GEOLGY AND ORE DEPOSITS IN THE VICINITY OF PUTNAM WASH, PINAL COUNTY, ARIZONA

by

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Approved:  

Directors of Thesis

Date
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Abstract

The Putnam Wash area is located in Pinal County at the confluence of Putnam Wash and the San Pedro River, 10.4 miles by road south of Winkelman, Arizona. The area is at the northern end of the Black Hills, a group of predominantly granitic hills projecting above a thick series of detrital Tertiary sediments.

Sedimentary rocks in the area include the Pre-Cambrian Apache group lying unconformably above the Pinal schist and Oracle granite, the Cambrian Troy quartzite, Devonian Martin limestone, and Cretaceous(?) shales and sandstones.

The oldest igneous rocks in the area are the facies of the early Pre-Cambrian Oracle granite complex, consisting of muscovite granite, porphyritic biotite quartz monzonite, and porphyritic biotite granodiorite. Diabase was intruded as sills and dikes during a Middle Cambrian deformation. The youngest igneous rocks are basalt, hornblende basalt and rhyolite porphyry of Tertiary age.

Metamorphic rocks include the earlier Pre-Cambrian Pinal schist, and tremolite tactite, a contact rock resulting from the intrusion of diabase into Mescal limestone.

Hydrothermal alteration of wallrock occurred along Tertiary fissures. Minerals formed include quartz, sericite, magnetite and later limonite and calcite. No relation exists between the alteration and the manganese mineralization.
Four periods of important structural deformation have been recognized. The oldest deformation involved the metamorphism of the Pinal schist and the intrusion of the Oracle granite. A Middle Cambrian deformation resulted in the intrusion of diabase along structural breaks. Laramide deformation produced a series of northwest-striking, east-dipping imbricate thrusts in the eastern part of the area, and a series of northwest-striking, west-dipping normal faults of large displacement in the western part. The fracturing was the result of differential vertical uplift. Differential vertical uplift of post-Gila conglomerate age, developed northwest-striking normal faults.

Mineral deposits include asbestos deposits of Middle Cambrian age, and vein manganese deposits of Tertiary age. The asbestos deposits occur in the Mescal limestone near its contact with diabase. The asbestos formed along bedding plane shear zones. The deposits are not economic.

Manganese oxides occur filling northwest faults. The deposits are widespread in the central part of the area, but production has been limited to the Tarr and Harper mine. A moderate tonnage of concentratable ore exists in these workings.

The Black Hills are one of the structural blocks comprising the western structural unit of the San Pedro-Aravaipa area. The manganese deposits are related to the late phase of the Laramide metallogenic epoch, one of three recognized in the area.
INTRODUCTION

Location and Accessibility

The Putnam Wash area is in Pinal County, Arizona, fourteen miles south-southeast of Winkelman (fig. 1). The area studied lies on both sides of Putnam Wash at its confluence with the San Pedro River. This is at the northern end of the Black Hills, a series of low hills lying between the Santa Catalina Mountains to the south and southwest and the Tortilla Mountains to the northwest. This report is primarily concerned with sections 5, 8, 16, and 17, and parts of sections 6, 7, 9, and 18, township seven south, range sixteen east, referred to the Gila and Salt River meridian (Plate II).

The area described in this paper can be reached either from Winkelman or Mammoth by state highway 77 (paved) which, where the highway crosses Aravaipa Wash, come within half a mile of the area. Aravaipa Wash is 10.4 miles south of Winkelman and 10.3 miles north of Mammoth on highway 77. When the San Pedro River is not in flood, it is possible to drive a jeep or small truck down Aravaipa Wash, across the river, and up Putnam Wash.

The area can also be reached from Mammoth by a poor dirt road, about eleven miles long, on the west side of the San Pedro River. When the river is in flood, this is the only means of access to the area.
MAP OF ARIZONA

By U.S. Geological Survey

Putnam Wash area
The nearest post offices are at Winkelman (pop. 55) and at Mammoth (pop. 800). Winkelman serves the neighboring Banner and Saddle Mountain mining districts, and is contiguous with Hayden (pop. 1500), site of the Kennecott Copper Corporation concentrator and the American Smelting and Refining Company smelter which treat the ore from Ray, Arizona. Mammoth serves the Old Hat and Bunker Hill mining districts.

The nearest railroad loading head is at Winkelman, on a spur of the Southern Pacific Railroad, which passes through Florence from the main line at Phoenix, Arizona.
Physiography and Regional Setting

The Black Hills are one of the highlands within the San Pedro Valley. The valley is a northwest-trending structural trough, existing since Oligocene or earlier, and in which several periods of detrital sedimentation have taken place. The valley lies within the mountain region of the basin-and-range province as described by Ransome (1919, p. 15).

The San Pedro River heads in Mexico and flows north into Arizona to join the Gila River at Winkelman. The Gila River flows southwest between the Mescal and Dripping Springs mountains on the north, and the Santa Teresa and Galiuro mountains on the south to its juncture with the San Pedro River (Plate III). Beyond this juncture, the Gila River flows northwest to the vicinity of Kelvin, where it swings west and cuts through the Tortilla Mountains.

The Galiuro Mountains form the eastern border of the San Pedro Valley, Pinal County, while the Santa Catalina Mountains, Black Mountain, and the Tortilla Mountains form the western border. All the ranges owe their present elevation with respect to the valley floor to block faulting. The Galiuro Mountains consist of a structural block, composed largely of volcanics, which has been elevated relative to its surroundings and tilted about ten degrees to the east. The range is the youngest major structural block in the region, and geomorphically is in early youth, with deep canyons,
nonrounded divides, and the form of a tilted block - features characteristic of youth in block mountains (Lobeck, 1939, p. 551). The eastern slope is a dip slope on which the consequent streams have been able to develop much more rapidly than the obsequent streams cutting into the scarp faces. Because of this, the greater part of the drainage is eastward into Aravaipa Valley, and the divide lies near the western margin of the block. Aravaipa Creek flows northwest between the Galiuro Mountains on the west and the Santa Teresa and Pinaleno Mountains on the east to the vicinity of the Aravaipa mining district, where the stream abruptly turns westward and cuts through the Galiuro Mountains in a canyon nearly 1,500 feet deep, and joins the San Pedro River opposite Putnam Wash. Aravaipa Creek, which originally flowed into the Willcox playa, was captured by a stream cutting eastward into the Galiuro Mountains from the San Pedro River.

The Santa Catalina, Black, and Tortilla Mountains are largely granitic, and geomorphically are in late youth. Drainage off the Santa Catalina Mountains is divided between the San Pedro River to the east and the Santa Cruz River to the west. Because the Gila River cuts the range, drainage off the Tortilla Mountains is into the San Pedro and Gila Rivers to the east, and the Gila River to the west. Drainage to the east off Black Mountain is into the San Pedro River, while drainage to the west is into the Gila River.
The Black Hills lie to the east of the Catalina-Tortilla axis, and Black Mountain lies to the west of it. Between the Black Hills and Black Mountain is a broad, low area formed by the pediments and alluvial aprons spreading out from the Santa Catalina, Tortilla, and Black Mountains. Most of this area is drained by tributaries of Putnam Wash, or its major tributary, Camp Grant Wash, so that flow is into the San Pedro River.

The Black Hills are a series of low, northwest-trending hills, about sixteen miles in length and six miles wide. They are predominantly granite, and project through the terraced detrital apron spreading out from the Santa Catalina, Black, and Tortilla Mountains. Highest elevations, of approximately 4,000 feet, occur in the southern portion of the hills around Tiger. Greatest relief, which is approximately 800 feet, is along the draws tributary to Putnam Wash in the northern part of the hills. In general, the relief is moderate, usually 50 to 300 feet, and the hills are rounded, with steep slopes occurring only in areas of pronounced relief or in areas which have undergone recent active erosion. All drainage is into the San Pedro River.

The Black Hills have been uplifted by doming and faulting, and are at present being stripped of their detrital cover. Some of the topography now exposed is exhumed but not eroded; other topographic features have been exhumed and modified by the present erosion cycle. Thus the areas
farthest west of the river, and in general longer exposed to the present erosion cycle, topographically consist of low hills with gentle slopes; the granite shows features typical of arid weathering such as large rounded boulders. Areas nearer the river, on the other hand, consist of hills of moderate elevation (200-300') with steep slopes; in many places the granite is cliff-forming.

Within the area mapped in detail (Plate VI), drainage shows good adjustment to structure. Many of the northwest draws have developed along major northwest faults or along outcrops of diabase which are readily eroded. In the areas of Pre-Cambrian and Paleozoic sediments, the northeast slopes invariably are dip slopes.

Below the mountain fronts, a series of terraces, cut largely into Tertiary intervalley sediments, extend down to the present channel of the San Pedro River. From a vertebrate fossil study, Gidley (1926, pp. 83-96) determined a Late Pliocene time for the completion of the deposition of the Tertiary sediments. However, Gazin (1942) has shown that the sedimentation continued into the Pleistocene.

Bryan (1926, pp. 169-170), on the basis of Gidley's dating, postulated a deformation which produced the existing mountains at the close of the Pliocene epoch. Following the deformation, three erosional cycles took place in the valley, the surfaces of which Bryan has named the Tombstone pediment, the Whetstone pediment, and the Aravaipa terrace.
Quoting Bryan:

"Following deformation, long-continued erosion formed a widespread surface, here termed the Tombstone pediment. Residuals above this surface represent rocks harder to erode or rocks distant from main drainage lines. The erosion surface conforms to the drainage pattern in all intricacies; is wide on main drainages; tapers into long, narrow triangles along minor streams; is enlarged on soft rocks, narrowed on hard rocks, and presents all the features of a peneplain in the normal cycle except for steepness of slope. The slope ranges from 50 to 200 feet per mile, gradients far in excess of those developed by streams in the old age stage in humid regions. The Tombstone pediment is, therefore, an expression of peneplanation, though perhaps not complete base leveling, in an arid region."

The Tombstone cycle was interrupted by accelerated downcutting of the streams. The Whetstone pediment, a second, less complete pediment, was thereby formed. Its cycle was in turn interrupted by incision of the streams to a lower level to form the Aravaipa terrace. The present streams lie below this terrace in channels once deeper than they are now, as shown by recent fill, which is presently being removed by renewed erosion which began, according to Bryan, in 1883.

Davis (1930) recognized two terraces between the Galiuro Mountain front at Copper Creek and the center of the valley at Mammoth. He believed the deposition of the valley sediments was contemporaneous with the earlier stages of upfaulting of the mountain block, a view with
which the writer concurs, and that the dissection of the sediments was contemporaneous with the later stages when the mountain block probably gained the final 1,000 feet of its uplift. This dissection, in response to uplift, is greatest near the mountain border, where uplift within the sediments was greatest, as though they were dragged up by the rising mountain block. This has, according to Davis, locally yielded two terrace levels, the upper being more dissected than the lower.

Because it can be correlated with an erosion surface on the west side of the river, the writer believes the upper terrace level on the east side of the river represents an erosion surface which has been modified by differential faulting as outlined by Davis. The writer recognizes three erosional cycles which developed three surfaces on the west side and two surfaces on the east side of the river. The highest surface on the west side, probably corresponding to Bryan's Tombstone surface, is represented by pediments off the north end of the Catalina Mountains, the east side of Black Mountain, and the south end of the Tortilla Mountains, which pass into valley sediments. Parts of this surface can also be found along the east side of the Catalina Mountains. This surface has not been observed on the east side of the valley within Pinal County. Below this surface on the west side of the valley is a terrace cut entirely in the valley sediments, corresponding to the Whetstone surface. This
surface is represented on the east side of the valley by the strongly dissected upper terrace level, which is continuous with the incompletely formed pediment in front of the scarp of the Galiuro Mountains. Below this surface is a large, well-developed terrace cut in the valley sediments on both sides of the river. This terrace, the Aravaipa terrace, covers most of the valley from east to west, and the present drainage is incised into it. The Black Hills project above this terrace.

The development, and present correlation, of the three surfaces was complicated by block faulting along both the mountain fronts and within the valley. This faulting controlled deposition of the valley sediments, influenced the development of the terraces, and in some cases, later displaced them. Thus, final correlation of the erosion surfaces must await the final solution of the valley structure.

A considerable thickness of playa lake beds exists within the valley sediments, indicating that at times the valley has acted as a closed basin. Closure probably was due both to damming by local voluminous sedimentation and to structure. Which cause predominated, if either, is at present unknown.

**Climate**

The climate of the Putnam Wash area is semi-arid. It is in a region receiving approximately 15 inches of precipitation a year (Smith, 1945). Most of the precipitation comes
during the torrential rains and thunder storms during July and August, and the winter rains between December and January. Snow rarely falls during the winter.

All the streams in the area are intermittent. The nearest perennial streams are the Gila River and the upper reaches of Aravaipa Creek. Putnam Wash flows occasionally during the torrential summer rains. Putnam Spring, which surfaces in the floor of the wash a quarter mile west of the area mapped, maintains a fairly constant flow. During the period of field mapping, water flowed from the spring in appreciable volume for 2,000 to 3,000 feet down the wash before sinking into the sand.

The San Pedro River, in the vicinity of Putnam Wash, usually flows several months out of the year. For months when the other portions of the river are dry, considerable flow will occur along the river for about two miles north and south of the San Pedro-Putnam Wash juncture. This undoubtedly reflects a subsurface impedance to flow, which is believed to represent a buried structural block rather than variation in the character of the valley sediments.

The average high temperature for the winter months is between 60 and 70 degrees; the average low temperature is between 30 and 40 degrees. The average high temperature for the summer months is between 100 and 105 degrees; the average low temperature is between 80 and 90 degrees.
Previous Work

Little previous work has been done within the area of detailed study covered by the thesis. The oldest report dealing with the area is that of Jones (1919, pp. 170-173), describing the manganese deposits. The report was abstracted by Wilson (1930, pp. 87-89) in a later publication. Mention of the asbestos deposits in the area was given by Wilson (1928, pp. 92-93).

Darton (1925, plate 4a and fig. 87) figured a cross-section of the north side of Putnam Wash and gave a brief description of the stratigraphy. Bruhn (1927, pp. 8-11) measured a stratigraphic section on the north side of Putnam Wash in connection with his study of the Apache group.

Dean, et. al., (1952) reported on milling tests conducted on the manganese ores.

Field Work

The field work for this report was performed during the fall months of 1952. Reconnaissance mapping of the San Pedro Valley in Pinal County was done during the summer of 1952.

Base map for the geologic mapping was the 1950 edition of the United States Geologic Survey Lookout Mountain Quadrangle (Plate II), which was enlarged to a scale of 1:6,000. Mapping was done directly on this base map.

Mapping of the Tarr and Harper mine workings was by tape and Brunton survey.
Purpose and Scope of Work

Reconnaissance work in the lower San Pedro Valley disclosed several complex areas where detailed work would be necessary before the local geologic history could be unraveled and its relation to the regional geologic history ascertained. One of these areas, that along Putnam Wash, was selected for detailed work. This report describes the Putnam Wash area, and relates its structure and ore deposits to the structural history and ore deposition of the San Pedro region as a whole. Since the regional history is not completely understood, the regional relations will, with detailed work in other areas, be subject to revision.

Acknowledgements

The writer wishes to gratefully acknowledge the assistance of Drs. B. S. Butler and E. B. Mayo, who directed the work for this report; L. A. Heindl, who often accompanied the writer in the field and made available to him much of his information on the San Pedro Valley; R. DuBois, J. F. Lance, A. F. Shride, and E. D. Wilson for their discussion with the writer of phases of this report; E. D. McKee, G. A. Kiersch, and J. W. Anthony for critically reading this manuscript and offering many valuable suggestions.

Appreciation is also extended Kennecott Copper Corporation for their assistance in this study.
LITHOLOGY

Sedimentary Rocks

Introduction and Summary

The sedimentary sequence comprises rocks of Pre-Cambrian, Paleozoic, Mesozoic, and Tertiary-Quaternary age. The oldest rocks are those of the Pre-Cambrian Apache group comprised of the Scanlan conglomerate (0-3'), Pioneer shale (0-28'), Barnes conglomerate (10-15'), Dripping Spring quartzite (approx. 360'), and Mescal limestone (85').

An angular unconformity, which locally is a disconformity, separates the Apache group from the overlying Middle Cambrian Troy quartzite (585'). Part of the Troy quartzite within the area probably is equivalent to the Middle Cambrian Santa Catalina formation which crops out to the northeast, east, and south.

A disconformity, which is part of a regional angular unconformity, separates the Cambrian strata from the Upper Devonian Martin Limestone (295').

An angular unconformity separates the Paleozoic sequence from the overlying Cretaceous (?) sediments. Faulting limits the thickness of Cretaceous (?) strata exposed to a maximum of approximately 100 feet.

The Tertiary-Quaternary Gila conglomerate rests with pronounced unconformity on all the older beds. Total thickness of the Gila conglomerate is unknown, but must be several
hundred feet in the area.

The Pre-Cambrian, Paleozoic, and Tertiary-Quaternary sediments in the area were first described by Darbon (1925, p. 274). Recognition of the Cretaceous (?) sediments was an outcome of the present study.

Plate IV compares the stratigraphic column of the Putnam Wash area with columns from the Dripping Springs, Santa Catalina, and Galiuro Mountains.

**Late Pre-Cambrian (Apache group)**

**Scanlan conglomerate**

The oldest sedimentary unit in the area is the Scanlan conglomerate of late Pre-Cambrian age. It rests unconformably on the Pinal schist and Oracle granite. The conglomerate consists of angular to subrounded fragments of white (predominantly), red, and gray vein quartz, 0.5 to 6 inches in diameter, in a matrix of medium-grained, very dusky red to grayish pink arkose (Plate VIII). Thickness varies from 0 to 3 feet.

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1. Particle size designations follow the Wentworth classification; see Krumbein and Sloss (1951, p. 71).

2. Color descriptions throughout are in agreement with the Rock-Color chart (1948) distributed by the National Research Council, based on the Munsell system of color classification.

**Pioneer shale**

The Pioneer shale lies above the Scanlon conglomerate, or, where it is absent, the Oracle granite and Pinal schist. The
formation consists of blackish red, fine-grained, micaceous arkose, and interbedded blackish red, sandy shale. The sandstone and shaly sandstone, which make up 30 per cent of the section, occur in beds 2-3 feet thick and in thin-bedded (0.16 to 0.5 in.) units one to five feet thick. The sandstone near the top of the unit is mottled white due to local reduction of iron. Thickness of the Pioneer shale varies from 0 to 28 feet.

**Barnes conglomerate**

The Barnes conglomerate locally rests on Pinal schist and Oracle granite, but elsewhere is gradational into the underlying Pioneer shale. It consists of conglomerate with interbedded sandstone lenses.

The conglomerate is composed of well-rounded, ellipsoidal, boulders to small pebbles of quartzite, vein quartz, and jasper, in a matrix of blackish red to grayish pink fine-grained arkose and feldspathic sandstone (Plate IX). Most of the gravels of the conglomerate range in size from that of large to very large pebbles.

The thin interbedded sandstones are of the same composition and character as the matrix of the conglomerate. In places, the conglomerate is missing entirely from the formation.

The Barnes conglomerate is 10 to 15 feet thick.

**Dripping Spring quartzite**

The Dripping Spring quartzite consists of a series of banded sandstones and quartzites gradational upward from the
Barnes conglomerate. Faulting and diabase intrusion have complicated the sequence, so the thicknesses recorded are only approximate.

Section of Dripping Spring quartzite on the north side of Putnam Wash:

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<thead>
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<th>Mescal limestone</th>
<th>Thickness (approx.) feet</th>
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<tr>
<td>Dripping Spring quartzite</td>
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<tr>
<td>3. Quartzite: banded, grayish red, dusky red, pale red, and white, medium to fine-grained arkosic quartzites and orthoquartzites. Bedding varies from 0.1 to 1 foot thick; commonly slabby</td>
<td>150</td>
</tr>
<tr>
<td>2. Sandstone: white, moderate reddish orange, and moderate reddish brown micaceous shaly sandstones and sandy shales interbedded with very dark red to light brownish gray orthoquartzites one inch to one foot thick. Cross-bedding is present in the sandstones and quartzites. Ripple marks and rain prints occur in the shales. Shaly sandstones and sandy shales comprise 30 per cent of the section</td>
<td>90</td>
</tr>
<tr>
<td>1. Quartzite: Blackish red, pale red, and white, medium to fine-grained arkoses, arkosic quartzites, and orthoquartzites. Cross-bedding is present, with black magnetite and red and grayish orange feldspathic laminae common in the cross-bedding. Beds range from ½ to 5 feet thick; the mean thickness is 2 to 3 feet</td>
<td>90</td>
</tr>
</tbody>
</table>

360 feet

Barnes conglomerate

Mescal limestone

Lying above the Dripping Spring quartzite is the Mescal limestone, the youngest formation of the late Pre-Cambrian Apache group in the Putnam Wash area. The formation is
composed entirely of limestone. Diabase intrusion has disturbed the sequence, so that the recorded thicknesses are only approximate.

The following section of Mescal limestone was measured ½ mile northwest of the Tarr and Harper mine (Plate I, NW¼, NW¼, NW¼, section 8).

Troy quartzite

<table>
<thead>
<tr>
<th>Thickness (approx.) feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Limestone: medium dark gray to dark gray, medium to fine-grained, cherty, dolomitic limestone. Thick bedded. Greater than 30 per cent chert. The chert is gray to black, often iron-stained. The rock weathers light gray. Upper 2 feet is often silicified. Upper 6 inches in places consists of a breccia of angular flat-lying white silicified limestone fragments ½-2 inches long in a blackish red matrix.</td>
</tr>
<tr>
<td>3. Limestone: medium light gray to white, very fine-grained, cherty limestone. Limestone is thinly laminated; laminae are silty or sandy. Light gray to black chert varies in quantity both vertically and laterally. Bedding medium (1 to 2 feet) to flaggy (1 to 2 inches). Weathers powdery, white to light gray.</td>
</tr>
<tr>
<td>2. Limestone: same as the above, but the chert is usually absent. Serpentine and chrysotile host rock. Plate X.</td>
</tr>
<tr>
<td>1. Limestone: pale reddish brown, black, and gray limestone, largely silicified. Weathers light brown, light gray, and moderate pink.</td>
</tr>
</tbody>
</table>

Dripping Spring quartzite

Bruhn (1927, pp. 9-10) recorded a six-foot quartzite bed within the limestones, and included 79 feet of the overlying
sandstones and quartzites in the Mescal sequence. Mapping by
the writer indicates the six-foot quartzite bed is part of
the Dripping Spring quartzite faulted into position at the
time of the diabase intrusion. It is absent from all other
exposures of the Mescal sequence. The presence of a thick
basal conglomerate and lithologic continuity with the over­
lying Cambrian beds, indicate that the 79 feet of quartzites
are part of the Troy quartzites and not of the Mescal lime­
stone.

Peleozoic

Troy quartzite

The Troy quartzite, of Middle Cambrian age, disconform­
ably overlies the Mescal limestone. Pre-Troy channeling into
the Apache group is pronounced in many places (Stoyanow, 1936,
p. 474), but none was detected in the Putnam Wash area. Diabase
intrudes the Troy quartzite to within 100 feet of its contact
with the overlying Devonian Martin limestone (Plate I, NW 1/4,
section 8; Plate XI).

A section of the Troy quartzite measured 1/2 mile north­
west of the Tarr and Harper mine (Plate I, NW 1/4, NW 1/4, NW 1/4,
section 8) is as follows:

<table>
<thead>
<tr>
<th>Martin limestone</th>
<th>Troy quartzite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (feet)</td>
<td>Thickness (feet)</td>
</tr>
<tr>
<td>8. Sandstone: white, medium to coarse-grained, cross-bedded sandstone. Bedding 1/2 to 3 feet thick. Weathers white to dark yellowish brown, coarse grains stand out in relief........ 86</td>
<td></td>
</tr>
<tr>
<td>7. Quartzite: pale red, medium to fine-grained, feldspathic quartzite, Bedding 1/2 to 1 foot thick................................................................. 21</td>
<td></td>
</tr>
</tbody>
</table>
6. Quartzite: white, medium to coarse-grained orthoquartzite. Weathers grayish yellow to pale yellowish orange....................... 148

5. Quartzite: pale red to very dusky red, becoming grayish pink in the upper 1/4, fine to coarse-grained arkosic quartzite and orthoquartzite. Cross-bedded. Beds 0.5 to 2 feet thick. Orange feldspar fragments are prominent in the arkosic quartzites. .......................... 163

4. Quartzite: very dusky red, medium to coarse-grained, cross-bedded, arkosic quartzites, interbedded with very dusky red conglomerates 1 to 4 feet thick. Bedding in the quartzites ranges from thin (1/2-1 in.) to medium (1-2 ft.), with the thinner beds predominating. Orange feldspar is conspicuous in the quartzites. The conglomerates are composed of round to angular, small to very large pebbles (chiefly large pebbles) of white quartz, and of sub-round granules of orange feldspar............. 74

3. Quartzite: same as unit 4, except the conglomerates are absent.......................... 18

2. Quartzite: white, medium to fine-grained, cross-bedded, arkosic quartzites, banded by one-eighth inch layers of very dusky red purple sand. Bedding 1 to 4 feet thick. Orange feldspar fragments are conspicuous. A few 2 to 3 foot conglomerates composed of 35 per cent or more feldspar occur in the unit..................... 70

1. Conglomerate: conglomerate consisting of rounded, subrounded, and angular, small pebbles to boulders (chiefly large pebbles) of quartzite, vein quartz, schist, and silicified limestone. Orange pebbles are characteristic. The matrix is a medium to coarse-grained arkose............................... 5

585 feet

Disconformity

Mescal limestone
As previously mentioned, Bruhn (1927, p. 9-10) placed 79 feet of the Troy quartzite in the Mescal limestone. He measured a total of 449 feet of quartzite between the Devonian Martin limestone and the limestones of the Mescal sequence. This thickness is considerably less than that measured by the writer. Bruhn measured his section in the Troy quartzite immediately north of Putnam Wash, where the Troy sequence is considerably complicated by faulting (Plate I). This probably accounts for the disparity in the thickness of the Troy measured by Bruhn and the writer.

A series of quartzite and limestone believed to be equivalent to the Troy quartzite occurs in one of the thrust plates in the northeastern portion of the Putnam Wash area (Plate I, SE1/4, section 5). The sediments have been intruded by diabase. The section is not complete, as both the base and top of the series are cut off by reverse faults. A section of the sequence exposed is as follows:

3. Quartzite: a series of quartzites showing considerable variation; dark reddish brown to dusky red, banded, medium-grained flaggy quartzites predominate. Moderate orange pink to pale reddish brown quartzites are also present........................................greater than 50 feet

2. Limestone: dark yellowish orange to yellowish gray medium-grained limestone. Extremely cherty (Plate XII). Thickness varies considerably throughout the area.........................20-50 feet

1. Quartzite: a series of grayish red purple, grayish red, dusky red, light red, and moderate orange pink, medium to coarse-grained, thick bedded to massive quartzites. Poorly developed cross-bedding.........................greater than 80 feet
No fossils were found in any of these units. Cross-beding, although poorly developed, indicates the beds are not overturned. The quartzites, particularly the lower unit, possess lithologic similarity to the Troy sequence previously recorded. The limestone, on the other hand, is suggestive of Mescal, although the Mescal limestone is nearly twice as thick.

These beds are provisionally correlated with the Troy quartzite on the basis of: (1) their lithologic character; (2) the fact that they may be fitted into the Cambrian paleogeography. This latter factor now merits attention.

Kiersch (1947, pp. 24-28) reports a total thickness probably greater than 625 feet for the Cambrian sequence in the Dripping Spring Mountains, twenty miles northeast of the Putnam Wash area. This he divides into a lower series of quartzites (Troy), which probably exceeds 400 feet in thickness, and an upper series of undifferentiated shales and quartzites, 225 feet thick. Kiersch believes the shale-quartzite series may represent the northernmost outcrop of the Santa Catalina formation observed in Deer Creek Valley by Stoyanow (1942, p. 1262). Similar beds intruded by diabase were observed by the writer in the Galiuro Mountains a few miles north of Aravaipa Creek.

In the Santa Catalina Mountains, twenty miles south of the Putnam Wash area, Bromfield (1950, pp. 12-22) reports approximately 916 feet of Cambrian beds, separated as follows: Troy quartzite, 314 feet; Santa Catalina formation, consisting
of alternating mudstones, sandstones, and quartzites, 239 to 298 feet; Southern Belle quartzite, 45 feet; and the Abrigo formation, of Upper Cambrian age, consisting of 218 feet of magnesian limestones and quartzites.

The Putnam Wash, Dripping Spring, and Santa Catalina sections are compared in Plate IV. At Putnam Wash, the normal Cambrian sequence (that for which a top and a bottom are present) consists entirely of sandstones and quartzites; beds corresponding to the Santa Catalina formation are missing. In the Dripping Spring and Santa Catalina sections they are present. The Abrigo formation is absent north of the Santa Catalina Mountains, which may indicate either: (1) angularity in the Cambrian-Devonian unconformity; or (2) nondeposition of the Abrigo formation north of the Santa Catalina Mountains.

The fact that the thickness of Troy quartzite is greater in the Putnam Wash area than in either the Dripping Spring or Santa Catalina Mountains (585' vs. 400' and 314'), suggests that some of the Troy in the Putnam Wash area probably is contemporaneous with the deposition of the Santa Catalina formation to the northeast, east, and south. If so, the thrust plate beds, which have been faulted in from the east, represent an intermediate facies between the Troy quartzite to the west and the Santa Catalina formation to the east.

Additional comments on the Cambrian stratigraphy will be found in the paragraphs on the age of the diabase (p. 38).
The Martin limestone, of Upper Devonian age, rests unconformably on the Troy quartzite, although evidence of the break is not apparent in most places. The Devonian strata are separated from the overlying Cretaceous (?) sediments by an unconformity of small angularity (2 to 5 degrees). Regionally, this unconformity possesses a stratigraphic hiatus ranging from Pennsylvanian-Cretaceous to Pre-Cambrian-Cretaceous (Plate IV).

A section of the Martin limestone measured \( \frac{1}{2} \) mile north of the Tarr and Harper mine (Plate I, NW\( _{1} ^{1} \), SE\( _{1} ^{1} \), SW\( _{1} ^{1} \), section 5) is as follows:

<table>
<thead>
<tr>
<th>Cretaceous (?)</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular Unconformity</td>
<td></td>
</tr>
</tbody>
</table>

**Martin limestone**

8. Limestone: light olive gray, medium light gray, and medium gray, medium to coarse-grained organic limestone. Thick bedded to massive. Some chert. Weathers light gray to medium light gray. \( \text{H}_2\text{S} \) liberated on striking with a hammer................. 96

7. Limestone: moderate yellowish brown to yellowish gray fine to coarse-grained organic limestone. Massive. Some chert. Weathers yellowish gray. Liberates \( \text{H}_2\text{S} \) on hammer blow......................... 76

6. Limestone: dusky red, medium-grained limestone. Bedding 0.25 to 2 feet thick. Weathers light gray................................. 9

5. Limestone: moderate yellowish brown nodular limestone with interbedded shale....... 12

4. Limestone: moderate yellowish brown, fine-grained, compact limestone. Thick bedded....... 4
3. Shale: pale reddish brown and dusky yellow shale possessing good fissility. Grades upward into a moderate yellowish brown, shaly, nodular limestone, which weathers grayish pink to moderate pink........ 17

2. Shale: pale yellowish brown shale possessing excellent fissility............... 55

1. Limestone: moderate yellowish brown, fine-grained limestones containing a few interbedded shales. Bedding $\frac{1}{2}$ to 3 feet thick. Weathers dark yellowish orange.............................. 26

Disconformity

Troy quartzite

Fossils occur throughout the limestone members of the section. In the lower units crinoidal fragments are abundant. In the upper units, corals and brachiopods occur, and the following were identified by the author:

- **Cyrtospirifer whitneyi**
- *Syringopora*, sp.
- *Cladopora*, sp.
- *Zaphrentis*, sp.

**Cretaceous (?)**

Overlying the Devonian strata in the area studied is a series of undifferentiated shales and interbedded sandstones, correlated with the Cretaceous on the basis of the presence of fossil plant material. Identification of the plants, and therefore exact dating, was not possible due to the poor preservation of the material. These beds may be related to the coal-bearing Cretaceous strata exposed along Deer Creek to the northeast (Campbell, 1903).
The Devonian-Cretaceous (?) contact is one of noticeable unconformity. Although the angularity is small, channeling into the top of the Devonian strata is readily apparent in many places.

The thickness of the Cretaceous sequence is quite variable throughout the Putnam Wash area because the sediments are faulted on the east (Plates I and VII). A maximum of about 100 feet is exposed.

A conglomerate, which in most places contains angular gravels of silicified Devonian limestone 1 to 2 inches in diameter, occurs at the base of the sequence (Plate XIII). The conglomerate is three to twelve feet thick. Above the conglomerate is a series of light brown shales, possessing excellent fissility, with interbedded pale yellowish brown, medium to fine-grained, thin bedded, shaly sandstones and mudstones. Many of the mudstones contain abundant plant material. The shales contain brown, medium-grained sandstone lenses 1 to 4 feet thick and 20 feet long.

Gila conglomerate

Overlying all the igneous, sedimentary, and metamorphic rocks in the Putnam Wash area is a thick series of conglomerates of Tertiary-Quaternary age. The conglomerates consist of sub-angular to sub-rounded, pebbles, cobbles, and boulders of volcanics, granite, quartzite, limestone, and schist in a finer matrix of the same material. Most of the coarse conglomerates consist of cobbles or boulders 0.25 to 1 foot in
diameter, whereas the finer conglomerates consist of pebbles 1 to 3 inches in diameter. Some sandstone beds are also present. Cross-bedding has been observed in places. The total thickness of the Gila is unknown, but in the Putnam Wash area it must have been in excess of 300 feet. Since the pre-Gila surface is quite irregular, the thickness of the Gila varies greatly over short distances.

The term "Gila conglomerate", as currently used, is applied to poorly-to well-consolidated alluvial materials of late Tertiary to Quaternary age deposited in the structural valleys of the Gila River and some of its tributaries (Heindl, 1952). Both the writer and L. A. Heindl (Personal communication, 1952) have recognized several distinct series of conglomerates within material that has been called Gila, so that the name can have only broad significance. The relations of these separate series is not fully understood, so that the exact age and correlation of the conglomerate beds exposed at Putnam Wash, beyond the broad designation of Gila conglomerate, is not presently known. Some of the material called Gila conglomerate in the San Pedro Valley probably is the time equivalent of the Whitetail conglomerate of the Globe-Superior area.

**Quaternary alluvium**

Quaternary deposits of unconsolidated sands and gravels occur filling the San Pedro River and Putnam Wash channels, and along many of the smaller washes. For the greater part,
Igneous Rocks

Introduction and Summary

The igneous rocks of the Putnam Wash area range in composition from granite to basalt, in size from small dikes and sills a few inches wide to portions of a pluton, and in age from Pre-Cambrian to Tertiary.

The oldest igneous rock in the area is the Pre-Cambrian Oracle granite, which is part of a large plutonic complex. Muscovite granite, porphyritic quartz monzonite, and porphyritic biotite granodiorite facies were observed in the Putnam Wash area. The late Pre-Cambrian Apache group rests unconformably on the Oracle granite.

Hornblende diabase, of Middle Cambrian age, extensively intrudes the Oracle granite, Apache group, and Troy quartzite as dikes and sills a few inches to several hundred feet thick. The Dripping Spring quartzite and Mescal limestone are the sedimentary units most extensively intruded by diabase.

Small basalt pipes intrude the older diabase-granite complex. The basalt is believed to be related to the Tertiary volcanic activity.

Hornblende basalt intrudes the Cretaceous (?) beds as a small pipe. Lineation indicates intrusion from the southeast. The intrusive is related to the Tertiary volcanism.

Two northwest-trending dikes occupy faults in the
western part of the area. They exhibit facies of rhyolite porphyry, hornblende rhyolite porphyry, and andesite porphyry. These dikes are post-basalt and probably are the youngest igneous rocks in the area.

**Oracle Granite**

The Oracle granite, of Pre-Cambrian age, occupies extensive portions of the western half of the Putnam Wash area (Plate I). It is younger than, and intrudes, the Pinal schist (Plate XIV), and is older than the late Pre-Cambrian Apache group, lying unconformably below it. Three facies of the Oracle granite were recognized in the area; granite, quartz monzonite, and granodiorite. The facies were not mapped separately because in many instances they can only be distinguished microscopically.

**Muscovite granite:** Muscovite granite occupies a small area on the south side of Putnam Wash below the granite-Apache group contact. Although the contact is gradational, the granite apparently was intruded by the quartz monzonite. A description of the muscovite granite is as follows:

Megascopic: a moderate reddish brown, medium-grained rock. Quartz, red orthoclase, and magnetite are distinctive.

Microscopic: a muscovite granite.

<table>
<thead>
<tr>
<th>Essential</th>
<th>Accessory</th>
</tr>
</thead>
<tbody>
<tr>
<td>orthoclase- 51%</td>
<td>magnetite- 5%</td>
</tr>
<tr>
<td>quartz- 35%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Varietal</th>
<th>Alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>muscovite- 5%</td>
<td>kaolin</td>
</tr>
<tr>
<td>oligoclase (Ab38An12)- 4%</td>
<td>hematite</td>
</tr>
</tbody>
</table>
Orthoclase occurs in anhedral grains 1-4 mm. in diameter. Replacement perthite is developed in some of the grains. Hematite stains the feldspar red. Deuteric alteration to kaolin has occurred.

Quartz occurs in subhedral to anhedral grains 1 to 4 mm. in diameter.

Muscovite occurs in shreds accompanied by magnetite. Part of the magnetite was formed in the deuteric alteration of biotite to muscovite. Chevrons of magnetite in the muscovite represent a relic herringbone structure, and indicate the biotite formed by reaction of the magma with augite or hornblende, releasing iron for magnetite.

Oligoclase occurs in anhedral grains 1 mm. in diameter. Deuteric alteration to kaolin has occurred.

Magnetite occurs in subhedral to anhedral grains. Its origin is of three types: as primary crystallization from the magma; as a product in the augite (or hornblende) to biotite reaction; and as a product in the biotite to muscovite alteration.

Paragenesis: see figure 2.

Quartz_monzonite: A porphyritic biotite quartz monzonite is the most abundant facies of the Oracle granite exposed along Putnam Wash. The quartz monzonite occupies the eastern two-thirds or more of the exposed granite area (Plate I). The quartz monzonite facies is observed intrusive into the Pinal schist (Plate XIV). A chilled border between the quartz monzonite and the schist is negligible; it may be zero to two feet wide, and in most places is no more than six inches wide. No contact metamorphism is present in the schists. These factors indicate the schists were probably at a high temperature at the time of intrusion. The contact between the quartz monzonite and granodiorite is apparently gradational over a narrow zone.

A description of the porphyritic biotite quartz monzonite is as follows:
Figure 2. Paragenesis of the muscovite granite.

**Magmatic Crystallization**
- Orthoclase
- Quartz
- Oligoclase
- Augite (?)
- Magnetite

**Magmatic Reaction**
- Biotite
- Magnetite

**Deuteric Alteration**
- Perthite
- Muscovite
- Magnetite
- Kaolin and Hematite
Megascopic: a pale reddish brown porphyritic rock containing phenocrysts of plagioclase about 0.8 cm. in length (some are much larger) in a medium-grained matrix. Biotite, quartz, and orthoclase are discernible in the matrix. The phenocrysts show best on a weathered surface. Alignment of the phenocrysts is present.

Microscopic: a porphyritic biotite quartz monzonite

<table>
<thead>
<tr>
<th>Essential</th>
<th>Accessory</th>
</tr>
</thead>
<tbody>
<tr>
<td>orthoclase and</td>
<td>magnetite- 1-3%</td>
</tr>
<tr>
<td>microcline- 27-33%</td>
<td>muscovite- 0-1%</td>
</tr>
<tr>
<td>andesine (Ab62An35)- 27-33%</td>
<td>apatite- 0-1%</td>
</tr>
<tr>
<td>quartz- 21-27%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Varietal</th>
<th>Alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>biotite- 3-6%</td>
<td>kaolin- 2-4%</td>
</tr>
<tr>
<td></td>
<td>sericite- 2-3%</td>
</tr>
<tr>
<td></td>
<td>chlorite- 1-3%</td>
</tr>
</tbody>
</table>

Andesine occurs in phenocrysts 0.6 to 1.5 cm. in length, which are strongly corroded, and in subhedral crystals up to 4 mm. in length. It has been intensely altered to sericite and kaolin, which occur in minute gashes which are partly controlled by cleavage.

Orthoclase occurs in subhedral to anhedral crystals up to 3 mm. in length. Replacement perthite has developed in places. It has undergone deuteric alteration to kaolin.

Microcline occurs in varying quantities. It possesses the same general relations as orthoclase.

Quartz occurs in anhedral crystals up to 3 mm. in diameter.

Biotite occurs in scattered euhedral to anhedral crystal plates 0.5 to 5 mm. in length. Anhedral plates show early deuteric growth. Later deuteric alteration to chlorite has occurred.

Muscovite occurs in a few scattered plates.

Magnetite occurs in anhedral grains 1 mm. in diameter, associated with biotite.

Apatite occurs in small euhedral crystals.

Some sections possess a fine-grained matrix, with grains less than 1 mm. in diameter.

Paragenesis: see figure 3.

Granodiorite: A porphyritic biotite granodiorite, which
is identical to much of the Oracle granite at Oracle, Arizona, occupies the western one-third of the exposed granite in the Putnam Wash area. A description of the porphyritic biotite granodiorite is as follows:

Megascopic: a pale red porphyritic rock containing phenocrysts of plagioclase 0.3 to 3 cm. in length in a fine- to coarse-grained matrix. Quartz and biotite are noticeable as coarse-grained constituents of the matrix. Alignment of the phenocrysts is present. Schistose inclusions, derived from the Pinal schist are present.

Microscopic: a porphyritic biotite granodiorite

<table>
<thead>
<tr>
<th>Essential</th>
<th>Accessory</th>
</tr>
</thead>
<tbody>
<tr>
<td>andesine (Ab(<em>{65})An(</em>{35})) - 35-40%</td>
<td>magnetite- 1-3%</td>
</tr>
<tr>
<td>microcline- 23-27%</td>
<td>muscovite- 1%</td>
</tr>
<tr>
<td>quartz- 23-27%</td>
<td>apatite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Varietal</th>
</tr>
</thead>
<tbody>
<tr>
<td>biotite- 6-11%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>sericite- 3-5%</td>
</tr>
<tr>
<td>kaolin- 2-3%</td>
</tr>
<tr>
<td>chlorite- 2-4%</td>
</tr>
</tbody>
</table>

Three grain sizes occur: large phenocrysts of andesine 1-3 cm. in length; medium-sized phenocrysts of andesine, quartz, and biotite 0.3 to 0.6 cm. in length; and a finer-grained matrix of quartz, andesine, microcline, and biotite 0.01 to 0.1 cm. in length.

Andesine occurs in all three grain sizes. The phenocrysts are subhedral, and strongly corroded. Some are bent; when this deformation occurred is unknown, but it seems probable that it occurred when the rock was in a semi-rigid state. Minute gashes of deuteric sericite and kaolin, partly controlled by cleavage, occur throughout the crystals.

Microcline occurs in fine-grained subhedral to anhedral crystals. Mild deuteric alteration to kaolin has taken place.

Quartz occurs in medium- to fine-grained anhedral crystals. Some of the larger grains are abnormally biaxial, indicating strain. The strain is probably the result of the same conditions which deformed the andesine.

Biotite occurs in medium- to fine-grained euhedral to anhedral plates. Some early deuteric stage growth
Figure 3. Paragenesis of the porphyritic biotite quartz monzonite.

**Magmatic Crystallization**
- Andesine
- Orthoclase
- Quartz
- Biotite
- Magnetite
- Apatite

**Magmatic Reaction**
- Andesine*

**Deuteric Alteration**
- Biotite
- Chlorite
- Sericite and Kaolin

*Andesine formed at this stage by reaction between the previously existing phenocrysts and the magma. The phenocrysts were also extensively corroded at this time.
has taken place. Chlorite occurs as a late deuteritic alteration from biotite.
Magnetite occurs in grains up to 1 mm. in diameter associated with biotite.
Apatite occurs in small euhedral crystals associated with biotite.
Muscovite occurs in scattered plates and grains.

Paragenesis: see figure 4.

Genesis of the Oracle granite: The magmas intrusive into the Pinal schist are the products of the complex processes active when the region was subjected to high thermal energy gradients attending the destruction of the geosyncline which served as the collection basin for the sediments now comprising the Pinal schist. Mobilization of crustal material subject to granitization-fusion-assimilation has yielded these magmas which were intruded into less intensely metamorphosed rocks. The corroded andesine phenocrysts may represent relic crystals, in which case liquefaction would not have been complete.

Thermal gradients across the quartz monzonite-Pinal schist contact could not have been steep, as evidenced by the lack of a chilled border around the intrusive rock. The metamorphism of the Pinal schist is believed, therefore, to be related to the same thermal cycle that at greater depth generated the magmas.

The Oracle granite complex appears to be more felsic (quartz monzonite) along its borders than it is in its interior (granodiorite) as exposed along Putnam Wash. This is contrary to what would be expected on the differentiation
Figure 4. Paragenesis of the porphyritic biotite granodiorite

Magmatic Crystallization

- Andesine
- Microcline
- Quartz
- Biotite
- Magnetite
- Apatite

Magmatic Reaction

- Andesine

Deuteric Alteration

- Biotite
- Chlorite
- Sericite and Kaolin
of a single uniform magma. Three explanations for this feature are possible: 1) the quartz monzonite resulted from the assimilation of the red granite by the granodiorite; 2) the granodiorite was slightly later than the quartz monzonite, so that their mutual border was a zone of mixing between the fluid granodiorite magma and the semi-crystalline quartz monzonite; 3) the intrusion of the two magmas occurred simultaneously but they were not mixed and a uniform rock did not result.

Because of limited detailed areal study, the writer does not feel justified in postulating which of these explanations, singularly or together, is the most plausible. Mapping of the internal structure in the Oracle granite, which time did not permit, is a pre-requisite to the solution of this problem.

Diabase

Sills and dikes of diabase are found extensively intruding the sedimentary rocks and granite in the area. Faulting, transverse and parallel to the bedding, largely controlled the intrusion. Emplacement of the diabase was accomplished by the forcible spreading apart of the rocks on both sides of the zone of weakness which initially channeled the diabase. The Dripping Spring quartzite underwent the greatest inflation by diabase sills. The contact of the diabase with the intruded rock is sharp; no evidence of any assimilative or replacement action was observed.
A description of the diabase is as follows:

Megascopic: three facies of the diabase have been distinguished: 1) a fine-grained border phase; 2) a medium-grained phase; 3) a coarse-grained phase.

The border phase is an olive black rock containing scattered "phenocrysts" which are actually clusters of augite crystals.

The medium-grained phase, which is by far the predominant type, is a dark greenish gray rock containing plagioclase laths 1 to 3 mm. in length. It may be nodular. Fluxion structure around the nodules has been observed.

The coarse-grained phase is similar to the previous one, except the plagioclase laths are larger, being 5 to 6 mm. in length.

The diabase weathers greenish black and grayish red to dark reddish brown. All the diabase is very susceptible to weathering. Limonite staining of the plagioclase in the coarse-grained diabase makes that phase quite conspicuous.

Microscopic: a hornblende diabase. Mineral count of the medium and coarse-grained phases as follows:

<table>
<thead>
<tr>
<th>Essential</th>
<th>Accessory</th>
</tr>
</thead>
<tbody>
<tr>
<td>labradorite (Ab(<em>{54})An(</em>{46})) - 38-43%</td>
<td>magnetite - 9%</td>
</tr>
<tr>
<td>augite - 5-15%</td>
<td>apatite - 2%</td>
</tr>
<tr>
<td>Alteration</td>
<td></td>
</tr>
<tr>
<td>hornblende - 10-46%</td>
<td></td>
</tr>
<tr>
<td>actinolite - 0-30%</td>
<td></td>
</tr>
<tr>
<td>sericite and</td>
<td></td>
</tr>
<tr>
<td>kaolin - 3-6%</td>
<td></td>
</tr>
<tr>
<td>limonite</td>
<td>chlorite</td>
</tr>
</tbody>
</table>

Labradorite occurs in euhedral crystals 2 to 3 mm. in length. It has undergone extensive deuteric alteration to kaolin and sericite.

Hornblende (uralite) occurs in anhedral grains and poor pseudomorphs after augite. The grains are 0.5 to 2 mm. in length, and pleochroic in green. Magnetite lenses occur in the hornblende, the iron having been released in the reaction of augite to hornblende.

Augite occurs in light brown euhedral to subhedral crystals averaging 1 mm. in length. It has undergone variable, but usually extensive, alteration to hornblende.

Actinolite occurs in columnar and fibrous aggregates. The individual prisms are a fraction of a mm. in length.
Actinolite is an alteration product after hornblende. Magnetite occurs in subhedral crystals 0.5 to 2 mm. in length, and in blebs associated with the augite to hornblende alteration. Apatite occurs in euhedral crystals up to 1 mm. in length. Chlorite occurs as an alteration product of hornblende. It is never present in quantity.

The border phase is essentially the same as that given above, except augite is more abundant and less altered to hornblende. The augite crystals commonly occur in clusters, giving a cumuloporphyritic texture. Labradorite crystals larger than those found in the medium-grained diabase are present in the border phase.

Paragenesis: see figure 5.

Ransome (1919, pp. 53, 56) assigned the diabase to the early Mesozoic or late Paleozoic on the basis of diabase dikes cutting Mississippian and Pennsylvanian strata in the Tortilla and Dripping Spring mountains. In the Mescal Mountains, Darton (1925, pp. 36, 254-256) observed the large diabase sills overlapped by the Troy quartzite, and therefore considered the diabase Pre-Cambrian. Elsewhere he noticed diabase invading the lower portion of the Troy quartzite. Darton believed the post-Pennsylvanian bodies described by Ransome, all of which are of small size, to be related to the Tertiary Quaternary basalt flows. In the Little Dragoon Mountains, Cooper (1950, p. 31) reports diabase sills intruding the Apache group and overlain by the Cambrian Bolsa quartzite.

Evidence that the large diabase sills are post-Middle Cambrian is found at a number of localities. At Superior, where two diabase sills with a total thickness of 3,100 feet occur, Short (1943, p. 38) considered the diabase to be post-Middle Cambrian and pre-Devonian. Diabase was found intruding
Figure 5. Paragenesis of the hornblende diabase

Magmatic Crystallization

Labradorite
Augite
Apatite
Magnetite

Deuteric Alteration

Hornblende
Magnetite
Actinolite*
Sericite and Kaolin
Chlorite

* The solutions responsible for the actinolitic alteration approached hydrothermal solutions in character.
the Troy quartzite to within 50 feet of its contact with the overlying Devonian Martin limestone, but nowhere was found intruding the Devonian beds. Similar relations exist in the Putnam Wash area, where diabase intrudes to within 40 or 50 feet, stratigraphically, of the Cambrian-Devonian contact, but nowhere was found either in the Devonian or along the contact. In the vicinity of Aravaipa Creek, about ten miles to the east, diabase was found intruding the shales and sandstones of the Santa Catalina formation below the Devonian contact. In the Salt River area east of Globe, A. F. Shride (personal communication, 1953) found the diabase intruding the Troy quartzite and truncated by erosion at the Cambrian-Devonian unconformity. In the Vekol Mountains, Carpenter (quoted by Kiersch, 1947, p. 59) found diabase intruding the Troy quartzite and cut by an unconformity within the quartzite section. Gravels of diabase occur in the quartzite above the unconformity.

A conclusion based on the preceding observations is that two ages of diabase is reasonably well established. One was in the Middle Cambrian, and the other was post-Paleozoic, probably Cretaceous or Tertiary. The diabase along Putnam Wash is considered to be of Middle Cambrian age.

The correlation of the Cambrian stratigraphy is related to the problem of the age of the diabase. Two thick quartzite units appear to be represented in the Cambrian of southern Arizona - one pre-diabase and the other post-diabase in age.
This is clearly shown in the Vekol Mountains. The post-diabase quartzite occurs in the Mescal and Little Dragoon Mountains; the pre-diabase quartzite occurs in the Superior and Putnam Wash areas. In the past both these units have been referred to as Troy or Bolsa quartzite.

The question may be raised as to whether a portion of the Cambrian section in the Dripping Spring Mountains may not be equivalent to the 400 feet of post-diabase quartzite in the Mescal Mountains. According to the present correlation (p. 22), all the Cambrian of the Dripping Spring Mountains is considered to be pre-diabase. Should this prove wrong, the sandstones and shales intruded by diabase at Aravaipa Creek must still be time equivalents of a part of the Troy quartzite at Putnam Wash, but would be below the Santa Catalina formation, which would be post-diabase. At present, it is not possible to say which of the alternatives is correct.

The writer questions the validity of the age designation as Middle Cambrian of many of the quartzite units that have been so dated; he further suggests the existence of an angular unconformity of considerable size within the Cambrian. It is difficult to imagine that erosion, following the intrusion of the diabase with its structural deformation and inflation of the rock column, would not yield an unconformity of at least fair proportions.

Basalt

Basalt, probably related to Tertiary volcanism, occurs
in small pipes in the southwestern portion of the Putnam Wash area. Most of the pipes are intrusive into diabase, which is altered over a distance of a few feet from the contact. The pipes are circular to elliptical in outline, and from 15 to 100 feet in width. They plunge steeply. Dating is based on lithologic similarity to volcanic rocks of Tertiary age in the Galiuro Mountains, ten miles to the east. A description of the Basalt is as follows:

Megascopic: a medium light gray aphanitic rock containing limonite flecks. In some specimens, a fine diabasic texture is discernible.

Microscopic: a diabase containing labradorite \((\text{Ab}_{55}\text{An}_{45})\) laths 0.4 to 0.6 mm. in length in an indeterminate groundmass. Magnetite grains up to 0.5 mm. in length are present; they are extensively altered to limonite.

**Hornblende basalt**

A single oval pipe of hornblende porphyry, 30 feet in length, intrudes Cretaceous (?) shales in the northwest part of the Putnam Wash area (Plate I, SW\(\frac{1}{4}\), NW\(\frac{1}{4}\), NW\(\frac{3}{4}\), section 5). The pipe is related to the Tertiary volcanism.

Lineation, expressed by the alignment of amygdules and hornblende crystals, is present in the hornblende porphyry. The lineation, the result of magma flow, strikes north sixty degrees west and plunges forty-eight degrees southeast. It approximately parallels the northeast and southwest sides of the pipe.

Slight baking of the shales occurs near the intrusive contact.

A description of the hornblende basalt is as follows:
Megascopic: a medium gray, amygdaloidal hornblende basalt. Amygdules containing calcite are common. Hornblende phenocrysts constitute 8% of the rock.

Microscopic:

<table>
<thead>
<tr>
<th>Phenocrysts</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>hornblende- 8%</td>
<td>labradorite- 60%</td>
</tr>
<tr>
<td>Vesicules</td>
<td>hornblende- 26%</td>
</tr>
<tr>
<td>calcite</td>
<td>magnetite- 6%</td>
</tr>
</tbody>
</table>

Hornblende occurs in euhedral to subhedral zoned crystals up to 1 mm. in length. It possesses greenish brown pleochroism. The hornblende in the matrix occurs in euhedral to subhedral crystals 0.1 to 0.2 mm. in length.

Labradorite occurs in euhedral laths 0.1 to 0.2 mm. in length.

Magnetite occurs in minute grains scattered throughout the rock.

Calcite occurs filling lensoid vesicules up to 2 mm. in length.

The rock possesses trachitic texture, with the elongate matrix crystals exhibiting fluxion structure around the phenocrysts.

Rhyolite porphyry

Three rhyolite porphyry dikes occur in the western portion of the Putnam Wash area (Plate I, sections 7, 17, and 18). The eastern dike, which is the largest and most persistent, occupies a fault (Plate XV). North of Putnam Wash this plane dips west; south of the wash it becomes vertical and near its southern outcrop it dips east. Moullion structure, paralleling the dip, is pronounced on the hanging wall of the dike.

Both of the west dikes probably occupy the same fault plane. The northernmost dike dips west; the southern dike dips west in its northern part and east in its southern part.
Two main types of rhyolite porphyry are present: a rhyolite porphyry, and a hornblende rhyolite porphyry. In addition, an andesite porphyry occurs along the east dike.

The east dike north of Putnam Wash consists largely of rhyolite porphyry. In a few places andesite porphyry occurs in 5 to 15 foot lenses along the footwall. The andesite porphyry represents an earlier intrusion along the fault. The dike consists of rhyolite porphyry for approximately 1,000 feet south of Putnam Wash; further south, hornblende rhyolite porphyry is the dominant material in the dike, although shoots of rhyolite porphyry are present.

The west dikes consist of hornblende rhyolite porphyry.

**Rhyolite porphyry**

Megascopic: a very light gray porphyritic rock containing euhedral crystals of "rhombic" quartz and prismatic sanidine crystals 1 to 2 mm. in length. Some of the sanidine shows clay alteration.

Microscopic:

<table>
<thead>
<tr>
<th>Phenocrysts</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>sanidine- 12-15%</td>
<td>biotite- 3-5%</td>
</tr>
<tr>
<td>quartz- 13-18%</td>
<td>indeterminate- 55-65%</td>
</tr>
</tbody>
</table>

Sanidine occurs in euhedral prismatic crystals 1 to \(1\frac{1}{2}\) mm. in length. Deuteric alteration to kaolin has taken place to some extent. Quartz occurs in euhedral "rhombic" crystals 1 to \(1\frac{1}{2}\) mm. in length. Biotite occurs in euhedral crystals 0.5 mm. in length.

**Hornblende porphyry**

Megascopic: a pale yellowish brown porphyritic rock containing euhedral crystals of hornblende, "rhombic" quartz, and prismatic sanidine 1 to 4 mm. in length. Some sanidine show deuteric kaolinitic alteration.
Microscopic:

**Phenocrysts**
- sanidine - 16-20%
- quartz - 18-23%
- hornblende - 3-5%

**Matrix**
- indeterminate - 50-55%

Sanidine occurs in euhedral prismatic crystals 1 to 5 mm. in length. Deuteric alteration to kaolin has taken place.
Quartz occurs in euhedral "rhombic" crystals 1 to 3 mm. in length.
Hornblende occurs in euhedral thin prismatic crystals 1 mm. in length.

---

**Andesite porphyry**

Megascopically: a dark yellowish brown porphyritic rock containing small feldspar and biotite phenocrysts. Phenocrysts constitute 15% of the rock. The rock possesses fluxion structure.

Microscopic:

**Phenocrysts**
- andesine - 10%
- biotite - 5%

**Matrix**
- andesine - 42%
- magnetite - 7%
- indeterminate - 36%

Andesine occurs in euhedral, commonly zoned, slightly corroded laths 1 to 2 mm. in length (phenocrysts) and as laths 0.1 to 0.2 mm. in length (matrix). The phenocrysts often contain inclusions of magnetite.
Biotite occurs as euhedral to subhedral crystals 1 mm. in length.
Magnetite grains 0.2 to 1 mm. in diameter are abundant. Most are euhedral.

The rock possesses a marked trachitic texture, with fluxion structure beautifully developed around the phenocrysts.

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**Metamorphic Rocks**

**Introduction and Summary**

Metamorphic rocks in the area include schists, phyllites, hornfels, and tactite. In age, the rocks range from Pre-Cambrian to Middle Cambrian.
The oldest metamorphic rocks are the schists, phyllites, and hornfels of the early Pre-Cambrian Pinal schist. The rocks are the result of regional synkinematic epi- to mesozonal metamorphism of a sedimentary sequence.

The youngest metamorphic rock is the tactite developed on the intrusion of the diabase into the Mescal limestone. The tactite is essentially a tremolite rock.

Included with the metamorphic rocks are the hydrothermally altered portions of the diabase and Mescal limestone. In part the hydrothermal alteration is spatially related to the manganese mineralization, but the two phenomena are largely independent. The end product of the hydrothermal alteration is a quartz-sericite-limonite rock.

**Pinal schist**

The Pinal schist, of early Pre-Cambrian age, consists of hornfels, phyllites, and schists representing regional synkinematic epi- to mesozonal metamorphism of a sedimentary sequence. The metamorphism is related to the high thermal period which generated the magma yielding the Oracle granite. The Pinal schist has been intruded by the Oracle granite (Plate XIV), while the late Pre-Cambrian Apache group overlies the schist in angular unconformity.

Medium gray to greenish black hornfels and phyllites are the most abundant rock types in the Pinal schist. A few sheared pebble conglomerates were observed. Mineralogically, the hornfels consist of about 44 per cent sericite, 44 per cent quartz, and 10 per cent magnetite, hornblende, and biotite. The
phyllites and schists examined consisted of about 42 per cent sericite, 42 per cent quartz, and 16 per cent oligoclase (Ab\_9An\_1).

The schistosity in the schists and phyllites, and mineral banding in the hornfels, parallels the bedding in all places where both are discernible. This permits an interpretation of the pre-Apache structure.

The thickness of the Pinal schist can not be readily determined, but it must be 300 to 600 feet in the area examined. Regional studies indicate it was several thousand feet thick originally.

**Tremolite tactite**

In many places tactite occurs in a 1 to 3 foot-wide zone at the contact of the Mescal limestone with diabase sills of appreciable thickness (15 feet or more). The development of serpentine and chrysotile are other contact effects. Invariably where these are present, the limestone is more fractured than where the tactite develops; in many places serpentine development and everywhere chrysotile development are associated with strong shearing, usually along bedding planes. The relations of serpentine and chrysotile will be discussed more fully in the section on mineral deposits. Away from the tactite zone, metamorphism consists of recrystallization only.

A description of the tremolite tactite is as follows:

Megasclopic: a compact, fine-grained rock, often banded. Vari-colored in shades of brown, red, green, gray, and black.
Microscopic:

<table>
<thead>
<tr>
<th>Mineralogy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>tremolite</td>
<td>80-95%</td>
</tr>
<tr>
<td>quartz</td>
<td>5-20%</td>
</tr>
<tr>
<td>magnetite</td>
<td>1-3%</td>
</tr>
<tr>
<td>calcite</td>
<td></td>
</tr>
</tbody>
</table>

Tremolite occurs in euhedral crystals 0.5 to 6 mm. in length, chiefly of small size.
Quartz occurs in anhedral grains 0.5 to 2 mm. in diameter, chiefly of small size. It is more abundant near the diabase contact.
Magnetite occurs in scattered grains.
Calcite occurs in residual grains 2 to 3 mm. in diameter.

Zones of coarser crystallization, 1 to 3 mm. in width, occur parallel to the bedding. They are more abundant away from the contact. In large part they reflect variations in the original rock such as porosity, which permitted the growth of crystals of relatively large size.

Chemically the metamorphism, which actually is a metasomatism, involves the addition of magnesium (nearly all the magnesium present was introduced), silica, and water, which reacted with calcium from the limestone to form tremolite and quartz. Some calcium has been removed from the system, for that present in the limestone is in excess of the amount needed to form tremolite tactite.

The diabase magma(s) was the source of the metasomatic solutions.

Hydrothermal alteration

Hydrothermal alteration has affected the diabase, and to a lesser extent, the Mescal limestone. While alteration is widely distributed throughout the Putnam Wash area, it is most common along the wash immediately east of Lookout Mountain.
Alteration solutions rose along both northeast and northwest fractures of Tertiary age. Most of the alteration occurred along northeast fissures. In most places, little or no displacement occurred along the fractures.

While alteration and manganese mineralization may be spatially related, they are in most places independent of one another. In most cases the two solutions rose along different channelways. The hydrothermal alteration preceeded the manganese mineralization.

A series of samples was taken across one of the alteration veins in diabase (Plate XVI), and these were examined microscopically to determine the order of destruction of the igneous minerals, and the paragenetic sequence of the alteration minerals. The results are summarized in figure 6. Labradorite was the first mineral attacked, but the mafic minerals were destroyed soon thereafter, before all the feldspar was altered. The mafic minerals were pseudomorphically replaced by magnetite-specularite, while the feldspar was replaced by sericite. As the alteration became more intense, quartz was introduced. Apatite was destroyed only under intense alteration. The final product of this alteration was a quartz-sericite-magnetite rock.

A low intensity carbonate stage followed the high intensity silicate stage of alteration. Calcite was introduced in thin veinlets throughout the rock, while magnetite broke down to limonite, and reacted with the solutions to yield some siderite. The final product of this stage of the
alteration was a quartz-sericite-limonite-carbonate rock, the first two minerals being residual from the previous alteration stage.

Alteration in the limestone followed a sequence similar to that described for the diabase. In the silicite alteration stage, however, quartz introduction in the limestone occurred at a much lower intensity than it did in diabase.

The alteration solutions of the silicate state contained potash, iron, and silica. Sulphur was absent; otherwise, pyrite would have formed. The solutions were capable of removing calcium, magnesium, aluminum, and, in the more intense alteration, potash. The absence of wollastonite in the limestone indicates that the alteration did not reach katazonal conditions. The presence of sericite in the lower temperature environment indicates that the solutions were neutral or alkaline.

The solutions of the carbonate stage of alteration contained Ca and CO$_2$. They were alkaline and probably at low temperature.
Figure 6. Graphic summary of the hydrothermal alteration

**SILICATE STAGE**

<table>
<thead>
<tr>
<th>Alteration Sequence of Igneous Minerals</th>
<th>Feldspar</th>
<th>Mafic</th>
<th>Apatite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paragenetic Sequence of Alteration Minerals</th>
<th>Sericite</th>
<th>Quartz</th>
<th>Magnetite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CARBONATE STAGE**

<table>
<thead>
<tr>
<th>Alteration Sequence of Minerals</th>
<th>Magnetite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paragenetic Sequence of Alteration Minerals</th>
<th>Limonite</th>
<th>Siderite</th>
<th>Calcite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
STRUCTURE

Introduction and Summary

Faulting, folding, and jointing are all displayed in the Putnam Wash area. The age of the structures range from Pre-Cambrian to Recent. Numerous periods of structural deformation are known: 1) pre-Apache, 2) post-Apache, 3) Middle Cambrian, 4) pre-Devonian, 5) pre-Cretaceous, 6) pre-Gila conglomerate, and 7) post-Gila conglomerate.

The pre-Apache deformation was characterized by the metamorphism and deformation of the Pinal schist, and the intrusion of the Oracle granite complex. Deformation in the Pinal schist resulted chiefly in folding. The folds now possess a north-east trend.

The post-Apache deformation resulted in the formation of an angular unconformity below the Cambrian. In the Putnam Wash area, no angularity is apparent along this contact, but local channeling in the Mescal limestone is present.

The Middle Cambrian deformation was characterized by bedding plane thrusting, normal faulting, and the intrusion of diabase. Most of the jointing is believed to be of this period. Folding was negligible.

The pre-Devonian deformation is not apparent within the Putnam Wash area, and has not been studied on a regional basis. Slight tilting, resulting in a regional unconformity, probably was the chief result of this deformation.

The pre-Cretaceous deformation is marked by the existence
of a pronounced regional angular unconformity. In the Putnam Wash area, pre-Cretaceous tilting amounted to 2 to 5 degrees. No other structural disturbance other than tilting was observed in the area examined.

The pre-Gila conglomerate (Laramide) deformation involves movement along east-dipping thrust faults and west-dipping normal faults. All the major faults strike northwest. Regional tilting of the sediments occurred during this deformation.

Most of the structures of the post-Gila conglomerate deformation are normal faults, although gentle warping in the Gila is present. In large part, the lines of failure were inherited from the Laramide deformation.

Individual structures will be discussed in detail under the headings of folding, jointing, and faulting. Each major heading will be further subdivided on the basis of the times of deformation previously outlined. A summary of the structure of the Putnam Wash area is given in figure 7.

Folding

Pre-Apache deformation

The rock cleavage of the Pinal schist parallels the bedding, and this feature permits determination of the structure within the schist. Folding in the schist is of two types; 1) minor folding related to other structures such as faulting and folding (actually, the result of several periods of deformation), and 2) major folds that are the result of the pre-Apache deformation. The folds of type one
<table>
<thead>
<tr>
<th>Deformation</th>
<th>Folding</th>
<th>Regional Warping</th>
<th>Faulting</th>
<th>Thermal Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>Thrust</td>
</tr>
<tr>
<td>Post-Gila</td>
<td>slight</td>
<td>strong</td>
<td>strong</td>
<td></td>
</tr>
<tr>
<td>Pre-Gila</td>
<td>present</td>
<td>strong</td>
<td>strong</td>
<td>strong</td>
</tr>
<tr>
<td>Pre-Cretaceous</td>
<td>strong</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Devonian</td>
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</tr>
<tr>
<td>Middle Cambrian</td>
<td>slight</td>
<td>probable</td>
<td>present</td>
<td>strong</td>
</tr>
<tr>
<td>Post-Apache</td>
<td>present</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Apache</td>
<td>strong</td>
<td>strong</td>
<td>present</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Summary of the structure of the Putnam Wash area.
only will be discussed here.

The minor folds in the Pinal schist are small, sharp drag folds formed near faults or on the limbs of major folds. The amplitude of the folds seldom exceeds three feet, and in most places is only one or two feet. Some folds are broken into small thrusts of 6 inches to 2-foot displacement.

The extent of the development of drag folds near faults apparently depended on whether the fault was a single, sharp break, or a zone of several parallel breaks, only one of which needed to have had appreciable displacement. Where the latter developed, some fold zones 20 feet wide extend on either side of the main break.

The development of drag folds related to the major folds seems to be related to slight variations in the strike of the limbs of the major folds. They are not as common as drag folds related to faulting.

The major folds of the pre-Apache deformation are best developed in the schist in the eastern thrust plate (Plate I, section 5). The folding comprises an anticline and a parallel syncline lying to the north of it. The folds strike approximately north 35 degrees east, and plunge northeast. They have been considerably modified by faulting (both pre-Apache and later), and by diabase intrusion. The crest of the anticline has been pierced by diabase (Plate I, NW 1/2, SW 1/4, section 5).

The Pinal schist in the western part of the Putnam Wash area strikes uniformly northeast, except where there is minor
drag folding, and it dips southeast. This structure probably constitutes the limb of a large fold.

The major folding in the Pinal schist occurred prior to the intrusion of the Oracle granite, which cuts across the folded structure. Both are, however, related to the same period of deformation.

**Middle Cambrian deformation**

One small asymmetrical anticline referred to this period of deformation was observed in the Dripping Spring quartzite (Plate I, NW 1/4, SW 1/4, SE 1/4, section 8). The anticline, about 100 feet wide, strikes northwest and plunges southeast. The axial plane dips to the east. The anticline probably is due to doming by diabase.

**Pre-Gila conglomerate deformation**

Three small outcrops of Apache group sediments possessing an anomalous attitude occur near the San Pedro River (Plate I, SE 1/4, section 5). Outcrops are meager, so no definite structural pattern is recognizable and the interpretation in the cross-sections (Plate I-A) must be regarded as speculative. Whatever the explanation, a combination of folding and faulting seems to be involved in the structure.

Most of the present dip of the sediments throughout the Putnam Wash area results from regional tilting during the pre-Gila conglomerate deformation. This tilting locally was modified by normal faulting of the same deformation period.

Drag folds in the Pinal schist are related to the pre-
Gila conglomerate deformation.

Post-Gila conglomerate deformation

Several low warps of a monoclinal character occur in the Gila conglomerate. The amplitude of the warps varies from 3 to 6 feet, and the width from 10 to 60 feet. They seldom can be traced for any distance because of the limited exposures of Gila conglomerate which show bedding. The length of those folds that can be traced is less than 50 feet.

The warps described above are confined to the Gila conglomerate, and do not reflect folding in the underlying rocks. They are spatially related to faults within the Gila conglomerate, and probably owe their origin to lateral pressures exerted on the conglomerate during movement along the faults.

A part of the dip possessed by the sediments is a result of post-Gila conglomerate tilting. The Gila conglomerate shows a regional dip, the result of regional tilting, of about 12 degrees to the northeast. This tilting has been considerably modified by faulting.

Jointing

Middle Cambrian deformation

The prominent joint system developed in the granite, diabase, and Dripping Spring and Troy quartzites is believed to be a result of the Middle Cambrian deformation. The joints are best displayed in the granite, so primary consideration will be given to that rock type (Plate XVII).
Three sets of joints are recognized in the granite. Their attitude varies considerably from area to area, but it is uniform within any given locale. The variation has two causes: 1) differential movement of blocks of granite following the development of the joint system, and 2) initial variation in the attitude of the joints due to physical anisotropism within the granite. Because the former cause could not readily be separated from the latter, no statistical analysis of the joint pattern was undertaken. The results of such a precise analysis would not have significance in proportion to its precision. Numerous observations show, however, the following average attitudes for the three sets:

1) strike N 35-50 W
dip 45-55 NE

2) strike N 35-65 W
dip 43-55 SW

3) strike N 10-40 E
dip 50 NW to 85 SE (a high northwest dip predominates)

Diabase has been intruded along joints of the northeast-dipping set, indicating that the joints were pre-diabase. The existence of parallel sets of joints in the diabase further indicates the same stress conditions continued beyond the period of diabase intrusion. Thus a stress analysis of the joints, restored to their original attitude, might provide some clue to the stress conditions at the time of the diabase intrusion.

The Troy-Martin disconformity indicates that the beds intruded by the diabase were essentially horizontal at the time of intrusion (unless it is assumed that any pre-diabase
tilting was compensated by post-diabase, pre-Devonian tilting, an unlikely assumption). Compensating for the present 35 to 45 degree northeast dip yields the following approximate dip values for the sets:

1) 0-15 NE
2) 80-90 SW
3) 65-90 NW

Rock undergoing stress will fail according to the conventional strain ellipsoid only in so far as the rock mass is physically isotropic. A high, though by no means complete, degree of isotropism may be expected in the granite, which is relatively uniform in mineral grain size and composition (the variations in mineral composition noted would not appreciably affect the strength properties of the rock). The effect of the internal structure observed in the granite could not be determined; limited observations indicate, however, that joints of the steep-dipping sets in places parallel the trace of the mineral alignment on exposed surfaces.

Despite the apparent approximation to ideal conditions, a short analysis shows that these dips, coupled with their respective strikes, cannot be resolved into the conventional pattern for the strain ellipsoid; two directions of shear and one of tension normal to the intersection of the shear planes. This failure to approach ideality probably is due to the fact that the pressures on a hypothetical block of the Oracle granite (which may be a cube, sphere, or cylinder)
are not identical in distribution to those of the ideal block, or the blocks in the experiments of Griggs (1936), which are used as the basis for many discussions of rupture. A block of granite in the real case would have force applied along a northeast-southwest direction (deduced from the direction of tear faults associated with Middle Cambrian thrust faults), a confining pressure of intermediate magnitude on the northwest and southeast surfaces of the block, and a confining pressure of least magnitude on the top and bottom of the block. In the ideal case, on the other hand, force is applied to two opposite surfaces while confining pressure is equal on the other surfaces.

The writer believes the flat-lying joints may be either extension or release joints. No evidence was found to suggest which type of joint is present. The steep-dipping joints are possibly related to shear surfaces resulting from compression along a northeast-southwest axis.

Jointing in the diabase parallels that in the granite, except for minor changes in the attitude which reflect the differences in the physical character of the rocks. Only the steep-dipping joints occur in the sediments; bedding planes occupy the position of the flat set.

**Pre-Gila conglomerate deformation**

Columnar jointing in quartzite is spacially associated with the large northwest fault cutting the Troy quartzite in the SW 1/4, NW 1/4, section 8, of Plate I. The columns are four
or six-sided, and 4 to 6 inches in diameter. The bounding surfaces may be plane, concave, or convex.

The jointing is probably related to faulting. The mechanics of the joint formation, however, is not understood.

Faulting

Pre-Apache deformation

Except for one short east-west fault (near the center of section 7, Plate I), no sizable faults were observed which could definitely be correlated with the Pre-Apache deformation. Undoubtedly such do occur, but it is difficult to separate them from faults of later periods of deformation.

Numerous small faults related to folding in the schist are present, but they are all too small to map.

Middle Cambrian deformation

The second greatest period of faulting in the Putnam Wash area was connected with the intrusion of diabase in the Middle Cambrian epoch. Two main types of faults of this age were observed: 1) bedding plane thrusts, and 2) tear faults associated with the thrusts.

Three faults, occupied by diabase only in part, are present. One of these outcrops on the southeast slope of Lookout Mountain; this fault apparently is occupied by diabase to the north. Another of these faults, a thrust fault, crops out in the southeast corner of section 6, Plate I. It brings the upper part of the Mescal limestone over Dripping Spring
quartzite and earlier diabase. The third fault, a thrust fault, crops out in the SW\(^{1/4}\), SW\(^{1/2}\), NW\(^{1/2}\), section 16, of Plate I. The vertical separation on this fault is approximately 80 feet.

Bedding plane thrusting is the characteristic type of faulting in the Middle Cambrian deformation of the Putnam Wash area. It is well displayed along the east side of the wash immediately east of Lookout Mountain, where repetitions in the sedimentary sequence, separated by diabase, are exposed. The repetitions result where the thrusts broke across the bedding for short distances.

Many of the sedimentary lenses within the diabase are quite thin, but are conformable with the general attitude of the beds. A. F. Shride (personal communication, 1953) has observed an intrusive mechanism which results in such relations in the Salt River area. This mechanism is equally applicable in the Putnam Wash area. Shride states that two separate sills of diabase surround a sliver of sediments; a younger (or older) sill below the sediments, and an older (or younger) sill above them. Thus the sliver is at no time "floating" in diabase. These relations are illustrated in figure 8, which represents a simplified and generalized section across the wash east of Lookout Mountain in the SE\(^{1/2}\), NW\(^{1/2}\), section 8, of Plate I.

Diabase occupies several joints of the northeast-dipping set. At the time of intrusion these joints were essentially horizontal. Thrusting along these joints, which would be comparable to bedding plane thrusting, localized the entry
Schematic diagram of the sequence of events resulting in the structure present on the east side of the wash east of Lookout Mt. (SE\textdegree, NW\textdegree, section 8, Plate I). The left side of the diagram corresponds to the east side of the wash; the sections appear as they would facing north.

In section A, a single sill of diabase has inflated the Mescal ls.

In section B, diabase fills a thrust fault that cuts across the strata at a low angle (that in the diagram is greatly exaggerated) causing a repetition of the beds with diabase separating the repeated strata.

In section C, intrusion of diabase along a thrust that cut across the strata resulted in the removal of part of the Mescal ls from the overthrust sheet of the previous thrust-intrusion. Contemporaneously, diabase inflated the Dripping Spring qtz near the base of the sequence. The left side of the diagram represents the present structure.
of the diabase. The intrusion of all the diabase into granite shown in Plate I appears to have been controlled by thrusting along the flat joints, or by steep northeast fractures, which are interpreted as tear faults.

Post-diabase movement has occurred along some of the faults. Brecciation of the diabase and intruded rock near their contact is present in these cases. These movements probably were slight. Such movement, modified by later high-angle faulting, is present along the diabase-Dripping Spring contact in the SW$_1^1$, NW$_2^1$, NW$_1^1$, section 8, of Plate I.

Tear faults occur as northeast faults associated with the thrusts. In many places they are occupied by diabase, and most belts of diabase transverse to the bedding owe their position to intrusion controlled by faults.

One of the tear faults provides an indication of the amount of horizontal displacement which has taken place on some of the thrusts. This fault is marked by the offset of the Dripping Spring quartzite and underlying beds at the south end of the granite ridge that is the extension of Lookout Mountain south of Putnam Wash (NW$_1^1$, NE$_1^1$, section 17, Plate I). The tear fault is offset to the south by the pre-Gila conglomerate fault along the large wash trending northwest across section 17. The tear fault is also exposed in the NE$_1^1$, SW$_2^1$, section 17, of Plate I, where displacement of the Apache sediments occurs. The stratigraphic separation at this point indicates a horizontal displacement along the
tear fault of approximately 1,200 feet. Unfortunately, this was the only tear fault permitting such a determination, so whether other faults of equal displacement occur within the area is unknown. The extent to which repetitions and omissions are developed in the beds intruded by diabase east of Lookout Mountain suggests displacements of several hundred feet on most of the thrust faults.

The orientation of the tear faults indicates compression along a northeast to southwest axis. Some of the deformation probably was due to the intrusive force of the diabase magma.

**Pre-Gila conglomerate deformation**

The pre-Gila conglomerate deformation was the period of greatest faulting. Major faulting of this age is of two types; thrust faulting and normal faulting.

A series of imbricate thrust faults and associated tear faults has resulted in a complex stratigraphic sequence in the S\(\frac{1}{2}\) of section 5, Plate I (see also, Plates VII and I-A). The thrusts strike northwest and dip at varying angles to the northeast. The associated tear faults strike northeast and dip steeply.

The thrust faults, three in number, are referred to in this discussion as the eastern, middle, and western thrusts.

The dip along the eastern thrust, which exposes Pinal schist and diabase in the hanging wall, varies considerably. Where it brings Pinal schist against Cretaceous(?) rocks at its northernmost outcrop, the dip is only 5 degrees. Further
south, in the SE$t$, NE$t$, SW$t$, of section 5, Plate I, the dip is approximately 35 degrees. Although the fault is not exposed in this location, its position can readily be determined from the known outcrops.

The dip on the middle and western thrusts is more uniform, ranging from 30 to 40 degrees. The middle thrust brings Cambrian beds on top of Devonian strata in the NE$t$, NE$t$ of section 8, Plate I, and Cambrian beds on top of Cretaceous(?) strata in section 5 of Plate I. The western thrust crops out in the NW$t$, NW$t$ of section 8, Plate I, bringing Devonian limestones over Cretaceous(?) beds.

The lack of disturbance of the rocks of the thrust blocks is noteworthy. The eastern thrust surface, where it separates schist from shales, contains a one to two-foot zone of iron-stained mylonite. Disturbance of the schists or shales did not extend for more than a few feet from the contact. A similar situation exists where the fault plane of the middle thrust is exposed (SE$t$, SW$t$, SE$t$, section 5, Plate I). Cambrian quartzite is separated from Devonian limestone by an eight inch zone of gouge. Outside this zone the rocks were undisturbed. At this location the lack of disturbance is notable because the limestone is only 25 to 30 feet thick, with another thrust fault at its base.

The Cambrian quartzite is in places broken by northwest-striking fractures normal to the plane of the thrust. These breaks show secondary silicification and iron-staining.

Near the San Pedro River is a series of small outcrops
of Apache group sediments (p. 55). The attitude of these beds probably is due in part to thrust faulting.

Along none of the thrusts could the horizontal displacement be determined. The magnitude of the stratigraphic overlap resulting from the faulting indicates the displacements are in the order of hundreds to a few thousand feet.

Besides the tear faults, a number of other faults of northeast strike occur within the Putnam Wash area. Examples are the faults cutting the Martin-Troy contact in the SW\(1_4\) of section 5, Plate I, and the diabase-Mescal contact in the NE\(1_4\), NE\(1_4\) of section 17, Plate I. Stratigraphic separation along these faults can be accounted for by either horizontal or vertical movements. The separation on the largest of the faults referred to in section 5, for example, could be accounted for by either a vertical movement of approximately 75 feet or a horizontal movement of 70 to 90 feet. Similarly, the separation on the fault in section 17 could be accounted for by either a vertical shift of approximately 20 feet, or a horizontal shift of 20 to 25 feet. Both vertical and horizontal shifts probably occurred along the faults.

Besides the thrusts and their associated tear faults, a series of northwest-striking normal faults constitutes a major feature of the pre-Cila conglomerate deformation. The three largest faults in this series are all in the western part of the area. These faults will be referred to in this discussion as the east, central, and west faults. The east faults exist only north of Putnam Wash; it "horsetails" into
the central fault at Putnam Wash (Plate I, SE\(\frac{1}{4}\) of section 7, and SW\(\frac{1}{4}\) of section 8).

All of the normal faults strike essentially parallel to the bedding, although the eastern fault has several segments striking northeast. Dips on the faults vary from 35 to 55 degrees, except for the northernmost exposure of the east fault which dips steeply northwest to northeast.

Separation on the fault was determined by stratigraphic offset. Because the faults strike parallel to the strike of the beds, the vertical separation will equal the vertical displacement, for the effect of strike slip in causing the observed vertical separation will be slight, unless huge horizontal displacement is postulated.

Vertical separation on the eastern fault is approximately 950 feet. The dip slip, figured for a 50 degree dip, is approximately 600 feet. The strike slip could not be determined, but it apparently is slight.

Vertical separation along the central fault varies from 350 feet north of Putnam Wash (measured at the northernmost outcrop of the fault), to approximately 1,500 feet south of Putnam Wash (measured in the N\(\frac{1}{4}\), section 17, PlateI). Evidently all the vertical movement along the eastern fault also occurred along the central fault below their junction. Since no segment of the east fault occurs west of the central fault, the latter is interpreted as being the older. Horizontal separation along the central fault is indicated by offset of the Pinal schist north of Putnam Wash, and offset
of the Middle Cambrian tear fault (discussed on p. 62) south of Putnam Wash. Both offsets indicate a separation of about 650 feet. The horizontal separation will be approximately the same as the strike slip. Because movement on the southern half of the fault continued after movement on the northern, it can be concluded that the later movement was essentially vertical. For this reason the suggestion that strike slip on the east fault was not large is made.

Dip slip on that part of the central fault north of Putnam Wash, figured for a dip of 35 degrees, is approximately 300 feet.

Separation on the west fault was measured at a location south of the area shown in Plate I (Plate II, section 20, T. 7 S., R. 16 E.). At that place there is approximately 550 feet vertical separation along the west fault. The horizontal separation could not be determined.

A number of northwest faults of considerably lesser magnitude than those discussed above occur throughout the area. Some are mineralized with chalcedony and quartz; for example, the fault outcropping in the NW\(^4\), SE\(^1\), SW\(^2\), section 8 of Plate I.

The boundary of older formations with the Gila conglomerate in places is an exhumed pre-Gila conglomerate fault. Examples occur in the central part of section 6 and the SE\(^1\), NW\(^4\), section 16 of Plate I.

The fault pattern of the pre-Gila conglomerate deformation is the product of a single force developing a number of
stresses. The pattern is not in agreement with that deduced from the strain ellipsoid. Rather, the writer is impressed with the close correlation between the observed fault pattern and that determined by Hafner (1951) for differential vertical uplift. Variations from strict identity between the two patterns can be related to two causes: 1) in his stress analysis, Hafner used constants for larger blocks than would be involved in the uplift of the Black Hills and the immediately surrounding area, and 2) Hafner could not feasibly calculate the effect of faulting on the stress pattern once faulting commenced. The similarities are more pronounced than the differences, however, so the writer postulates differential vertical uplift as the cause of the pre-Gila conglomerate structure.

Post-Gila conglomerate deformation

Considerable post-Gila conglomerate faulting has occurred in the area. It has modified the regional dip of the Gila conglomerate, so that the local dip ranges from 0 to 50 degrees. Post-Gila conglomerate faulting is of two types: 1) major faults that cut the underlying rocks, and which in most places represent movement along old fault lines, and 2) faults confined to the Gila conglomerate, which because of its lithologic character and absence of overburden, acted as a strength unit different from the underlying rock. Faults of the latter type are abundant.

It is usually difficult to assess the importance of any fault viewed in the Gila conglomerate along, because: 1) all faults in this formation are quite sharp, consisting of a
narrow zone of gouge 2 to 3 inches wide with undisturbed beds immediately adjacent (Plate XVIII); 2) because of poor exposures faults cannot be traced for appreciable distances; 3) the lack of marker beds within the Gila conglomerate makes the displacement on any fault confined to this formation alone virtually impossible to determine.

The most prominent post-Gila conglomerate faults in the Putnam Wash area are in the SE$_{1}^{1}$ of section 8 of Plate I, and in section 16 and adjacent parts of section 17 of Plate I. Some of the faults bring Gila conglomerate against older rock. The outstanding example of this type fault is in the east-central part of section 17 of Plate I. Here a fault striking northwest and dipping 50 degrees southwest has a minimum vertical displacement of 200 feet. The extension of this fault may be the cause of the subsurface obstruction which results in the variable flow of the San Pedro River discussed on page 10.

The two large post-Gila conglomerate faults in the SE$_{4}^{1}$ of section 8 of Plate I are interesting in that they both cause a reversal in the dip of the Gila conglomerate. Plate XVIII illustrates this reversal in dip across the westernmost of the faults. The relative movements on the faults is unknown.

The easternmost fault is inferred to be the extension of the normal fault in the Troy quartzite on the north side of Putnam Wash. Most of the movement along the northern segment occurred prior to the movement along the southern portion. The southern extension of this earlier movement probably occurred along a plane now in the position of the westernmost
post-Gila conglomerate fault. A minimum of 280 feet of vertical displacement is required on the northern segment of the fault to account for the observed repetition in the Troy quartzite.

A prominent fault that brings Gila conglomerate against Oracle granite crops out on Putnam Wash about a half mile to the west of the area shown on Plate I. The fault dips about 30 degrees to the west (Plate XIX). L. A. Heindl (personal communication, 1953) has traced this fault, which is locally offset, for nearly 15 miles. The overall strike of the fault is a few degrees east of north. Shearing along the fault plane, and the direction of antithetic faults (Plate XIX) indicate that the latest movement along the fault was of a normal character.

The San Manuel fault to the south is almost identical in character to the fault outcropping in Putnam Wash. The writer has traced the San Manuel fault northwest and southeast from the vicinity of San Manuel, which is nearly in the center of the known extensions of the fault. The fault can be traced for nearly six miles, and appears to be an echelon to the Putnam Wash fault. Both faults probably reflect the same forces.

The origin of these faults is uncertain. Steele and Rubly (1948, p. 186) consider the San Manuel fault to be a high angle normal fault dipping to the west which was later tilted to the east. E. D. Wilson (op. cit. p. 193) questions this interpretation because it requires an abnormal thickness
of Gila conglomerate.

It has been suggested that the San Manuel and Putnam Wash faults are thrust faults. This would require a pre-Gila conglomerate high in the present Black Hills area which would be situated to the east of a low serving as a basin for Gila conglomerate deposition. Thrusting from the southwest of a thickness of the Gila beds over the pre-Gila conglomerate high (which is Oracle granite in both areas) would give the present relations. The existence of the necessary structural conditions can be neither demonstrated nor disproved with the evidence now available. However, secondary features connected with the faults do not support reverse movement.

A third possibility is that the faults represent low angle normal faults. Hafner (1951, p. 394) has shown that low angle normal faults may be the result of differential vertical uplift. The writer believes this mechanism is worthy of careful consideration.
MINERAL DEPOSITS

Introduction and Summary

Mineral deposits in the Putnam Wash area are of two types: 1) asbestos deposits in the Mescal limestone, and 2) vein manganese deposits. In addition, quartz veins in the Pinal schist have been prospected.

The asbestos occurs in shear zones in the Mescal limestone, and is genetically related to the intrusion of the middle Cambrian diabase. The chrysotile in the deposits is brittle and short fibered; all the deposits are small, and none have been prospected extensively.

The manganese deposits are in veins filling northwest-striking faults of Tertiary age. Manganese is present as pyrolusite, psilomelane, and manganite. The widths of the veins vary from 1 to 20 feet; horses are common within the veins. Movement along the faults was continuous throughout the period of ore deposition. Ore shoots depend for their localization on the degree of brecciation in the vein. Some production of manganese has been achieved.

Prospect pits have been sunk on quartz veins cutting the Pinal schist in the W², NE¹, SE¹, section 5, Plate I. Gold was probably the metal sought. Most of the quartz veins are lateral secretion veins paralleling the schistosity of the Pinal schist. A few veins cutting the schistosity were observed.
Asbestos Deposits

General Relations

The genetic relations established by Shride (1952) for the asbestos in the Salt River are equally applicable to the deposits at Putnam Wash. The formation of the asbestos was related to 1) favorable limestone beds, 2) proximity to the diabase contact, and 3) thrusting or shearing, in most places along bedding planes.

Asbestos formed only in the purer limestone beds of the Mescal; no asbestos formed in the cherty members. Characteristically, the asbestos occurs where the diabase has intruded the laminated limestones.

In the Putnam Wash area, asbestos does not occur more than ten feet from the diabase contact. The nearby diabase sills are all of moderate size - 20 feet or more in thickness. The diabase was the source of the introduced magnesium and silica.

Shearing, in most places along bedding planes, was perhaps the most important factor in the formation of asbestos. Where it was absent, massive serpentine formed and chrysotile was absent. Plates XX and XXI illustrate excellent examples of the importance of thrusting and its attendant shearing effect on the formation of asbestos. Plate XX illustrates an occurrence in the northern part of the Putnam Wash area. Here a massive 4-foot bed of slightly recrystallized limestone separates a 3-foot zone of asbestos (top of photo) from a
3-foot tremolite tactite zone in immediate contact with diabase. The limestone in the asbestos zone has been completely serpentinized, with the chrysotile occurring in lenticular veins slightly inclined to the plane of the zone itself. The broken character of the asbestos zone observable in the photograph is a result of shearing during movement along bedding planes. The tactite zone is only slightly broken and it is not sheared. Tremolite and massive serpentine have formed, the latter being restricted to the more open fractures and bedding planes.

Plate XXI illustrates an area south of Putnam Wash. Here a 20-inch zone of tremolite tactite developed at the diabase contact. Serpentine increases in quantity away from the diabase, and it is abundant at the immediate top of the zone. Immediately above the tactite asbestos occur in lenticular veins in a completely serpentinized 10-inch zone of bedding plane movement. Extensively recrystallized limestone, with minor serpentine at its base, extends for five feet above the asbestos zone.

Only cross fiber asbestos veins were observed. Following Shride (1952), the cross fiber veins can best be explained as fillings in "tension" or "gash" fractures in the shear zone that were repeatedly or gradually opened. The fractures are usually slightly inclined to the plane of the shear zone. Several generations of chrysotile in a single large fracture are common. The actual mechanism of asbestos formation must be complex; although shearing stress seems to be a pre-requisite for chrysotile development (see the discussion of Plates
XX and XXI), the chrysotile actually forms in the "gash" veins, which might be expected to be zones of lesser stress. The stress relations are probably not so simple, and the asbestos formation must be examined from the standpoint of a dynamic system.

All the asbestos deposits in the Putnam Wash area are of small size. No asbestos zone exceeding three feet in width was observed; in most places the zone is only one to two feet wide. The fiber is short; none longer than one inch was seen, and most of it is one-third to two-thirds of an inch in length. Most of the fiber was brittle (although this may be due largely to weathering), but some moderately flexible fiber was collected.

**Asbestos Deposits**

**SW 1/4, SW 1/4, NW 1/4, section 16:** A prospect pit has been sunk on an asbestos-bearing shear zone. The zone is several feet wide and parallels the bedding. Asbestos development is quite irregular throughout the zone. The fiber is brittle, and all of it was under one-half inch in length.

**NW 1/4, SE 1/4, SE 1/4, section 8:** A one-foot asbestos zone crops out on both sides of the small east-west wash at this locale. The fiber is all under one-half inch in length. Plate XXI was taken on the north side of the wash.

**SE 1/4, NW 1/4, SE 1/4, section 8:** A one- to three-foot zone of asbestos crops out on both sides of Putnam Wash. Most of the fiber is one-quarter to one-half inch in length, although some fiber three-quarters to one inch long was observed. The fiber
is quite brittle.

A prospect pit has been sunk in the area on the north side of Putnam Wash. Another pit has been sunk on the east side of the nose on the south side of the wash. Asbestos also crops out at the tip of the nose in Putnam Wash.

This location has been discussed briefly by Wilson (1928).

S:\$\frac{1}{4}$, SE:\$\frac{1}{2}$, NW:\$\frac{1}{2}$, section 8: Asbestos has formed in a three-foot shear zone developed in a septum of limestone in diabase. This deposit is unique in that the shear zone is not parallel to the bedding, but is inclined at about 45 degrees to it. The shear, at the time of its formation, had a strike to the northwest and a dip of about 45 degrees to the northeast. The shearing also involved the diabase above the limestone septum.

Much of the fiber at this location is one-half to one inch in length. It is, however, very brittle.

Two small pits have been sunk on the deposits. About 20 feet downslope to the west a narrow 100' tunnel, starting in diabase, was driven to intersect the limestone septum.

NW:\$\frac{1}{4}$, NW:\$\frac{1}{4}$, NW:\$\frac{1}{4}$, section 8: A three-foot zone of asbestos has been opened by a small prospect pit. Asbestos is relatively abundant throughout the zone. Much of the fiber is three-quarters- to one inch in length and somewhat flexible.

SE:\$\frac{1}{4}$, NW:\$\frac{1}{4}$, NW:\$\frac{1}{4}$, section 8: A three-foot zone of asbestos has been opened by a prospect pit (Plate XX) 500 feet northwest of the last locality. The zone is identical in character to the previous one. Both prospects are in the same stratigraphic position, so it is quite probable that the asbestos
zone is continuous over much if not all of the distance between them.

This is the best asbestos zone in the Putnam Wash area.

Manganese Deposits

General Relations

Manganese oxides occur as fissure fillings and minor replacements along a series of northwest faults in the central part of the Putnam Wash area. All the faults strike north 30 to 60 degrees west. Dips vary from 65 degrees southwest to 45 degrees northeast. Horses up to 6 feet in width are common within the veins, which range from one to twenty feet in width. Brecciation of the ore indicates movement occurred along the vein throughout mineralization.

The fractures are not mineralized throughout their length. The major channels for the ore solutions were related to warps along the fault plane. Ore shoots within the mineralized channels depend on 1) the degree of brecciation within the vein, and 2) the character of the material composing the fault breccia. In quartzite breccia, manganese fills open spaces, and the ore is commonly of lower grade. In limestone breccia, replacement and open space filling by manganese has yielded ores of higher grade. Little ore has been found in diabase because the major veins have not been observed cutting diabase, and the diabase was intermediate in favorability between the limestone and the quartzite as an ore host. The diabase did not brecciate as readily as the quartzite or limestone, and
was more favorable to replacement than quartzite and less favorable than limestone.

Mineralogy

Pyrolusite, psilomelane, and manganite are the chief manganese minerals. Pyrolusite and psilomelane are the most important quantitatively. Limonite, barite, and calcite are the chief gangue minerals.

Manganite $\text{(MnO(OH))}$: Manganite occurs in small prismatic crystals and crystal aggregates throughout the ore shoots. It is most abundant in the Tarr and Harper mine area; elsewhere, it appears to be of minor importance. Areas of quartzite breccia usually run relatively high in manganite.

Manganite was the original manganese mineral deposited along the veins. It has since largely altered to pyrolusite and psilomelane. The original manganite occurred as crystals 0.1 to 5 mm. in length, most of which were 1 mm. in length or smaller. The crystals occur both in compact masses representing the complete filling of open spaces in the breccia, and in layers of radiating needles surrounding and replacing fragments of breccia and gouge. The crystals are subparallel, and in places so closely spaced as to present a fibrous appearance. The prismatic crystals are oriented normal to the surface of the layers.

Psilomelane $\text{(BaO·MnO·MnO}_2·2\text{H}_2\text{O})$: Psilomelane is one of the important manganese minerals. Its occurrence is quite varied. Some psilomelane appears to be primary. Most of it
is secondary, however, and occurs in two forms: 1) intimately intermixed with pyrolusite, both of which are pseudomorphic after manganite, and 2) botryoidal masses which represent the recrystallization of manganite and/or pyrolusite aggregates.

Psilomelane is most abundant in the Benningfield property. In the Tarr and Harper mine area it is present in less quantity, and in places may be subordinate to manganite.

Pyrolusite (\(\text{MnO}_2\)): Pyrolusite is the most abundant manganese oxide. It constitutes probably better than 50% of the manganese minerals of the ores. Nearly all the pyrolusite is pseudomorphic after manganite; in a few sections, it was observed pseudomorphic after psilomelane.

Pyrolusite occurs both altered from, and altered to, psilomelane. This is due to varying conditions along the veins, which permitted the alteration to one form or the other, depending on local conditions. Until the stability relations of the manganese oxides are known, it is impossible to postulate what these conditions were.

Limonite (\(\text{Fe}_2\text{O}_3\cdot n\text{H}_2\text{O}\)): Limonite, near goethite in composition, occurs as thin stringers throughout the veins. It is most abundant in the Tarr and Harper mine area. Whether the original iron mineral was limonite is not known. In view of the probable low temperature of the veins, it is quite possible that it was the original mineral. The limonite was deposited late in the mineralization.

Barite (\(\text{BaSO}_4\)): Small bladed crystals of barite have been observed in the ore. The barite is spotty in its distribution,
and is rather rare. It is most common in the Benningfield ores.

Where present, barite occurs with calcite in the alternating calcite - manganese oxide bands.

Calcite \((\text{CaCO}_3)\): Calcite is the most abundant gangue mineral. It was syn- and post-ore. Syn-ore calcite occurs in coarse-grained bands alternating with the manganese oxide layers. Some of the calcite bands show minor replacement by crystals of manganite. Post-ore calcite occurs in coarse-grained veinlets cutting the ore.

Why the calcite in the limestone of the fault gouge should be replaced by the manganese oxides, while calcite was being deposited with the oxides, appears to be a surface energy phenomenon. The calcite in the limestone gouge is fine-grained and considerably strained, and would possess a higher surface energy and a greater tendency to go into solution than the coarse-grained, relatively unstrained calcite occurring in the manganite-calcite bands. Thus, a surge of the mineralizing solution precipitated manganite in the open spaces and replaced the limestone gouge with manganite. The limestone passing into solution apparently saturated it with calcite which was precipitated as a coarse-grained layer on top of the manganite. A later surge of the mineralizing solution would continue to deposit manganite in the open spaces, and selectively replace the limestone gouge because of its greater solubility. This would result in the gradual substitution of coarse calcite for the finer limestone gouge.
Paragenesis

The paragenesis of the manganese ores is as follows:

Manganite __________________________
Psilomelane _______________________
Pyrolusite _________________________
Limonite _________________________
Barite ________________
Calcite __________________________________________

Chemical Composition of the Ores

Chemical analyses of the ores were made in conjunction with milling tests conducted by the U. S. Bureau of Mines (Dean, 1952). The analyses were:

<table>
<thead>
<tr>
<th>Lot</th>
<th>Mn</th>
<th>Fe</th>
<th>SiO₂</th>
<th>Insol</th>
<th>CaO</th>
<th>Ba</th>
<th>Al₂O₃</th>
<th>Zn</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>26.0</td>
<td>1.5</td>
<td>40.4</td>
<td>43.6</td>
<td>2.8</td>
<td>3.36</td>
<td>3.6</td>
<td>nil</td>
<td>0.009</td>
</tr>
<tr>
<td>B</td>
<td>33.6</td>
<td>0.9</td>
<td>21.8</td>
<td>25.5</td>
<td>1.3</td>
<td>6.50</td>
<td>5.3</td>
<td>nil</td>
<td>0.005</td>
</tr>
<tr>
<td>C</td>
<td>25.1</td>
<td>8.1</td>
<td>25.6</td>
<td>28.7</td>
<td>3.8</td>
<td>2.7</td>
<td>3.6</td>
<td>nil</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Genesis of the Deposits

The manganese deposits are epithermal deposits of probable Tertiary age. While in the immediate area it is not possible to date the deposits closer than post-middle Cambrian and pre-Gila, similar deposits on the east side of the San Pedro Valley are post-Paleozoic, probably post-Cretaceous, and pre-middle Tertiary. Further, the fault system containing the deposits in the Putnam Wash area is more characteristic of the pre-Gila deformation than any other.
In the absence of any evidence to the contrary, manganite is believed to be the chief primary ore mineral in the deposits. In this case, the genesis suggested by Savage (1936) is applicable to the Putnam Wash deposits. Manganese is transported as the bicanbonate in slightly acid solutions. When the solutions become slightly alkaline by reaction with the limestone gouge and wallrock, unstable manganous hydroxide, Mn(OH)$_2$, will form and remain in solution. Under these circumstances, the manganese may be considered to exist in the solution as manganese bicarbonate and manganese hydroxide in unstable equilibrium.

The manganese hydroxide may be oxidized and precipitated as manganite, MnO(OH)$_2$. This in turn readily oxidizes to pyrolusite, MnO$_2$. The oxidation of manganite to pyrolusite is believed to be chiefly an effect of near surface oxidation. However, some of the oxidation could have taken place as a phase of ore reposi-
tion. No criteria were observed that would indicate the stage in which the alteration predominantly took place.

The ore solutions were, therefore, characterized by 1) low temperature and slight acidity; 2) abundant bicarbonate and manganous ions; 3) minor amounts of barium and sulphate ions; 4) unknown amounts of calcium ions. The latter is indetermin- nate, because much of the calcite now observed in the deposit could be derived from the limestone present. What other ions may have been present in the solutions is not known.
Manganese Deposits

Benningfield Property; NW^1/4, SE^1/4, SE^1, section 8: A northwest-striking fault that dips vertical to 75 degrees to the southwest, brings Dripping Spring quartzite against Nescal limestone and diabase in this area. The fault is mineralized, and it has been prospected by a small pit and two tunnels, one of about 15 feet and the other of about 70 feet. The ores of lots A and B given in the analysis were from this area.

A short offshoot lying to the southwest of the main fracture has also been mineralized. It has not been prospected.

NW^1/4, SW^1/4, SE^1, section 8: At this location a prospect tunnel has been driven on two narrow manganese-bearing faults cutting the Gila conglomerate. In all, three large manganese-bearing faults were observed at this location; two dipping to the east (on which the tunnel was driven), and another lying to the west and dipping west. In addition, numerous smaller faults containing manganese and calcite are present.

The deposition of the manganese in these faults was entirely from surface waters. The secondary nature of the mineralization is indicated by the disappearance downward of manganese along the smaller faults, and by the fact that many of the beds in the Gila, distant from the manganese-bearing faults, are cemented by manganese oxides. The source of the manganese was the deposits on the north side of Putnam Wash.

It is doubtful that the manganese in the Gila could ever be of economic importance.

NW^1/4, NE^1/4, SW^1/4, and SW^1/4, SE^1, NE^1, section 8: Several
prospect pits have been opened along a fault of northwest strike and steep southwest dip. The fault is mineralized throughout its length, but manganese occurs in quantity (and then not in large quantity) only where sediments, particularly limestone, have been involved in the brecciation. The character of the ore is the same as that in the Tarr and Harper mine area.

Hydrothermal alteration is abundant throughout this zone. It shows, however, no clear spacial relation to the manganese ore; most, but not all, of the faults that served as channel-ways for the alteration solutions strike northeast. The manganese appears to be the result of a period of hydrothermal activity somewhat later than the alteration.

\(\text{SW}_4, \text{NW}_4, \text{NW}_4\), section 8: Manganese occurs along a fault zone about four feet wide which crops out on the west side of the wash. The fault strikes \(N 60^\circ W\) and dips 50 degrees southwest. A prospect pit has been opened on the outcrop. The fault may be a continuation of the fault described at the last locality.

Manganese occurs in pods replacing diabase. Considerable hydrothermal alteration is also present, but it is apparently independent of the manganese mineralization except in so far as the two phenomena utilized similar channels. The alteration in the diabase is confined to the footwall of the fault.

\(\text{NE}_4, \text{SW}_4, \text{NW}_4\), section 8: a short northwest-striking fault has brecciated Dripping Spring quartzite which was then cemented by manganese. A minor occurrence.
Crescent claims; Tarr and Harper mine: The center of manganese mineralization is in a northwest-trending wash in the south-central portion of section 8. The wash is on the north side of Putnam Wash and drains into the latter.

Two faults are of importance in the area. One, which contains the main vein, crops out on the east side of the wash. The vein ranges in width from 3 to 20 feet. Horses of barren country rock are common where it is widest. Ore shoots have been worked on the middle and northern portions of the vein. The vein strikes north 35-45 degrees west, and dips 45 degrees northeast. Slickensides on a horse block exposed on the footwall of the inclined shaft rake 27 degrees south. This represents one of the least movements along the fault. Throughout the manganese zone the fault follows the Mescal-Troy contact rather closely, although it breaks away from the contact and into the limestone at its northern and southern outcrops.

The other fault crops out on the west side of the wash, and marks the contact between the Troy quartzite and diabase. Only minor mineralization has occurred along this fault, which strikes northwest and dips southwest. It is later than, and displaces, the main vein.

The ore is typical of the manganese ore throughout the Putnam Wash area. Soft masses of pyrolusite and psilomelane, present either as relatively pure pods or cementing and replacing breccia, occur in shoots throughout the vein. The ore
is commonly cut by small limonite and calcite veins. Analysis C, pp. 58, is representative of the ore.

The workings are shown in plates V, XXI - XXV. The workings seldom cut outside the vein. Offsets of the vein by cross faults are not common, and those observed do not completely cut off the vein.

History: The Tarr and Harper mine was first described by Jones (1919). According to Jones, the deposits were first worked in 1917 by the Arizona Rare Metals Company, which produced 408 tons of ore. In 1918, R. D. Harper operated the mine, and up to the time of Jones' visit near the end of April, had shipped 4 carloads of ore and was loading the fifth. The ore was hand-sorted and screened to give a product carrying 40% manganese.

How long after April 1918 the deposits were worked is unknown. They were probably shut down following the decline in metal prices at the end of World War I.

No further record of production is known until 1952. The deposits were worked for a few months in the summer of 1952 by L. M. Beam and G. Ishimoto, lessees, who mined several tons of ore for shipment to Henderson, Nevada. The property has been inoperative since September, 1952.

The claims, recorded as Crescent 1-5 at Florence, Arizona, are owned by T. C. Kinsey of Mammoth, Arizona.

Future Mining: The writer estimates that 5,000 tons of ore of the grade shown in the analyses on page 58 could be readily developed in the Crescent workings, with fair prospects
for considerably greater production. However, the ore itself is not of sufficiently high grade to constitute a directly marketable product. Concentration tests were carried out on the ores given in the chemical analyses by the U.S. Bureau of Mines (Dean, 1952). For the Benningfield ores, lots A and B, they conclude:

1) The Benningfield ores were readily amenable to concentration by gravity methods.

2) By tabling ore A, a product was made with a manganese recovery of 59% that would, when sintered, assay plus 48% manganese.

3) Combined jigging and tabling of sample A recovered 78.4% of the manganese in combined products that sintered 46.5% manganese.

4) Combined jigging and tabling of sample B recovered 78.4% of the manganese in a product that, when sintered, assayed 53.7% manganese.

5) Flotation methods of beneficiating the ore proved inferior to gravity methods. High grade products were not obtained and the recovery of the manganese was low.

6) Over-all recoveries of high-grade concentrates from the deposit as a whole depend on the proportions of A and B ore present.

For the ores typical of the Tarr and Harper mine (lot C), they conclude:

1) The Orsen Branch ore is of intermediate grade (25.19% Mn) and is amenable to concentration, but relatively complex methods of treatment are required owing to the intimate association of iron and manganese oxides.

2) Combined jigging, tabling, and magnetic separation recovered 82.9% of the manganese in a product that sintered to plus 48% manganese.

3) Selective flotation employing a fatty-acid collector recovered 63.1% of the manganese in a concentrate that, when sintered, assayed 48.2% manganese.

4) Jigging of minus-3 mesh ore recovered 96.1% of the manganese in a product that sintered to plus 35% manganese.
REGIONAL CORRELATION

Introduction

Before giving a resume of the geologic history of the San Pedro-Aravaipa area, a few preliminary statements are necessary on the data that formed the basis for the present conclusions. The ideas presented in the following sections are based on personal observations and published reports, particularly of Kiersch (1947), Kuhn (1940), Peterson (1938), Ransome (1919), Ross (1925, 1 and 2), Steele (1948), and Wilson (1930; 1941; 1951). Discussions of the region with L. A. Heindl proved invaluable. The conclusions presented are provisional pending further study.

Structural Blocks

The writer postulates the existence of a number of structural blocks in the area, which are shown in Plate XXVI. In the east is the Pinaleno block, divided into the Graham sub-block and the Santa Teresa sub-block. To the north is the Stanley block. Together these blocks are referred to as the eastern unit. The central unit consists of the Galiuro block to the south, and the DSM (Dripping Spring - Mescal) block to the north. The Galiuro block is separated from the Pinaleno block by the Aravaipa block. The western unit consists of the western Tortilla and eastern Tortilla blocks, the Black Hills block, and the Catalina block, which is divided into the northern and southern sub-blocks. The San Pedro block occurs between the western and central units.
The structural blocks are characterized by a greater or lesser independence of reaction to applied stress with respect to the neighboring blocks. The blocks show differential uplift; different types of structure develop in the different blocks; and they may exhibit different igneous histories. Structural deformation, largely by faulting, increases in intensity and quantity near the margins of the blocks. Thus the boundaries are not sharp as drawn on the map.

It is possible that the Aravaipa and San Pedro blocks do not exist as blocks, but may simply represent the larger zones of deformation between the eastern, central, and western units. What evidence is available indicates that deformation is much greater throughout these blocks than it is throughout the other blocks.

The units are series of blocks each of which has acted more or less as a unit through portions of upper Cretaceous-Tertiary time. There has been a tendency, not without reversals, for the blocks of the unit to act less independently and more as a unit as time has progressed. Thus early in the Laramide deformation, the contact between the northern and southern sub-blocks of the Catalina block was the locus for the intrusion of the Leatherwood quartz diorite and its associated structural effects. Since then, the two sub-blocks have largely acted as a single block. Similarly, the intrusion and deformation in the Stanley-Aravaipa area resulted in the union of the Stanley and Pinaleno blocks, which have acted largely as a unit since early Tertiary time.
The relation of the eastern Tortilla, Galiuro, and Stanley blocks to the DSM block is not clear. From the Gila River north to Globe, the structure becomes increasingly complex, and much more work is necessary before the regional relations can be clearly understood. However, the DSM block appears to have acted as a unit with each of its neighbors at various times. Most frequently, it has acted as a unit with the Galiuro block (the central unit). The deformation and intrusion in the Saddle Mountain-Christmas area may have served to "weld" these blocks together.

Geologic History

1) Pre-Cambrian- geosynclinal sedimentation, predominantly clastic, with associated volcanism (the Pinal sediments).

2) Pre-Cambrian- deformation of the Pinal geosyncline; folding, faulting, metamorphism, granitic intrusion.

3) Pre-Cambrian- erosion, with nearly complete removal of the Pinal schist.

4) late Pre-Cambrian- deposition of the Apache group.

5) early Cambrian- erosion. Tilting(?).

6) middle Cambrian- thrust faulting and intrusion of diabase. Erosion.

7) middle to upper Cambrian- deposition of sediments, predominantly clastic. Deposition may not have occurred throughout entire area.

8) Ordovician to Silurian- erosion. Tilting(?) and faulting(?).

9) Devonian to Permian- deposition of marine sediments, predominantly limestones with some shales and sandstones.

10) Permian to Cretaceous- erosion, Folding(?) and faulting.

11) upper Cretaceous- deposition of Cretaceous sediments, predominantly clastic, followed by extrusion of andesitic volcanics.
12) **late Cretaceous to Eocene—** Laramide deformation, early phase: folding, faulting, intrusion of Copper Creek granodiorite stock; Leatherwood quartz diorite stock; San Manuel quartz monzonite stock; Aravaipa granite and granodiorite batholith. Intrusion of diorite dikes in Saddle Mountain-Christmas-Banner area. Leatherwood and San Manuel stocks intruded by later diabase. Laramide deformation, late phase: initiation of differential movement among the units and major blocks. Normal faulting. Thrust faulting; east-dipping thrusts in northern Black Hills, Aravaipa-Stanley, east side of Catalina Mountains; west-dipping in Dripping Spring Mountains, Galiuro Mountains near Table Mountain. Thus in the San Pedro Valley, the thrusts dip toward the center of the valley. Some igneous dike intrusion.

13) **Oligocene—** deposition of Oligocene beds now found near Redington, Sombrero Butte(?), Tiger(?), Saddle Mountain(?), and Aravaipa(?). Beginning of uplift of eastern and western units in upper Oligocene. Volcanism, with extrusion of andesites and basalts now found in the Catalina Mountains, Black Hills, Galiuro Mountains, and Turnbull Mountains, occurred near end of Oligocene.

14) **Miocene—** faulting and tilting of Oligocene sediments and volcanics. Uplift and erosion continued in eastern and western units. Deposition of oldest Gila. A thick (greater than 5,000 feet) series of tuffs, andesites, and rhyolites extruded in the Galiuro block, centering near the south end.

15) **middle or late Miocene—** continued volcanism in Galiuro block. Intrusion of rhyolite at Tiger, Putnam Wash, Banner(?), and Aravaipa-Stanley(?).

16) **early Pliocene—** extrusion of basalts and andesites in the Galiuro block. Deposition of Gila (equivalent to Whitetail?).

17) **Pliocene to Pleistocene—** Uplift and erosion of the central unit, and continued uplift and erosion of the eastern and western units. Major period of Gila deposition. Uplift of mountains to near present height.
18) Pleistocene to Recent—erosion of terrace levels in Gila conglomerate. Faulting. Uplift of segments of the blocks and the blocks themselves; e.g., Sombrero Butte segment, Black Hills block.

**Metallogenic Epochs**

Three periods of mineralization are recognized; these are:

1) **late Cretaceous to Eocene—Laramide, early phase:** copper deposits at Copper Creek, Marble Peak, San Manuel, and Aravaipa. Lead-silver at Copper Creek (Blue Bird). Pyritic gold at Saddle Mountain (?). Laramide, late phase: gold-tungsten deposits of Campo Bonito, Piety Hill, Antelope Peak, Black Hills. Manganese deposits of the Black Hills, Table Mountain.

2) **middle to late Miocene—Lead-zinc deposits, with gold and silver, at Tiger, Aravaipa-Stanley, Saddle Mountain(?), Banner(?).**

3) **early Pliocene—gold deposits of the Rattlesnake district; Clark district(?). Lead-silver deposits of upper Copper Creek basin (?), may be Miocene.**

A fourth period of mineralization would be the formation of the nonmetallic asbestos deposits in the middle Cambrian.

The districts mentioned above are plotted on Plate XXVI.
REFERENCES


PLATE VI

Panorama of the Putnam Wash area. View looking west from state highway 77.
Panorama of the north portion of the Putnam Wash area looking northwest from the San Pedro River. Putnam Wash and Lookout Mountain appear in the left central part of the photograph. From left to right the sequence is: 1) Dripping Spring quartzite (dark gray) forming a northeast dip slope off Lookout Mountain; 2-2 a ridge of Troy quartzite; 3-3 a ridge of Martin limestone (light gray); 4, Cretaceous (?) outcropping in the saddle; 5) Martin limestone outcropping at the base of the ridge and separated from the Cretaceous (?) by a thrust fault; 6) Cambrian (?) outcropping on the ridge and separated from the Martin limestone by a thrust fault; 7) Pinal schist outcropping and separated from the Cambrian (?) by a thrust fault; 8) Gila conglomerate.
PLATE VIII

Scanlan conglomerate. The conglomerate consists of angular fragments of white quartz.

PLATE IX

Barnes conglomerate. Lower right corner of the photograph illustrates the appearance of the conglomerate on a plane surface. The other portions of the photograph show the pebbles in the conglomerate weathering out in relief. A six-inch ruler provides a scale.
Mescal limestone. The banding in the limestone is characteristic.
PLATE XI

View of the northwest ¼ of section 8, Plate I, illustrating the intrusion of diabase into the Troy quartzite. The photograph was taken from the crest of Lookout Mountain. The geology is drawn on the upper photograph.

The white spot below the upper Mescal limestone outcrop immediately left of center is the dump from an asbestos prospect.

Symbols

M - Martin limestone  ML - Mescal limestone
T - Troy quartzite  DS - Dripping Spring quartzite

D - diabase
PLATE XII

Cambrian (?) limestone. Note the abundance of cherty layers.

PLATE XIII

Basal Cretaceous (?) conglomerate. The conglomerate is composed of angular fragments of silicified Devonian Martin limestone.
PLATE XIV

Intrusion of the Oracle granite into the Pinal schist. The foliation of the schist is vertical. A dike of the Oracle granite cuts the schist in the left half of the photograph. The contact is shown in red.

PLATE XV

The eastern rhyolite porphyry dike (white) intruding the Oracle granite (gray). The dike dips west. Mullion structure is present on the hanging wall of the dike.
PLATE XVI

Hydrothermal alteration in the diabase along a fracture. The diabase is dark gray, the altered rock light gray, and the vein filling white or black. Most of the vein filling is calcite, in places iron-stained. Note the sharp line between unaltered and altered diabase along the lower left margin of the alteration.

PLATE XVII

Jointing in the granite exposed along Putnam Wash. The hammer provides a scale. Three joint sets are apparent; one dipping toward the observer, another dipping to the left, and a third dipping to the right.
Faulting in the Gila conglomerate. The upper photograph illustrates the sharp walls which characterize faults in the Gila conglomerate. The hammer provides a scale.

The lower photo shows the reversal in dip caused by this fault. The red lines indicate the direction of dip of the conglomerate beds.
The Putnam Wash fault exposed along the north side of Putnam Wash. The upper photograph illustrates the fault bringing Gila conglomerate over Oracle granite. The lower photograph illustrates the antithetic faults associated with the Putnam Wash fault. The red lines indicate the fault plane.
PLATE XX

Asbestos prospect north of Putnam Wash. Asbestos zone (A, top of photo) is separated from diabase (black, bottom of the photo) by limestone (L) and tactite (T). Hammer provides a scale.

PLATE XXI

Asbestos prospect south of Putnam Wash. Tactite (T) separates the asbestos zone (A) from diabase (black, left of the photograph). Recrystallized limestone (L) extends above the asbestos zone.
PLATE XXII

Crescent claims, Tarr and Harper mine area, viewed from the south side of Putnam Wash. The workings are in the canyon in the right center of the photograph. The manganese vein crops out prominently on the right (east) wall of the wash.

PLATE XXIII

Headframe of the inclined shaft. Ore loading station is seen in the right center of the photograph. The manganese vein crops out prominently behind the inclined shaft, and above the ore loading station.
PLATE XXIV

First tunnel, Tarr and Harper mine. Manganese vein crops out to the right and left of the tunnel, and in the foreground in front of the tunnel. Mescal limestone (white) crops out in the left half of the view. Note the sharp contact between the vein and the Mescal limestone exposed in the left center part of the photograph.

PLATE XXV

Vertical shaft and second tunnel, Tarr and Harper mine. The collar of the shaft is exposed in the lower right half of the photograph. Two timbers in the second tunnel are visible behind the Palo Verde in the center of the left half of the photograph.
7 pieces
SEDIMENTARY ROCKS

Tertiary-Quaternary

- al
  Gila conglomerate and alluvium

Pre-Cambrian

- dsq
  Barnes conglomerate and Dripping Spring quartzite

IGNEOUS ROCKS

Tertiary

- Trhy
  Rhyolite

- Tv
  Volcanics

Laramide(?)

- gr
  Granite

Middle Cambrian

- db
  Diabase

Pre-Cambrian

- Gr
  Oracle granite

Faults

Strike and dip

Geology by:

J.R. Rillebrand, 1952
A PORTION OF THE TOPOGRAPHIC MAP OF ARIZONA
CONTOUR INTERVAL 328 feet
SCALE 1:500,000
MINE WORKINGS, CRESCENT CLAIMS

TAPE and BRUNTON SURVEY
elevations referred to collar of shaft 1

VEIN

TUNNEL 2

SHAFT 2
(vertical, 34' deep)

TUNNEL 1

SHAFT 1
(inclined)

INACCESSIBLE
approx 60' deep

ROPE OUTLINE
25' level

GEOLOGY
LEVEL

SECTION a-a
Geology modified from the geologic map of the state of Arizona

First order structural boundaries between blocks

Second order structural boundaries between blocks

Third order structural boundaries between blocks

Copper Districts
1) San Manuel
2) Copper Creek
3) Marble Peak

Gold-Tungsten Districts
4) Antelope Peak
5) Black Hills
6) Campo Bonito
7) Piety Hill

Lead-Zinc-Silver-Copper Districts
11) Saddle Mountain
12) Christmas
13) Banner
14) Mammoth
15) Copper Creek Basin
16) Klondyke
17) Aravaipa
18) Stanley

Manganese Districts
8) Putnam Wash
9) Black Hills
10) Table Mountain

Gold Districts
19) Rattlesnake
20) Clark