of copper is reported to have been found in stopes in these upper workings and immediately below them, now for the most part inaccessible. The ore shipped came from these stopes. The vein cut in the principal tunnel is reported to be 4 feet wide and to contain chalcocite and bornite.

On Stanley and Little Stanley buttes there are small prospect tunnels and shafts belonging in part to the same company as the Friend mine. In one of these tunnels on the north end of the top of Stanley Butte there is a zone from 2 to 3 feet wide of brecciated purple latite or andesite with calcite seams. This strikes N. 50° W. and dips 80° E. A little copper stain is visible. On the west side of Little Stanley Butte biotite latite is cut by a vein about 2 feet wide of coarse calcite darkened with manganese, with a little yellowish chert. Thin seams of gypsum appear on cleavage surfaces of the calcite. Tiny crystals stud the cherty lining of cavities in the calcite and have been examined by W. T. Schaller and E. S. Larsen, who have furnished the following data. They are black as seen under the hand lens but deep blue by transmitted light under the microscope. The index of refraction is about 2.5. The mineral is soluble in acids. The properties suggest those of anatase, one of the minerals composed of titanium oxide, and the appearance greatly resembles that of some deep-blue to almost black vein anatase from Colorado. The mineral is therefore considered to be probably anatase, although positive proof was not obtained. The country rock of both veins is lava of Tertiary age.

J. C. Anglin, of the Friend mine, found a vein of calcite colored black with manganese oxide in Cretaceous sandstone near the mine.

COPPER REEF MINE

Property.—The Copper Reef mine is on the southwest slope of the mountain of the same name, about 3½ miles northwest of Stanley and 12 miles by road from San Carlos, on the Arizona Eastern Railroad. The property comprises 125 unpatented mining claims and a 600-acre mill site[60] and is owned by the Copper Reef Consolidated Mines. There is an engine house containing a compressor and other machinery, a blacksmith shop, and a storehouse at the portal of the principal tunnel, and buildings for the office, boarding house, and dwellings a short distance down the shope. In Hawk Canyon a low dam and pumping plant supply water for the mine.

The principal underground workings are the California tunnel and drift. The tunnel extends about 300 feet from its mouth in a N. 44° E. direction, then turns and continues an additional 1,100 feet approximately N. 20° E. About 600 feet from the tunnel mouth there is a drift that extends about 1,000 feet with an average trend of about S. 40° E. Some winzes have been sunk and a little stoping done below this drift, principally near the southeast end. On the mountain some distance east of and several hundred feet higher than the tunnel mouth is the North Star shaft, reported to be 735 feet deep. There are several shallower shafts and other workings on the property.

History.—The Copper Reef Consolidated mine was incorporated in 1910 in Arizona, but the deposits were known considerably earlier,

[60] Weed, W. H., Mines Handbook, vol. 15, p. 258, 1922.

and some work had been done. Operations were suspended in 1915 but have been resumed several times since then. A small amount of lead ore obtained near the top of Copper Reef Mountain and small quantities of copper ore from other parts of the property are reported to have been shipped. At present the property is in charge of a caretaker, L. W. French, who furnished data as to underground development and other information. The company is now involved in litigation which hinders development of the property.

Character of the deposits.—The principal workings on the property are all in the Tornado limestone, which strikes about N. 50° W. and dips 25°–35° SW. The drift off the California tunnel exposes mineralized limestone along a large portion of it. The mineralized zone is from 1 foot to several feet wide, makes a small angle with the direction of bedding in the limestone, and dips steeply northeast. Workings below the level of the drift expose irregular mineralized bodies several feet wide containing oxidized copper ore making out along the bedding. On the slope above the tunnel mouth there are a number of irregular patches of oxidized ore exposed in shallow pits and cuts. In places the mineralization seems to have been confined to a given bed in the limestone, but in most exposures the outlines are irregular. The shafts that have been sunk in a number of places are reported to have run out of ore at depths of 20 to 40 feet. Although several were driven hundreds of feet lower they are reported to have encountered almost no further evidence of mineralization. Apparently they were started on gash veins that pinched out at shallow depths.

The ore from the California workings contains quartz, calcite, barite, hematite, limonite, manganese oxide, chrysocolla, malachite, copper pitch, chalcocite, and remnants of chalcopyrite and pyrite. Bornite and azurite are also reported to have been found but were not observed during the present investigation. The ore is reported [61] to average 5.4 per cent of copper and 68 per cent of silica, with some silver and gold. In surface exposures on and near Copper Reef Mountain beds of limestone are largely replaced by specularite with some actinolite.

PROSPECTS ON RAWHIDE MOUNTAIN [62]

On the northeast face of Rawhide Mountain claims have been located on slips in the Tertiary lava. Silver ore is reported to have been found in these prospects. Southwest of the mountain in the Tornado limestone there is a short tunnel and probably other workings on slips showing some mineralization.

[61] Weed, W. H., op. cit.

[62] Examination of this part of the region was facilitated by the guidance of Mark Claridge, of Hawk Canyon.

STARLIGHT MINE

Property.—The Starlight mine is owned by the Tribullion Smelting & Development Co., of New York, which also owns a copper mine at Kelly, N. Mex. The property consists of 12 overlapping patented claims covering about 180 acres on Kelly Gulch, about 8 miles from San Carlos. Most of the property lies in the San Carlos Indian Reservation, the boundary fence passing through the south corner of the group of claims. The mine was formerly connected with San Carlos by a wagon road down Kelly Gulch. There are several buildings in the gulch opposite the mouth of the principal tunnel, but, having been abandoned for years, they are in poor repair.

In Kelly Gulch is a tunnel reported to be 1,900 feet long, now partly caved and inaccessible. In a short side canyon known as Godless Gulch there are a number of open cuts and caved tunnels. There are also several shafts on the property, two of which are of the order of 150 feet deep.

History.[63]—The deposits here were evidently worked by the Spaniards or Mexicans in very early days, as when the deposits were rediscovered in 1886 there were several glory holes in Godless Gulch and the remains of an adobe smelter near by. They were at that time inside the Indian reservation and therefore could not be worked. In 1901 the land on which the deposits crop out was thrown open to location, although most of it was still within the reservation, and in 1903 work was started. In 1905 ore valued at $6,876 is reported to have been shipped. In 1906 ore on which the smelter returns aggregated $15,900 was shipped. The claims were surveyed for patent in 1907. Apparently little work has been done since then, and the place has been deserted for about 12 years.

Character of the deposits.—The deposits appear to be entirely in the Tornado limestone, but Cambrian quartzite and pre-Cambrian metamorphic rocks are also present. The Paleozoic rocks are fractured, tilted, and locally overturned. In Godless Gulch the limestone is much disturbed but appears to strike in general about N. 25° W. and to dip 60° E. Down the gulch to the east is Cambrian quartzite lying in about the same attitude, though dipping somewhat more steeply. The limestone thus appears to dip under the older quartzite, and the formations are therefore overturned. Under the quartzite exposed in the stream bed is yellowish-brown schist, evidently belonging to the Pinal schist. The quartzite forms the sides of Godless Gulch from the limestone boundary east to the point where it enters Kelly Gulch, and forms both walls of Kelly Gulch for some distance on both sides of this point, cropping out on the west

[63] Historical data principally from Stevens, H. J., Copper Handbook, vol. 6, pp. 984–985, 1906; vol. 10, p. 1696, 1911. More recent information supplied by Fritz Wolf, of Stanley, in whose company the mine was visited.

side for over a mile above the junction. South of Godless Gulch both the quartzite and limestone dip west, assuming their normal stratigraphic relations. A narrow ravine entering Kelly Gulch from the east just above the mine buildings is walled with a fine-grained dark-green rock that has the composition of an altered soda-rich granodiorite or soda granite. It consists largely of a micrographic intergrowth of quartz and feldspar and small hypidiomorphic feldspar laths, most of which have a composition approximating that of oligoclase-andesine. Orthoclase is present but is subordinate in amount to the plagioclase. A little apatite was noted. Quartz occurs in individual grains as well as in the intergrowths, but much of it appears to have been introduced by later hydrothermal processes. Chlorite, epidote, and calcite were also produced in this later period, doubtless in part from the decomposition of original ferromagnesian minerals, none of which appear to remain.

The mineralized rock in the upper part of Godless Gulch is in small irregular bodies that replace the fractured limestone. These are the only exposures of ore in place that could be seen at the time of visit. Ore is reported to have been encountered in the long tunnel in Kelly Gulch at 1,400 or 1,500 feet from the portal. This tunnel passed through quartzite for the first 600 feet from the mouth and then entered limestone. There is little ore on the dump of the tunnel in Kelly Gulch, but some was found on dumps in Godless Gulch. This is a mixture of chrysocolla, malachite, azurite, anglesite, cerusite, hydrated iron oxide (largely limonite), quartz, calcite, and a little residual galena.

PARKS BROTHERS PROSPECT

On Kelly Canyon just upstream from the Starlight mine are some unpatented claims owned by the Parks brothers. The tunnel visited is in a somewhat chloritized felsite containing a little pyrite. Ore similar to that at the Starlight mine is reported to have been found elsewhere on these claims.

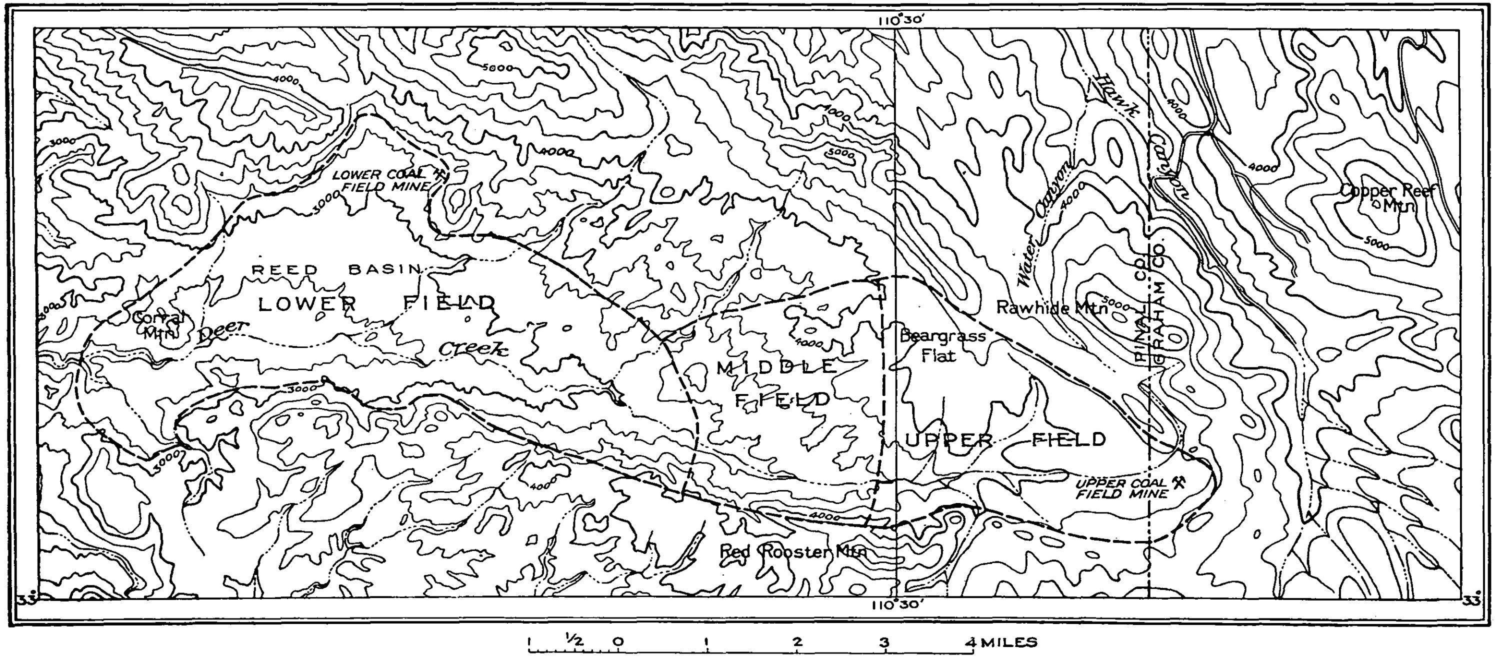
MITCHELL BARITE PROSPECT

Near Kelly Canyon, somewhat less than 2 miles southeast of the Starlight mine, is a vein containing barite, which has been prospected with a view to mining that mineral.

COAL FIELDS

GENERAL FEATURES

Location and extent.—Just west of the Stanley mining district are three areas in which prospecting for coal has been undertaken. The easternmost is known locally as the " upper field." The " mid-



MAP OF THE COAL FIELDS IN THE ARAVAIPA-STANLEY REGION dle" and "lower" fields are progressively farther west. The upper field, which comprises essentially the headwater basin of Deer Creek, is the only one included on Plate I, but all are shown on Plate XIII. The principal workings in the lower field, to which a brief visit was made in the course of work near Christmas, are in secs. 22 and 23, T. 4 S., R. 17 E., in the Christmas quadrangle. The middle field lies roughly halfway between the other two.

Accessibility.—When work was in progress the coal fields could be reached by wagons. The road up Hawk Canyon already mentioned is reported to have been originally built to reach the upper field. The traces of a road can still be seen leaving the canyon a short distance above the mouth of Garden Gulch, winding up a side gulch, and entering the basin of Deer Creek through a narrow pass at the northeast end. It is now so washed out that it would require reconstruction all the way from Hawk Canyon to the basin to make it passable for a wagon. The present trail from Hawk Canyon follows a somewhat different route than that of the old road. The lower and middle fields were reached by a road from Dudleyville, south of the present town of Winkelman, on Gila River west of the coal fields. The road originally extended only to what was then the camp of the Saddle Mountain Mining Co. on Ash Creek about 7 miles from Dudleyville, but in 1904 it was continued as far as the middle coal field. This road entered the valley of Deer Creek about 1½ miles northeast of the camp above referred to. The camp was at the place marked "Old Mill" on the topographic map of the Christmas quadrangle prepared by the United States Geological Survey. A branch of this road was built on the south side of the hills bordering Deer Creek and entered that stream just west of the lower end of Reed Basin. It is still possible to traverse this branch road with a wagon, at least into the lower part of Reed Basin, but the road in Deer Creek below the basin has been obliterated. Another road was started in 1907 up Deer Creek from its confluence with Gila River but never got farther upstream than the point where the road built in 1904 reached Deer Creek. This road was never used to any extent and is now badly washed out. If developments in the vicinity of the coal fields should warrant it, any of these roads could be put into passable shape without great expense.

History.—The early history of the coal fields has already been described by Walcott and Bannon[64] and by Campbell[65] but for the sake of completeness is outlined here.[66] The upper field was

[64] Walcott, C. D., and Bannon, M., Deer Creek coal field, White Mountain Indian Reservation, Ariz.: 48th Cong., 2d sess., S. Ex. Doc. 20, pp. 2–3, 1885.

[65] Campbell, M. R., The Deer Creek coal field, Ariz.: U. S. Geol. Survey Bull. 225, pp. 248–251, 1904.

[66] Many of the data here given were supplied or confirmed by C. H. Mellor, of Winkelman, and Martin Flaherty, of Stanley.

discovered in 1881 by David and Bob Anderson and other prospectors. The ground was then included in the San Carlos Indian Reservation, but in spite of warnings of the illegality of their actions from the Indian agent the prospectors carried on desultory development for several years. In 1883 they were removed by soldiers but are reported to have returned. In 1896 the boundary of the Indian reservation was shifted north, and thereafter claims in this area could legally be acquired. For a time there was considerable activity in the upper field, small shipments of coal were made to Globe, and claims were staked in the middle and lower fields, but the difficulties were too great for the resources of the prospectors, and their plans for development had to be abandoned. Work seems to have been continued in the areas to the west after activity in the upper field ceased, but in 1907 all development was abandoned, and nothing has been done since then. A little prospecting for coal was also undertaken in the Stanley district, to the east, but apparently with negative results.

UPPER FIELD

The upper field was abandoned so long ago that most of the workings are almost obliterated, and it was nowhere possible to go underground. Dumps of shale and slaked coal can still be seen. According to the reports already cited and the statements of residents of the vicinity, a number of slopes, pits, and shafts were sunk, most of them small. A tunnel 110 feet long and shafts 200 and 150 feet deep are the most extensive workings reported.

The coal is in narrow beds in the sandstone and shale in the lower part of the Cretaceous strata. There are probably several beds of coal, but all are thin. The thickest measured by either Walcott or Campbell is only 10 inches thick. Two samples were collected by Walcott and Bannon and analyzed by the United States Geological Survey. The results of the analyses show that the coal has about 20 per cent of ash, 60 per cent of fixed carbon, 19 per cent of volatile matter, and 0.5 per cent of moisture. The coal is reported to be such as would make a fair grade of coke but is greatly crushed.

MIDDLE FIELD

The middle field was not visited during the present investigation, and the available data regarding it are meager. A number of openings have been made, but apparently the development here is less than in either the upper or the lower field.

The coal beds here are similar to those in the upper field and may well be continuations of the same beds. No detailed data regarding them are available.

LOWER FIELD

The greatest development in the lower field is in the vicinity of the Lower Coal Field mine. (See Pl. III.) An inclined shaft, which at the time of Campbell's visit was 160 feet deep, was sunk at this point. Before this a slope 150 feet long had been driven into the coal-bearing rock 420 feet north of the location of the shaft. A coke oven was built near the shaft, probably about 1907, and a small amount of coke was made. A shaft about 100 feet deep, called the Crowe shaft, is reported by Campbell on the south side of the basin. According to him it is about a mile west of the old Manning ranch. This may be the place now known as Ming's ranch and, if so, would seem to be in the middle field, although included by Campbell in the lower field. The boundaries of the different fields are of course far from definite.

There are reported to be several other shafts and slopes in the lower field, but they are probably all smaller than those mentioned above. Prospecting by means of churn drills was undertaken about 1907 in the lower field and perhaps also the middle field, but it is reported that the results were not altogether satisfactory.

The stratigraphic positions of the coal beds in the lower field are similar to those of the beds in the other two fields. Coal crops out on the south side of the basin as well as on the north, which is not true so far as known in the other fields, but as the structure of the Cretaceous strata is broadly synclinal this is not surprising.

The sections measured by Campbell indicate that the coal is in thicker beds here than in the upper field and also that some of it has escaped the crushing reported to be characteristic of that field. Near the mouth of the Reed slope he measured 3 feet 1 inch of coal with 3 inches of bone in the upper part, and in other places he found thicknesses of more than a foot. He expresses the opinion[67] that there are two coal beds underlying the greater part of the basin and that they range in thickness from 24 to 30 inches. He quotes four analyses of samples collected in the lower field, the most favorable of which is given below.

Analysis of lowest coal in Crowe shaft

Moisture	1.76
Volatile combustible matter	36.65
Ash, light reddish	34.78
Fixed carbon	26.81
Sulphur	1.91
Silica in ash	51.5
Coke, dull, not swollen, friable.	

[67] Campbell, M. R., op. cit., p. 257.

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