THE GEOLOGY AND ORE DEPOSITS OF THE INDIANA
MINE AREA, PIMA COUNTY, ARIZONA

by

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submitted to the faculty of the
Department of Geology
in partial fulfillment of
the requirements for the degree of

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1951

Approved: ________
Director of Thesis, 6-29-51
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Chapter I

Introduction

Location, Culture, and Transportation

The Indiana mine is in the Silver Bell mining district in the northern part of the Waterman Mountains which are about 30 miles northwest of Tucson in Pima County, Arizona (Fig. 1). The area covered by this report includes parts of Sections 19, 30, and 31 of Township 12 South, Range 9 East, and parts of Sections 13, 24, and 25 of Township 12 South, Range 8 East, which are based on the Gila and Salt River Base Line and Meridian. The 15 patented claims of the Indiana-Arizona Mining Company are all located inside the Papago Indian Reservation except portions of the four most eastern claims. The main shaft of the Indiana mine is about 2,730 feet northwest of Silver Hill which is the highest peak in the Waterman Mountains.

The nearest town is Marana which has a population of about 900 people. Marana is approximately 16 miles northeast of the Indiana mine and is located on state highway 81. The El Paso Natural Gas Company has a pumping station nearly nine miles east of the Indiana mine where about 60 people live. Approximately one and a half miles north of the Indiana
mine is the American Smelting and Refining Silver Bell drilling camp. There are five metal quonsets and three small buildings at this camp. The buildings at the Indiana mine include three for living quarters, a hoist house, and a shop. The mine is equipped for small scale leasing.

The route to the Indiana mine goes north from Marana along state highway 84 for four and three-tenths miles and then west along an oiled road for two and one-tenth miles. Here the route turns south over an improved dirt road for five and one-tenth miles and then west for 10.2 miles. The mine is located in a saddle in the mountains, and the buildings are visible from the point where a narrow branch road goes left two and one-tenth miles to the mine. In dry weather the roads are easily passable, but during the rainy season which is in July and August the roads are sometimes impassable for a day or two.

In the past, ore shipments have been trucked to Naviska which is a loading point on the Southern Pacific Railway about three miles north of Marana. From Naviska the ore was shipped to the Eagle Pitcher mill at Sahuarita, to the American Smelting and Refining Smelter at El Paso, Texas, or to the Shattuck Denn Mining Corporation at Bisbee, Arizona. The trucking is over relatively flat roads except for the first quarter of a mile from the mine, where the road has
about a six percent downgrade from the mine.

Topography

Arizona has been divided into three physiographic provinces by Ransome 1/; the Plateau Province which covers the northern and northwest part of the state; the Mountain Province which takes in the mountainous belt from the southeast part of the state to the northwest corner of the state; and the Desert Region which is the area southwest of the Mountain Province (Fig. 1).

The Indiana mine area is in the eastern part of the Desert Region. In general the Desert Region is characterized by narrow mountains that have northwesterly trends and are separated by broad flat valleys filled with alluvium. The northern part of the Waterman Mountains has a northwest trend; however, in general, the northwest trend of the mountains is more pronounced west of the Waterman Mountains. In the Watermans the ridges usually parallel the strike of the beds, and dip slopes are common.

Throughout the area the massive limestones, quartzites, and granite form the cliffs and prominent ridges, while the
shales, thin-bedded limestones and quartzites, and alaskite form the gentle slopes and valleys.

All the streams in the area are intermittent but flow with considerable velocity during cloudbursts. The direction of drainage is controlled to a large extent by the strike of the beds. That is, a stream may follow the strike of a bed for several hundred feet, cut across the bed, and then continue along the strike of another bed in the original direction. In some places where the drainage cuts across the bedding, faults are the controlling factor.

The drainage to the east flows into the Avra valley which drains north into the Santa Cruz river. The drainage to the west flows into an unnamed tributary which drains north into Greens reservoir.

The highest point in the area is Silver Hill which has an elevation of about 3,600 feet above sea level and is about 1,200 feet above the surrounding plains.

Climate

The Indiana mine area has a semiarid climate similar to the climate at Casa Grande which is about 40 miles northwest of the area and about 1,000 feet lower. The following data were recorded at Casa Grande 2/.

2/ Smith, H. V., The Climate of Arizona, Bull. 197, Agricultural Experiment Station, Univ. Arizona, July 1945.
The mean average temperature is about 71 degrees. The mean maximum temperature is about 107 degrees in July with a mean minimum temperature of 34 degrees in December.

The mean average precipitation is seven and four-tenths inches. The precipitation varies from an average low of six-hundredths inches in May to a high of one and eleven-hundredths inches in July.

Flora

The flora of the area is of the desert variety which includes catclaw, creosote bush, greasewood, sage, ironwood, and mesquite. There are many types of cacti which include cholla, prickly pear, yucca, hedgehog, pincushion, ocotillo, barrel, and sahuaro. The sahuaros are especially abundant on the lower plains. Because of the low amount of precipitation, there is very little grass.

Previous Work

The Waterman Mountains were mapped on a scale of eight miles to the inch in 1924 by E. D. Wilson and C. Lausen as
shown on the Geologic Map of the State of Arizona 3/, but no

detailed study of these mountains has ever been made.

In the past, geologists from various mining companies
have examined the Indiana mine, but no report has ever been
published. None of the examinations involved more than a
few days and, therefore, could not have been complete.

From 1947 to 1950 the American Smelting and Refining
Company did a considerable amount of exploratory drilling
and geological mapping in the Silver Bell Mountains, about
six miles north of the Waterman Mountains. The Silver Bell
Mountains are in an old mining district which produced copper,
silver, and some gold. The result of drilling done by the
American Smelting and Refining Company has been to outline
the boundaries of a large low-grade porphyry copper deposit
which may be another large open pit copper producer.

Purpose and Scope of the Examination

This thesis was undertaken as partial fulfillment for
a Master of Science degree at the University of Arizona.
The field work was done during the summer, and the laboratory
work in the fall of 1950. About three months were spent in

3/ Darton, N. H., Geologic Map of the State of Arizona,
the area. Field work is being continued to the south for the purpose of eventually mapping the entire Waterman range.

The area is not covered on any published topographic map except on the Topographic map of the state of Arizona


which is drawn to a scale of one inch equals eight miles.

Since the scale of this map was too small, aerial photographs were used on which to map the geology and to prepare a larger scale base map. Photographs of the area were taken by the Buehman and Kurth studio in March, 1950, and have an average scale of one inch equals 715 feet.

The photographs were orientated by using a radial line plot with the north direction determined by solar observation. Contouring was done by sketching and by using a stereoscope and two floating lines. This method is described in detail by Desjardins \[\text{5/ Desjardins, L., Techniques in Photogeology, Am. Assoc. Petroleum Geologists Bull. No. 12, Vol. 34, Dec., 1950.}\]

A small pocket aneroid barometer was used to locate elevation control points throughout the area. The drainage, contours, and geology were transferred from the photographs to the base map with a vertical sketchmaster. To determine the average scale of the map a measured section line was used
which is about 9,000 feet long.

The area in the immediate vicinity of the Indiana mine was mapped with a plane table and alidade by using a scale of one inch equals 50 feet and a contour interval of 50 feet. All the mine workings were mapped by using a scale of one inch equals 20 feet.

A rock-color chart 6/ was used in the field to describe the rocks in the measured sections.

Acknowledgments

Grateful acknowledgments are due the faculty members of the University of Arizona, College of Mines, Doctors B. S. Butler, M. N. Short, A. A. Stoyanow, F. W. Galbraith, and J. Harshbarger, and Professor E. D. McKee for their valuable suggestions and helpful criticisms of the field work and of the manuscript.

As thesis advisor Dr. Short especially aided with the petrographic determinations and in the preparation of the maps. Dr. Galbraith was helpful during the preparation of the base map from aerial photographs. The paleontological identifications were made or verified by Dr. Stoyanow, who was also of
great assistance with the stratigraphic correlation.

Dr. Butler gave considerable aid in the interpretation of the structure and ore deposits. Professor McKee gave advice as to the proper manuscript forms.

Appreciative thanks go to the American Smelting and Refining Company who furnished the author and his family a quonset at the Silver Bell drilling camp without which living quarters would have been extremely poor. Especial thanks are due Mr. F. V. Richard and Mr. L. H. Chapman from the Tucson office for their wholehearted cooperation.

Mr. F. S. Christy, also of the American Smelting and Refining Company, assisted in measuring the ground lines for the underground maps.

Mr. S. J. Macneil, the owner of the Indiana mine, helped greatly by providing aerial photographs and also by supplying the food during the field season for the author and his family. Mr. Macneil, too, furnished all available company data and reports covering the Indiana mine.

Many thanks are due Mr. R. B. Mulchay, Consulting Geologist for Anaconda Copper Mining Company at Cananea, Mexico, for his visits to the area and for helpful suggestions concerning the field work and mine mapping.

Dr. E. D. Wilson, of the Arizona Bureau of Mines, first suggested the area as a thesis problem and gave many suggestions about the work. Mr. G. L. Dillard, caretaker at the
mine, was very helpful in supplying information about the past history and production.

Special thanks are due Olive N. Ruff, the author's wife, for operating the plane table during the field work and for helping to compile this manuscript.

More thanks go to many others who contributed time and effort to this thesis. Space does not permit mentioning all the names.
CHAPTER II

GENERAL GEOLOGY

Summary

The oldest formation of central Arizona, the Pinal schist, is not exposed in the Indiana mine area, but crops out about 25 miles to the northwest in the Slate Mountains. 7/

\[7/\text{Hogue, W. G., The Geology and Ore Deposits of the Northern Part of the Slate Mountains, Pinal County, Arizona, Master's Thesis, Univ. Arizona, 1940.}\]

The oldest rock in the Indiana mine area is the Precambrian Waterman alaskite. This rock crops out over a considerable area west of the Indiana mine.

Later Precambrian Waterman granite intruded the Waterman alaskite both as small dikes and larger irregular bodies. After the intrusion of the granite, there was a long period of erosion. The Precambrian Apache series may have been deposited and then eroded during the post Precambrian erosion interval, but there is no evidence to substantiate this idea. The alaskite and granite probably remained as a positive area until Early Middle Cambrian time.

Overlying the Waterman alaskite and granite are the Lower Middle Cambrian Troy quartzite, the Upper Middle Cambrian Cochise formation, the Upper Cambrian Abrigo formation, the
Upper Devonian Martin limestone, the Lower Mississippian Escabrosa limestone, the Lower Pennsylvanian Naco limestone and possibly some Upper Pennsylvanian limestones, the undifferentiated Permian formations, and the undifferentiated Cretaceous beds. This sedimentary series is apparently conformable but is separated by at least four disconformities. The beds are steeply dipping and have been disturbed greatly by faulting. The Cretaceous beds are the only rocks of Mesozoic age present in the area. Apparently the Paleozoic and Mesozoic rocks remained horizontal and undisturbed until at least the close of the Cretaceous period.

Probably during the Cretaceous-Tertiary (Laramide) interval the region was subjected to stresses which produced large, broad, northwest-southeast folds and also persistent high angle northwest-southeast faults. At this time the major tilting of the formations occurred. Slightly later faults striking east to northeast displace the northwest faults. The horizontal displacement of most of the east to northeast faults is about 100 feet. There are exceptions like the Waterman fault which has a horizontal displacement of about 900 feet.

Ore solutions rose along the east to northeast faults, probably in Middle Tertiary time, with apparently very little, if any, mineralization along the northwest faults. Evidently the east to northeast faults are tension faults and permitted easy circulation of the mineralizing solutions. The ore deposition was controlled not only by the east to northeast faults,
but also by the type of host rock. Rocks that produced open fractures under stress such as quartzites and thin-bedded limestones were good ore horizons. On the other hand, the more massive limestones healed readily after fracturing and did not allow free circulation of the ore solutions with the result that they were poor ore horizons. At the Indiana mine the ore occurs as a vein deposit with very little replacement of the host rock.

There has been only a small amount of post-ore faulting, probably of Late Tertiary age. Most of the post-ore faults have small horizontal displacements of from one to 50 feet.

Sedimentary Rocks

Troy Quartzite

The Troy quartzite, of Lower Middle Cambrian age\(^8\), is


the oldest sedimentary rock in the area and rests disconformably on Precambrian Waterman alaskite and granite.

At the base of the Troy quartzite near the south end of the area is a ten-foot bed of grayish to reddish-orange granule quartz conglomerate. Above the conglomerate are 175 feet of thin-bedded, medium to coarse-grained ferruginous quartzites with small lenses of conglomerate. Throughout the section many of the beds show
medium scale crossbedding. The particles in the Troy are, in general, sub-angular to sub-rounded.

The description of the Troy as measured at the south end of the area follows:

Upper Middle Cambrian. Cochise formation.

Lower Middle Cambrian. Troy quartzite.

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quartzite: whitish to pale red, medium to coarse grained, thin-bedded (1-2 feet), cross laminated (medium scale), weathers moderate brown speckled with black, somewhat pitted surface, cliff forming. ........ 175</td>
</tr>
<tr>
<td>2. Conglomerate: grayish reddish orange, thick-bedded (5-10 feet), granules to pebbles, sub-angular to sub-rounded, quartz, cliff forming. 10</td>
</tr>
<tr>
<td>Total thickness 185</td>
</tr>
</tbody>
</table>

Disconformity.

Precambrian. Waterman alaskite.

The Troy quartzite can be recognized easily because it forms rust to black massive cliffs. On dip slopes, light reflection from the relatively smooth surface of the quartzite gives it a shiny appearance.

The Troy quartzite was identified by its stratigraphic position and lithology, since no fossils were found in the formation.

At the base of the Troy the slopes are usually covered with quartzite float so that the contact with the underlying alaskite and granite is not easy to locate within 25 or 50 feet. Where observed, the contact between the Troy quartzite and the Waterman
alaskite or granite is usually distinct. In local areas there is a conglomerate along the contact.

The Troy quartzite decreases in thickness to the north, and a section of Troy measured at the north end of the Waterman Mountains was only 95 feet thick. At the north end the Troy quartzite rests predominately on Precambrian Waterman granite rather than alaskite.

Cochise Formation.

Conformably overlying the Troy quartzite is the Upper Middle Cambrian Cochise formation. The Cochise formation was divided into two units for mapping purposes, a lower part which consists of 288 feet of quartzites, limy shales, and limy sandstones, and an upper part which consists of 239 feet of thin-bedded limestone.

The sequence in the Cochise formation is as follows:

Upper Cambrian. Abrigo formation.

Upper Middle Cambrian. Cochise formation.

Upper Cochise.

<table>
<thead>
<tr>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet</td>
</tr>
</tbody>
</table>

1. Chert: medium light gray, aphanitic, thin-bedded (1 foot), weathers light to moderate brown, iron stained, rough, cliff forming. .... 2

2. Limestone: medium dark gray, aphanitic, thin-bedded (1 foot) whitish and rust colored silty irregular layers that are more resistant to erosion than the surrounding limestone, some irregular scattered chert layers, weathers medium gray, rough, cliff forming. ............... 14
<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Chert: medium light gray, aphanitic, thin-bedded (1 foot), weathers light to moderate brown, iron stained, rough, cliff forming. ...... 2</td>
</tr>
<tr>
<td>4. Limestone: medium dark gray, aphanitic, thin-bedded (1 foot), whitish and rust colored silty irregular layers that are more resistant to erosion than the surrounding limestone, some irregular scattered chert layers, weathers medium gray, rough, cliff forming. ............. 36</td>
</tr>
<tr>
<td>5. Concealed. .................................. 58</td>
</tr>
<tr>
<td>6. Limestone: medium light gray, aphanitic, thick-bedded (3 feet), weathers medium light gray, rough, cliff forming. ........................ 9</td>
</tr>
<tr>
<td>7. Limestone: medium light gray, aphanitic, thin-bedded (0.5 foot), weathers medium light gray, rough, slope forming. ..................... 13</td>
</tr>
<tr>
<td>8. Limestone: medium light gray, aphanitic, thick-bedded, (3 feet), some rust colored silty irregular layers, weathers medium light gray, rough, cliff forming. ..................... 12</td>
</tr>
<tr>
<td>9. Limestone: medium light gray, aphanitic, very thin-bedded (0.5 inch), very silty (whitish), weathers medium light gray, weathers into small pieces (2 inches), rough, slope forming. ....... 10</td>
</tr>
<tr>
<td>10. Limestone: medium gray, aphanitic, thin-bedded (1 foot), scattered white calcite veinlets (1/8 inch), weathers light to moderate brown, brown caused by brown silt in irregular layers, rough, cliff forming. ................... 5</td>
</tr>
<tr>
<td>11. Limestone: light gray, aphanitic, thin-bedded (1 foot), some chert lens both conformable with bedding and cutting across bedding, (1 foot wide, 30 feet long), very irregular some brown silty inclusions, weathers light gray, rough, cliff forming. ............................ 40</td>
</tr>
<tr>
<td>12. Limestone: light gray, aphanitic, thin-bedded (1 foot), large amount of silty layers in lower part grades into lesser amount at the top, weathers light gray, rough, cliff forming. ............. 15</td>
</tr>
<tr>
<td>Layer</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>13.</td>
</tr>
<tr>
<td>14.</td>
</tr>
<tr>
<td>15.</td>
</tr>
<tr>
<td>16.</td>
</tr>
</tbody>
</table>

**Total thickness of Upper Cochise:** 239 feet

**Lower Cochise**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Limy quartzite: medium gray, fine-grained, thick-bedded (3 feet), thin beds (8 inches) of shaly quartzite separate the thick beds; in the shaly beds are impressions that may be worm trails or concretions; weathers light to moderate brown, rough, cliff forming. 36 feet</td>
</tr>
<tr>
<td>2.</td>
<td>Limestone: medium light gray, aphanitic, very thin-bedded (3/8 inch), weathers yellowish gray, weathers into small pieces (1 inch), rough, slope forming. 15 feet</td>
</tr>
<tr>
<td>3.</td>
<td>Limy shale: dusky yellow, very thin-bedded (1/4 inch), some paper thin beds, micaceous, a few thin-bedded (2 feet) medium light gray limestone beds, weathers dusky yellow, slope forming. 22 feet</td>
</tr>
<tr>
<td>4.</td>
<td>Limy sandstone: medium gray, very fine-grained, thin-bedded (0.5 foot), concretions which look like worm trails, weathers dusky yellow, rough, cliff forming. 12 feet</td>
</tr>
</tbody>
</table>
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Thickness (Feet)

5. Quartzite: speckled medium light gray, very fine-grained, massive, medium scale cross bedded (2 feet), weathers purplish brownish gray to black, cliff forming. ................. 7

6. Limy shale: dusky yellow, very thin-bedded (1/4 inch), micaceous, weathers dusky yellow, slope forming. ........................................ 15

7. Quartzite and limy shale: quartzite speckled medium light gray, very fine-grained, thin-bedded (0.5 foot), weathers purplish brownish gray to black. Limy shale, dusky yellow, very thin-bedded (1/4 inch), some paper thin beds, micaceous. The shale and the quartzite are interbedded, cliff forming. ................. 6

8. Limy shale partly covered: dusky yellow, very thin-bedded (1/4 inch), some paper thin beds, micaceous, weathers dusky yellow, smooth, slope forming. ........................................ 18

9. Quartzite: speckled medium light gray, very fine-grained, thin-bedded (2 feet), weathers purplish brownish gray to black, smooth, cliff forming. ............................ 2

10. Limy shale: dusky yellow, very thin-bedded (1/4 inch), some paper thin beds, micaceous, smooth slope forming. ........................................ 6

11. Quartzite: white, fine-grained, thin-bedded (1 foot), weathers very light gray, smooth, cliff forming. ........................................ 1

12. Limy sandstone: buff, very fine-grained, very thin-bedded (2 inches), weathers buff, smooth, slope forming. ........................................ 23

13. Quartzite: light olive gray, medium grained, thin-bedded (1 foot), weathers moderate brown to black, rough, cliff forming. ........................................ 3

14. Limy sandstones, quartzites, and limestones partly covered: interbedded, thin-bedded (0.5 foot), weathers buff to rust, slope forming. ............................ 86
15. Quartzites and sandstones: dark reddish brown coarse to fine-grained, thin-bedded (1 foot), highly ferruginous, weathers purplish black, cliff forming. ......................... 6

16. Liny sandstones, quartzites and limestones partly covered: interbedded, thin-bedded (0.5 foot), weathers buff to rust, slope forming..30

Total thickness of Lower Cochise. 288

Total thickness of Cochise formation. 527

Lower Middle Cambrian. Troy Quartzite.

In the Waterman Mountains the upper part of the Cochise formation is easily recognized by the light to medium brown silty inclusions which weather out of the limestone. In weathering the limestone forms a very sharp hackly surface. Units 14 and 16 are excellent markers throughout the area.

The lower part of the Cochise is recognized by the large amount of thin-bedded quartzites, sandstones, and shales. The unit can be confused only with the shales in the Abrigo formation when a limited amount of the formation is exposed. Ripple marks with ratios of nine to one, which indicates deposition by water, were observed in the sandstone.

The Cochise formation was correlated on stratigraphic position and lithology since no fossils were found in it.

According to Stoyanow 9/ and as observed by the author in

the Swishelm Mountains, the upper part of the Cochise formation is characterized by blue limestone and the lower part by shales and sandstones.

Following is the section in the Whetstone Mountains as described by Stoyanow:

Upper Cambrian. Abrigo formation.

Middle Cambrian. Cochise formation.

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Limestone: blue, upper part beds of oolitic and pisolithic limestone, some shale beds, cliff forming.</td>
</tr>
<tr>
<td>2. Shales and limestones: yellow, pink, gray, white, purple, buff, and red, rubbly limestone at top.</td>
</tr>
<tr>
<td>3. Sandstones: pink and reddish, thin-bedded.</td>
</tr>
<tr>
<td>Total thickness</td>
</tr>
</tbody>
</table>

Middle Cambrian. Troy quartzite.

The upper part of the Cochise from the Waterman Mountains correlates very well with the upper unit in the Whetstone Mountains, except for thickness, and the lower part of the Cochise in the Waterman Mountains correlates with the lower two units in the Whetstone Mountains, except for thickness.

In Peppersauce Canyon, about 4.5 miles northwest of the Waterman Mountains, the Santa Catalina formation separates the Abrigo formation from the underlying Troy quartzite. Following is the section as described by Stoyanow 10/ at Peppersauce Canyon:

Upper Cambrian. Abrigo formation.

Middle Cambrian. Southern Belle quartzite.

Quartzite: White, massive, cliff-forming. .......... 26

Middle Cambrian. Santa Catalina formation.

Quartzites, shales, and sandstones: alternating, thin-bedded, rusty quartzite, yellow and red sandstone, and brown and green micaceous shale. .......... 415

Middle Cambrian. Troy quartzite.

Although the Santa Catalina and the Cochise formation are the same age and approximately the same thickness, the Santa Catalina formation lacks the upper unit of thin-bedded limestone.

A Cambrian section measured by Hogue in the Slate Mountains 11/:


about 25 miles northwest of the Waterman Mountains, also lacks the upper limestone unit.

Evidently a facies change took place in Middle Cambrian time to the north and east of the Waterman Mountains. This produced a sandy facies near the shore and a limestone facies farther from the shore. The limestone facies did not continue very far north of the Waterman Mountains but did swing southeast through the Picacho de Calera Hills 12/ and the Whetstone Mountains.

12/ Stoyanow, A. A., personal communication, April, 1951.
Upper Cambrian

Abrigo Formation.

The Abrigo formation conformably overlies the Cochise formation and is 104 feet thick. This formation consists of sandstones, shales, and limestones. The lower 17 feet of the formation is a very fine-grained, grayish orange pink, limy sandstone. It is very thin-bedded (1 inch), and weathers to a light brown or buff with a medium rough surface and is slope forming. The upper 87 feet consists of interbedded sandstones, shales, and limestones. The sandstone and shale beds are usually 15 to 20 feet thick, and the interbedded limestones are usually one foot thick.

The Abrigo formation can be recognized because of the buff to dusky yellow-green sandstones and shales. The shaly members show frequent concretions or worm casts.

Fragments of large unidentifiable trilobites were found 45 feet from the base of the formation in a four-inch bed of oolitic limestone. The limestone is silty, has a light gray color and weathers light buff.

Fragments of small unidentifiable trilobites were found 47 feet from the base of the formation just above the large trilobites. These smaller trilobites were found in a six-inch bed of crystalline light gray limestone which weathers light buff.
No trilobites were found on the weathered surface, but when the limestone was broken, casts and molds were obtained.

The lithology, trilobite fragments, and worm casts identify this formation as Cambrian. The stratigraphic position identifies it as the Upper Cambrian, Abrigo formation.

Martin Limestone.

The Martin limestone is 330 feet thick and rests disconformably on the Abrigo formation. The Martin limestone, as in most areas where it crops out, contains abundant and well-preserved fossils. In the Waterman Mountains the formation is characterized by gray limestones which weather light yellowish orange. The section is described as follows:

Lower Mississippian. Escabrosa limestone.

Disconformity.

**Thickness (Feet)**

Upper Devonian. Martin limestone.

1. Limestone: very light gray, aphanitic, massive, weathers light yellowish orange, silty, rough, cliff forming. ..................... 10

2. Limestone: light gray, fine-grained, thin-bedded (0.5 foot), weathers light yellowish orange to white, silty, rough, slope forming. 16

3. Limestone: medium gray, aphanitic, thin-bedded (0.5 foot), weathers light yellowish orange, smooth, slope forming. ................. 14

4. Limestone: medium gray, aphanitic, thin-bedded (0.5 foot), upper three feet very fossiliferous, silica replaced, good preservation, Schuchertella sp., Cyrtia (Tenticospirifer) cyrtiniformis, Spirifer whitneyi, Spirifer hungerfordi, weathers light yellowish orange, smooth, cliff forming. ..................... 10
5. Limestone: medium gray, aphanitic, thin-bedded (0.5 foot), weathers light yellowish orange, smooth, slope forming. .......................... 3

6. Limestone: medium gray, aphanitic, thin-bedded (0.5 foot), abundant brachiopod fragments, silica replaced, poor preservation, weathers light yellowish orange, smooth, cliff forming. ........ 2

7. Limestone: light gray, fine-grained, very thin-bedded (0.2 foot), to fissile, weathers white, rough, slope forming. .......................... 2

8. Limestone: medium gray, aphanitic, thin-bedded (0.5 foot), abundant brachiopods, silica replaced, good preservation, beds are separated by thin seams of light gray to white limestone (1/8 inch), weathers light yellowish orange, silty, rough, cliff forming. ......................... 5

9. Limestone: light gray to white, fine-grained, thin-bedded (0.5 foot), few brachiopod fragments silica replaced, poor preservation, weathers light yellowish orange, breaks into small pieces (2 inches) upon weathering, rough, slope forming 17

10. Limestone: medium light gray, aphanitic, thick-bedded (3 foot), abundant brachiopod fragments, Spirifer orestes, silica replaced, fair, Cladopora sp. extremely abundant, most fossils and Cladopora sp. confined to the lower three feet, good marker, weathers light olive gray, rough, cliff forming. .......................... 24

11. Covered. .......................... 30

12. Limestone partly covered: medium gray, aphanitic, thick-bedded (4 feet), fragments of large brachiopods, silica replaced, poor preservation, scattered calcite false geodes, weathers buff, rough slope forming. .......................... 8

13. Quartzite: white, medium-grained, thick-bedded (3 feet), good marker, weathers buff, rough, cliff forming. .......................... 3

14. Limestone: pale red, crystalline, massive, white calcite stringers and nodules throughout, weathers pale red, rough, cliff forming. .......................... 45
15. Limestone: medium light gray, aphanitic, 
   massive, weathers buff, rough, slope forming.  18

16. Limestone: medium gray, aphanitic, very 
   thick-bedded (5 feet), weathers light olive 
   except for a five-foot bed which has its base 
   1\(\frac{1}{2}\) feet above the bottom of the member and 
   weathers dark gray, rough, cliff forming. ...  35

17. Limestone: medium light gray, aphanitic,  
   very thick-bedded (5 feet), weathers buff, 
   rough, cliff forming. .........................  17

18. Limestone: medium gray, aphanitic, very  
   thick-bedded (4 feet), weathers pale yellowish 
   orange, rough, cliff forming. ..................  15

19. Limestone: white, aphanitic, thin-bedded 
   (1 inch), weathers white and looks like 
   powdered chalk, smooth, slope forming. ......  15

20. Limestone: medium gray, aphanitic, thin- 
   bedded (2 feet), weathers buff, rough, cliff 
   forming. ....................................  2

21. Limy sandstone: very light gray to white, 
   very fine-grained, very thin-bedded (1/8 inch), 
   weathers to white chalky silt, smooth slope 
   forming. ...................................... 39

Total thickness 330

Disconformity.

Upper Cambrian. Abrigo formation.

The three-foot white quartzite member 13 is an excellent 
marker bed throughout the Waterman Mountains. Besides the light 
yellowish orange color of the weathered surface of the Martin 
limestone and the abundant fossils in the upper part, the forma-
tion can be recognized because it forms a slope below the high 
cliffs of the overlying escabrosa limestone.

As noted in the described section, fossils are abundant in 
the upper 1\(\frac{1}{2}\) feet of the formation above the bed of white quartzite.
In a faulted section of Devonian limestone, brachiopod fragments were found that could not be definitely located in the section but probably occur somewhere below the bed of white quartzite. These brachiopod fragments were examined by Stoyanow 13/ who could not positively identify them because of the poor preservation.

A section at the north end of the Waterman Mountains measured only 96 feet from the bottom of the white quartzite member 13 to the Escabrosa-Martin contact. This is 48 feet less than the section measured at the south end. The contact at the south end is apparently conformable since it shows no evidence of an unconformity. However, the contact at the north end is wavy and irregular and suggests channeling of the Devonian limestone before the deposition of the overlying Escabrosa limestone.

The contact of the Martin with the Abrigo formation is apparently conformable although there is a considerable hiatus. There is no evidence of any erosion or channeling of the Abrigo before the deposition of the Martin limestone.

The lower 56 feet of the Martin limestone is lithologically similar to the Copper Queen limestone found at Bisbee, Arizona, and described by Stoyanow 14/. According to Stoyanow the Copper

13/ Stoyanow, A. A., oral communication, March 5, 1951.

Queen limestone is very easily distinguished in the Bisbee district because it appears as a white band in the upper part of the Cambrian section above the gray, slope-forming Abrigo. The Copper Queen limestone is almost unknown anywhere in Arizona except at Bisbee. Since no paleontological evidence was found to correlate these lower whitish beds with the Copper Queen limestone they are included in the Martin limestone.

Escabrosa Limestone.

At the south end of the area the Escabrosa limestone rests with apparent conformity on Devonian limestones. At the northwest end of the mountains there is evidence of an old erosion surface separating the Mississippian and Devonian limestones. The contact at the northwest end is wavy and irregular, and along it pale red Devonian limestone seems to have been channeled before the deposition of the Escabrosa limestone. The Escabrosa is massive, light gray, and cliff forming.

The sequence is as follows:

Lower Pennsylvanian. Naco limestone.

Disconformity.

Lower Mississippian. Escabrosa limestone. Thickness (Feet)

1. Covered. ........................................... 35

2. Limestone: grayish orange pink to very light gray, aphanitic, locally crystalline, thick-bedded (2 feet), horn corals and crinoid stems, few, calcite replaced, poor preservation, some small (1 to 6 inch) chert lens, weathers grayish orange, rough, cliff forming. ........................................... 21
3. Limestone: light gray, aphanitic, thick-bedded (4 feet), scattered horn corals, calcite and silica replaced, poor preservation, weathers very light gray, rough, cliff forming. ........... 29

4. Limestone: light olive gray to grayish orange, aphanitic, thin-bedded (1 foot), some beds sandy, medium-grained, some beds one color - some the other, weathers yellowish gray to grayish orange, rough, cliff forming. .................. 13

5. Limestone: medium dark gray, aphanitic, thin-bedded (1 foot), weathers medium gray, rough, cliff forming........ 6

6. Sandstone: white with some light gray quartz grains, medium-grained, thin-bedded (1 foot), weakly cemented, good marker, weathers moderate brown, cliff forming. ....................... 1

7. Limestone: light olive gray, aphanitic, thick-bedded (4 feet), horn corals, silica replaced, poor preservation, abundant corals in zone up to 23 feet from the base, above this few corals, few Syringopora sp., weathers light gray, rough, cliff forming. .......................... 38

8. Limestone: light olive gray, aphanitic, very thin-bedded (0.5 foot), abundant horn corals, few brachiopods, silica replaced, poor preservation, weathers light gray, rough, cliff forming. 3

9. Limestone: light olive gray to grayish orange, aphanitic, thin-bedded (2 feet), horn corals, abundant in upper 2 feet, silica replaced, poor preservation, weathers light gray, rough, cliff forming. ................................. 11

10. Limestone: light olive gray to grayish orange, aphanitic, weathers light gray, rough, cliff forming. ............................... 4

11. Limestone: medium dark gray, aphanitic, thin-bedded (1 foot), weathers medium gray, rough, cliff forming. ............................. 6

Thickness
(Feet)
12. Limestone: light olive gray to grayish orange, aphanitic, thin-bedded (1 foot), scattered stringers of grayish orange calcite (1/8 inch), weathers yellowish gray to grayish orange, rough, cliff forming. .......... 18

13. Limestone: medium dark gray, aphanitic, lower ten feet massive, upper 19 feet thin-bedded (1 foot), few, silica replaced, fair preservation, *Michelinia* sp., weathers medium light gray, rough, cliff forming. .......... 29

14. Sandstone: white, medium-grained, thin-bedded (2 feet), weakly cemented, friable, good marker, weathers moderate brown, rough, slope forming. 2

15. Limestone: light gray, aphanitic, massive, weathers very light gray to pale orange, rough, cliff forming. ....................... 11

16. Chert: chert band in limestone, very light gray, aphanitic, massive to thin-bedded (0.5 foot), band very resistant to erosion and persistent, but irregular in thickness of individual layers in limestone, band stands out from limestone surface (0.1 foot), weathers purple black to moderate brown, rough, cliff forming. .... 3

17. Limestone: light gray, aphanitic, massive, few crinoid stems, calcite replaced, poor preservation, weathers medium light gray, rough, cliff forming. ....................... 5

18. Limestone: light gray, aphanitic, massive, chert band, very light gray, chert weathers purple black to moderate brown, very persistent and resistant to erosion, chert in lenticular bodies and beds (0.3 foot), limestone weathers medium light gray, rough, cliff forming. .... 8

19. Limestone: light gray, aphanitic, massive, few crinoid stems, calcite replaced, poor preservation, weathers medium light gray, rough, cliff forming. ....................... 39

20. Limestone: medium dark, aphanitic, thick-bedded (3 feet), few brachiopod fragments, silica replaced, poor preservation, *Syringopora* sp., few, weathers light grayish orange, rough, cliff forming. .. 34

Total thickness 316
Disconformity.

Devonian. Martin limestone.

The cliff forming habit of the Escabrosa limestone and the resistant chert band about 86 feet above the base make the formation easily recognizable from a distance.

In the Waterman area isolated outcrops of Escabrosa limestone can be identified by the persistent horn corals and the two thin marker beds of sandstone.

Ransome describes the Escabrosa limestone as a thick-

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bedded, white to dark, granular limestone predominately formed from crinoid remains. Girty 16/, on the basis of fossil evidence,

---


determined the age of the Escabrosa as Kinderhook and Osage.

Later, Stoyanow 17/ found fossils of Burlington age in the upper part of the Escabrosa. The strata described by Stoyanow are in Peppersauce Canyon, in the Santa Catalina Mountains about 45 miles northwest of the Waterman Mountains. The lithology,
fossil evidence, and stratigraphic sequence correlate the limestone with the Escabrosa as originally described by Ransome.

Naco Limestone.

The Naco limestone rests with an inferred disconformity on the Escabrosa limestone. The Naco limestone is light gray and more thinly bedded than the Escabrosa limestone. Where the strata are steeply inclined the more resistant beds stand out like parallel resistant igneous dikes.

The section is as follows:

Permian. Undifferentiated Permian.

Concealed with recent wash and fault contacts.

Pennsylvanian. Naco limestone.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>(Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Limestone: pale red, aphanitic, very thin-bedded (0.5 foot), calcite replaced brachiopods and gastropods, abundant, poor preservation, good marker, weathers light olive gray, rough, cliff forming, interbedded with pale red sandy limestone, very fine-grained, very irregular, weathers black to moderate brown, rough, cliff forming.</td>
<td>2</td>
</tr>
<tr>
<td>2. Limestone: pale red, aphanitic, very thin-bedded (0.1 foot), Chaetetes milleporaceous in upper part, silicified, weathers very light gray, breaks into small pieces upon weathering (0.2 foot), rough, slope forming.</td>
<td>11</td>
</tr>
<tr>
<td>3. Limestone: pale red, aphanitic, very thin-bedded (0.1 foot), weathers very light gray, breaks into small pieces upon weathering (0.2 foot), rough, some interbedded sandy limestone beds, very fine-grained, thin-bedded (1 foot) smooth, slope forming.</td>
<td>8</td>
</tr>
<tr>
<td>4. Limestone: pale red, aphanitic, thin-bedded (0.5 foot), sandy (very fine-grained), weathers moderate brown to black, rough, slope forming.</td>
<td>53</td>
</tr>
</tbody>
</table>
5. Limestone: pale red, aphanitic, very thin-bedded (0.1 foot), weathers grayish orange, breaks into small pieces upon weathering (0.2 foot), rough, slope forming. ........................................... 13

6. Limestone: pale red, aphanitic, very thin-bedded (1/4 inch), sandy (very fine-grained), weathers moderate brown to black, rough, slope forming. ........................................... 40

7. Limestone: pale red, aphanitic, sandy (very fine-grained), shaly, thin-bedded (0.5 foot), weathers moderate red, some areas light brownish gray weathering to light gray, smooth, slope forming. ........................................... 8

8. Covered. .................................................. 75

9. Limestone: very light gray, aphanitic, thin-bedded (1 foot), weathers light gray, rough, limestone conglomerate at top, 1 foot thick, white to medium gray, limestone fragments small (1 inch), subangular, 55 feet from base 1 foot of same type conglomerate, few sandy limestone beds (1 foot), slope forming. 70

10. Limestone partly covered: pale red to buff, aphanitic, thin-bedded (0.5 foot), sandy, very fine-grained, weathers buff, smooth, slope forming. ........................................... 10

11. Limestone: very light gray, aphanitic, thin-bedded (10 inches), weathers light gray, rough, areas of buff limestone, sandy (very fine-grained), weathers buff, rough, slope forming. 72

12. Limestone: light gray, aphanitic, thin-bedded (1 foot), weathers black to grayish orange, looks extremely like sandstone on the surface, resistant; rough, cliff forming. ........................................... 17

13. Limestone: very light gray, aphanitic, very thick-bedded (5 feet), brachiopod fragments, silica replaced, poor preservation, weathers light gray, rough, top 5 feet cliff forming, bottom 16 feet slope forming. ........................................... 21

14. Limestone: light greenish gray, aphanitic, very thin-bedded (1/4 inch), weathers light greenish gray, smooth, slope forming. ........................................... 3
15. Limestone: light gray aphanitic, thin-bedded (1 foot), sandy (fine-grained), weathers light gray, 1-foot bed on top weathers along bedding so surface looks covered with buckshot, pitted surface; this weathering decreases progressively toward the bottom, at 20 feet from the bottom 1-foot bed the same as the top, rough, cliff forming. ............................... 23

16. Limestone: very light gray, aphanitic, very thin-bedded (1 inch) on the top getting thin-bedded at the bottom (1 foot), weathers light gray, smooth, slope forming. ............................... 16

17. Limestone: light gray, aphanitic, thin-bedded (1 foot), weathers black to grayish orange, looks like sandstone on the weathered surface, resistant, rough, cliff forming. ............................... 55

18. Limestone: very light gray, aphanitic, thick-bedded (2 feet), brachiopod fragments, common, silica replaced, poor preservation, *Spirifer occidentalis*, weathers light gray, rough, top 16 feet cliff forming, bottom 40 feet slope forming. ............................... 56

19. Limestone: light gray aphanitic, very thin-bedded (1 inch), weathers black to grayish orange, smooth, slope forming. ............................... 7

20. Limestone: very light gray, aphanitic, thick-bedded (2 feet), weathers light gray, rough, top 6 feet cliff forming, bottom 22 feet slope forming. ............................... 28

21. Limestone: light gray, aphanitic, very thin-bedded (1 inch), weathers black to grayish orange, smooth, slope forming. ............................... 7

22. Limestone: very light gray aphanitic, thick-bedded (2 feet), weathers light gray, rough, top 2 feet cliff forming, bottom 13 feet slope forming. ............................... 15

23. Limestone: light gray, aphanitic, massive, streaked with grayish orange calcite stringers (1/4 inch), weathers buff, rough, cliff forming. ............................... 5
24. Limestone: very light gray, aphanitic, thick-bedded (2 feet), weathers light gray, rough, cliff forming.

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
</tr>
</tbody>
</table>

25. Chert conglomerate: pale reddish brown, pebbles, sub angular, poor sphericity, chert cement, pale reddish brown, firm, locally the conglomerate facies changes to pale reddish brown fissile shale or to white cherty quartzite, slope forming.

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

Total thickness 67 feet.

Disconformity.

Lower Mississippian. Escabrosa limestone.

Considering the thickness of the Naco limestone, fossils throughout the formation are scarce. There is a bed of Chaetetes milleporaceous 667 feet above the base of the Naco limestone. This bed is about two feet thick and is an excellent marker horizon when it can be located. Where the coral has been completely silicified, it is easily mistaken for a bed of chert.

In a faulted and folded series of Naco limestone Linoprodactus cora and Composita argentea were found. These fossils probably occur at least 100 feet above the top bed in the measured section.

The Naco limestone was deposited under entirely different conditions than those under which the Escabrosa limestone was deposited. The Escabrosa limestone was deposited under relatively stable conditions which were favorable for the accumulation of massive limestone beds. On the other hand, the lower part of the Naco limestone was deposited under changing conditions which gave rise to a cyclic series of limestones.
For 451⁄2 feet above the basal chert conglomerate there is a definite alternation of two distinct limestone members.

The characteristic members are described as follows: Thickness (Feet)

1. Limestone: light gray, aphanitic, thin-bedded, weathers buff, black to grayish orange, rough but somewhat smoother than other member, slope forming but slightly more resistant than other member. .............................................. Ul

2. Limestone: very light gray, aphanitic, thick-bedded, weathers light gray, rough, slope forming. 16

The almost exact repetition of these members shows that there must have been cyclic deposition during the early part of the Pennsylvanian period, at least in the Waterman Mountain area. Cyclic deposition is especially characteristic of the Pennsylvanian deposits of North America and Europe 18/.


Above the cyclic series of limestone there are over 210 feet of pale red arenaceous, thin-bedded limestones which appear to correspond to the reddish arenaceous limestones that Lausen 19/


observed in the Whetstone mountains. He also found Linoproductus cora in this upper series of limestones.

The chert conglomerate that separates the Naco limestone from the Escabrosa limestone contains silicified corals of
Mississippian age. These fossils apparently were released from the Escabrosa limestone during the erosion period between the deposition of the Escabrosa limestone and that of the Naco limestone. Since sediments of the upper Mississippian age are absent in the area, there must have been a period of either non-deposition or pre-Pennsylvanian erosion. The basal chert conglomerate with residual Mississippian fossils indicates that there may have been a thicker Mississippian sedimentary series in the area and that the upper part of the series was eroded before the deposition of the Naco limestone. The chert conglomerate is correlated with the basal conglomerate 20/


found near Superior and many places in Arizona between the Naco and the Escabrosa limestone.

Undifferentiated Permian.

No attempt was made to measure the Permian limestones and sandstones which are stratigraphically above the Naco limestone in the southeast part of the area. The Upper Permian limestone can be recognized by its dark color, persistent band of chert layers in the lower part, and its cliff forming habit. The lower part of the Permian has a very fine-grained sandstone member and below that a light gray limestone with abundant calcite stringers.
An approximate section follows:

Cretaceous. Undifferentiated Cretaceous.

Covered. Probably fault contact.

Permian. Undifferentiated Permian.

<table>
<thead>
<tr>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Feet)</td>
</tr>
</tbody>
</table>

1. Limestone: dark gray to black, aphanitic, thick-bedded, brachiopods and gastropods, silica replaced, persistent chert bands in the lower part, weathers rough, cliff forming. ................................... 550

2. Sandstone: pale red, very fine-grained, thin-bedded (1/2 inch), weathers pale red, rough and somewhat flaky, cliff forming. .... 150

3. Limestone: medium light gray, aphanitic, thick-bedded, abundant calcite stringers (1/4 inch), large calcite replaced gastropods, few, weathers medium gray, rough, cliff forming. .......................... 250

Total thickness 950

Covered. Probably fault contact.

Pennsylvanian. Naco limestone.

The correlation of the Permian section is based on stratigraphic position and lithology. The upper limestone in the section probably correlates with the Snyder Hill formation.

As shown on Plate I, the Permian beds strike about north 45 degrees west and dip about 80 degrees to the southwest. The section is wedge shape, thickens toward the south, and becomes even thicker south of the area mapped. At the south end of the area, the Permian beds separate the Cretaceous sediments from the Pennsylvanian Naco limestone. At the north end of the area, the
Permian beds wedge out completely which leaves the Cretaceous sediments resting directly against the older Paleozoic formations.

The difference in strike and dip between the Permian and Cretaceous beds along their contact indicates that faulting causes the wedging out of the Permian formations. However, it is possible that the wedging out of the Permian is caused by post-Permian-pre-Cretaceous erosion. No residual fragments of Permian limestone were found in the Cretaceous sediments which would indicate a post-Permian-pre-Cretaceous period of erosion. Undifferentiated Cretaceous.

The undifferentiated Cretaceous beds are the youngest sedimentary rocks in the area and crop out in the northeast part of the area where they are partially covered by recent alluvium. The majority of the exposures are found in the banks or beds of the intermittent streams.

The relation between the undifferentiated Permian and the undifferentiated Cretaceous is not clear because the contact is covered. The difference in strike and dip between the Permian beds and the Cretaceous beds along their contact indicates a fault contact.

The strike of the Cretaceous beds is about north 60 degrees west and the dip is about 75 degrees southwest. The beds strike roughly parallel to the mountain front. The Cretaceous section was not measured, but by rough estimation it should be at least
The Cretaceous beds which are easy to distinguish from the Paleozoic beds are composed of very fine-grained to very coarse-grained sandstones and quartzites, arkoses, conglomerates, shales, and limestones. The sediments vary in color. In general, the quartzites, sandstones, and arkoses are very light gray to white; the shales are green, yellow, and red, with green and yellow predominant. The limestones are medium dark gray and weather to medium gray.

A description of a conglomerate phase near the base of the section follows:

<table>
<thead>
<tr>
<th>Thickness (Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conglomerate: brownish black, bonded by medium to coarse-grained arkosic sand which has a salt and pepper color, coarse chert cobbles (2 inches), medium sphericity, rounded, white to gray color, weakly cemented.</td>
</tr>
</tbody>
</table>

The conglomerate bed strikes north 59 degrees west and dips 57 degrees southwest. About 135 feet east of the described conglomerate phase there are limestone beds in which Cretaceous lamellibranchs occur. According to Stoyanow [21], these lamellibranchs are probably *Corbula* sp. which have also been found in the Cretaceous limestones at Tombstone, Arizona.

Quaternary Alluvium.

A large part of the Cretaceous beds have been covered by recent alluvium, and where the alluvium is of considerable
thickness it was mapped. This alluvium consists of unconsoli-
dated gravel, sand, and silt of recent origin. Because of its
recent age, the alluvium has no relation to the overall struc-
ture or mineralization of the area.

Igneous Rocks

Acid Intrusives.

Waterman alaskite.

The oldest rock in the area is Precambrian Waterman
alaskite. The alaskite is less resistant to weathering than
the other rocks in the area and is easily eroded. It forms
the plains west of the Indiana mine.

There is no absolute proof for the age of this alaskite,
but there are several features which indicate a Precambrian age.
In the Slate Mountains and in the Santa Catalina Mountains, the
Troy quartzite rests on the Precambrian Apache group of sediments.
In the Slate Mountains the Apache group was measured by Hogue 22/

22/ Hogue, W., op. cit.

and found to rest on Pinal schist and to be about 1,543 feet in
thickness. In the Santa Catalina Mountains Stoyanow 23/ measured

23/ Stoyanow, A. A., Correlation of Arizona Paleozoic Forma-
the Apache group which has a thickness of about 1,050 feet and rests on Archeozoic granite.

In the Indiana mine area this great thickness of quartzites, shales, and conglomerates is missing. No place in the area contains any suggestion of the Apache group altered or otherwise. Where the bottom of the Troy quartzite can be observed it is found resting on alaskite with an apparent erosional contact.

If the alaskite were intruded into the Troy quartzite at least 1,000 feet of sediments would have had to be assimilated. Assuming that this could happen, it is unlikely that the alaskite would have assimilated the sediments so completely that no trace of them has remained and that the assimilation would have been so even that for several miles the alaskite intruded only the quartzite and in no place broke through the quartzite as an alaskite dike.

Also, if the alaskite were intruded into the Troy quartzite, there should be some evidence of a chilled zone along the contact. The alaskite has large feldspar phenocrysts (1 inch) at the contact and shows no evidence of cooling more quickly along the borders. No metamorphic minerals, which would indicate an intrusive body, were found in the area.

A typical specimen of Waterman alaskite is as follows:

**Megascopic:** A grayish rock with green splotches. The rock is coarse-grained with large pinkish microcline euhedral crystals which have a maximum dimension of about one inch. The pinkish color is caused by small fractures filled with
reddish iron oxides. Smoky gray anhedral quartz cements the feldspar crystals. The greenish color is imparted to the rock by scattered particles of epidote.

Microscopic: The texture is hypautomorphic-granular. The primary minerals listed in order of abundance are as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcline</td>
<td>40 percent</td>
</tr>
<tr>
<td>Quartz</td>
<td>45 percent</td>
</tr>
<tr>
<td>Sericite</td>
<td>10 percent</td>
</tr>
<tr>
<td>Accessories:</td>
<td></td>
</tr>
<tr>
<td>hematite,</td>
<td></td>
</tr>
<tr>
<td>leucoxene,</td>
<td></td>
</tr>
<tr>
<td>epidote</td>
<td>5 percent</td>
</tr>
</tbody>
</table>

The microcline is euhedral and shows excellent grid twinning. It is broken by very small fractures that are filled with reddish-brown dusty hematite. The quartz occurs as anhedral masses and as cementing material. It shows some undulatory extinction. The muscovite occurs as wavy shreds which are colorless to pale green and show very faint pleochroism. Large, white, non-opaque, wedge-shaped crystals of leucoxene are scattered throughout the rock. The leucoxene probably results from the alteration of sphene. Grains of blue-black hematite occur which have a bomb-shell structure. The grains of hematite commonly are inclusions in the muscovite. The microcline and muscovite both have been partly altered to epidote. The epidote shows high relief and occurs as very small subhedral to anhedral grains.

Waterman granite.

The Precambrian Waterman granite is slightly younger than the Waterman alaskite. This belief is based on the fact that the granite dikes cut the Waterman alaskite, but nowhere do the dikes intrude the sediments.

The granite, in contrast to the Waterman alaskite, is resistant to erosion and forms the high ridge at the north end of the mountains. Here the Troy quartzite rests with an apparent erosional contact on the Waterman granite.

A suggested reason for the thinning of the Troy quartzite at the north end of the mountains follows: During the Precambrian
erosion period, after the intrusion of the granite into the alaskite, the granite was more resistant to erosion and remained as an erosional high. As a result, when the sea advanced and the Troy quartzite was deposited, a greater thickness of Troy quartzite was laid down over the alaskite than over the granite high.

A typical specimen of Waterman granite is as follows:

Megascopic: A pinkish-gray, fine-grained, saccharoidal rock. The rock is composed of pink to white feldspar in places showing crystal outlines surrounded by gray anhedral quartz. One specimen contains a microcline crystal about one half inch long surrounded by granite.

Microscopic: The rock has a medium-grained texture. The primary minerals listed in order of abundance are as follows:

- Quartz .................................. 35 percent
- Microcline .................................. 30 percent
- Orthoclase .................................. 20 percent
- Andesine ....................................... 9 percent
- Chlorite ........................................ 3 percent
- Muscovite, magnetite, and sericite .......... 3 percent

The quartz occurs as subhedral and anhedral grains and as the cementing material. The microcline and andesine also occur as subhedral and anhedral grains with part of the andesine intergrown with microcline. The orthoclase which is altering to sericite occurs as subhedral grains. The muscovite occurs as shreds and anhedral grains. Scattered throughout the rock are small grains of magnetite.

Rhyolite

The Cretaceous sediments in the northeast and east part of the area were intruded by at least one rhyolite dike. Although the contact of the rhyolite with the sediments was not observed, the general trend of the dike indicates that it was intruded.
parallel to the Cretaceous bedding (Plate I).

The rhyolite is slightly more resistant to erosion than the Cretaceous sediments and at some places weathers to form a mound about a foot high. In most places the dike is covered by recent alluvium so that it is extremely hard to trace. There is definite flow structure paralleling the sides of the dike. This flow structure was evidently developed during the intrusion of the dike. Since the rhyolite dike intrudes the Cretaceous sediments, the age of intrusion is post-Cretaceous.

A typical specimen of rhyolite is as follows:

Megascopic: The rock has a yellowish-gray aphanitic groundmass with occasional small white crystals of feldspar. There are a few very small quartz particles scattered in the groundmass.

Microscopic: The rock has a very fine-grained xenomorphic-granular texture with a few small euhedral orthoclase crystals. The primary minerals listed in order of abundance are as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthoclase</td>
<td>70 percent</td>
</tr>
<tr>
<td>Quartz</td>
<td>20 percent</td>
</tr>
<tr>
<td>Albite</td>
<td>10 percent</td>
</tr>
</tbody>
</table>

The orthoclase is euhedral except where the crystals have been corroded by fine-grained quartz and orthoclase. The orthoclase is altered to a cloudy white and shows weak Carlsbad twinning. The quartz occurs as a fine-grained constituent of the groundmass. Albite is scattered throughout the rock in very small lenticular masses which give a flow structure to the rock. The albite has weak albite twinning.

Porphyritic granite.

The Cretaceous sediments have been intruded by porphyritic granite dikes. These dikes weather about the same as the surrounding Cretaceous sediments. All of the specimens of porphyritic granite are highly altered by surface weathering.
The porphyritic granite dikes take very unpredictable courses. They may follow the bedding or they may cut it. The surface outcrops of the dikes start and stop abruptly without any apparent reason. As the porphyritic granite intrudes the Cretaceous sediments, the dikes are post-Cretaceous. No age relation is known between the porphyritic granite, dacite and rhyolite dikes.

A typical specimen of porphyritic granite is as follows:

Megascopic: The rock has a greenish-gray fine-grained groundmass with scattered white euhedral orthoclase crystals. Very small specks of magnetite and pyrite give the rock a gray color.

Microscopic: The texture is porphyritic with a fine-grained groundmass. The primary minerals listed in order of abundance are as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>60%</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>20%</td>
</tr>
<tr>
<td>Oligoclase</td>
<td>5%</td>
</tr>
<tr>
<td>Sericite</td>
<td>5%</td>
</tr>
<tr>
<td>Muscovite</td>
<td>5%</td>
</tr>
<tr>
<td>Magnetite and sphene</td>
<td>5%</td>
</tr>
</tbody>
</table>

The orthoclase is in large (0.5 to 4.0 m.m.) euhedral crystals which have been slightly corroded by quartz. There are pronounced sericite rings around the orthoclase. The oligoclase is euhedral and subhedral and has also been considerably altered to sericite. The groundmass is composed of fine-grained quartz, shreds of muscovite, and altered feldspar. The magnetite and sphene occur as small euhedral grains.

Dacite

Dacite in the form of dikes and irregular bodies intrudes the Waterman alaskite. The intrusions occur in the large alaskite mass and also occasionally along the alaskite-Troy quartzite
boundary, so the age of the dacite is at least post-Middle Cambrian. The dikes are probably post-Cretaceous and of about the same age as the porphyritic granite dikes.

A typical specimen of dacite is as follows:

Megascopic: The rock has a greenish-gray aphanitic groundmass with scattered rounded particles of dark gray quartz.

Microscopic: The rock has a light gray fine-grained texture with occasional rounded grains of quartz. Feldspar laths are scattered throughout the rock. The primary minerals listed in order of abundance are as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>50 percent</td>
</tr>
<tr>
<td>Quartz</td>
<td>15 percent</td>
</tr>
<tr>
<td>Sericite</td>
<td>15 percent</td>
</tr>
<tr>
<td>Chlorite</td>
<td>10 percent</td>
</tr>
<tr>
<td>Magnetite</td>
<td>5 percent</td>
</tr>
<tr>
<td>Calcite</td>
<td>4 percent</td>
</tr>
<tr>
<td>Garnet</td>
<td>1 percent</td>
</tr>
</tbody>
</table>

The lath form of the feldspar is evident, but because of the intense koaline alteration the exact type of plagioclase feldspar cannot be determined. The quartz is subhedral and anhedral with scattered rounded grains. The sericite occurs as small veinlets and as alteration rims around the quartz, calcite, and chlorite. Fibrous masses of chlorite appear to be altering from quartz and feldspar. Subhedral garnet and magnetite grains are scattered sparsely in the rock. The calcite is in small anhedral grains.

Because of the minor amount found, the dacite was mapped only on the large-scale map of the Indiana mine area (Plate II).

Structure

Folding

There has been considerable folding of the rocks in the Waterman Mountains, but folding is subordinate to faulting.

Folds in the Cretaceous sediments in the northeast part of
the area strike generally northwest-southeast (Plate I). The folds are small, but they do help to locate the direction from which the forces acted.

The Paleozoic sediments in the northern part of the Waterman Mountains are folded into a broad syncline. The axis strikes about north 55 degrees west and pitches to the southeast.

Since the folds in the Paleozoic sediments and in the Cretaceous sediments have a northwest strike, they probably result from the same regional stresses which acted in a northeast-southwest direction after the deposition of the Cretaceous rocks.

The regional stresses had the same direction as those that produced the northwest-southeast rolls in Tombstone.

Several small folds in the sediments northeast of the Indiana mine are near faults and are probably the result of drag folding.

Faulting

Pre-ore faults

The Waterman Mountains are complexly faulted, and more detailed work must be done to map all the faults.

The Indiana fault is the major pre-ore fault of the area and has a steep dip and a northwest strike. The displacement is variable with a minimum vertical displacement of about 1,400 feet. The surface trace of the fault suggests a dip to the northeast but does not indicate a low angle fault. The Indiana fault splits in numerous places and completely encloses blocks of sediments.

The northwest faults, like the Indiana fault, were the first faults formed. Later east to northeast faults displace the northwest faults. The major east-northeast fault is the Waterman fault. This displaces the Indiana fault, and the continuation of the Indiana fault to the southeast is probably the fault passing about 900 feet east of Silver Hill.

The Waterman fault has a horizontal displacement of about 900 feet. However, most of the east-northeast faults have displacements of only about 100 feet.

Post-ore faults

There has been only a small amount of post-ore movement. The post-ore faults are high angle and probably have had considerable strike-slip movement. The movement on most of the post-ore faults is from 10 to 50 feet.
CHAPTER III

ORE DEPOSITS

Indiana Mine

History

A report on the Indiana mine \(25/\) indicates its discovery was in 1880. In the early days prospecting was for high-grade silver ores. No record of development between 1880 and 1912 has been found.

Between 1912 and 1916 the mine was operated by lessees who shipped several thousand tons of ore to the smelter from the two upper levels.

John J. and Sidney J. Macneil purchased the property in 1916. Sidney Macneil, the present owner, drove the third level about 200 feet and sank the shaft to its present depth of about 350 feet. The fourth level was flooded at the time of this examination.

Cost of trucking ore to the railroad loading ramp at Naviska in 1919 was \$2.00 per ton.

Lead-zinc ores were shipped by rail from Naviska to the Eagle-Pitcher mill at Sahuarita - a distance of almost 50 miles.
A few shipments were made to the Shattuck Denn Mining Corporation at Bisbee, Arizona.

Copper-silver-lead ores were shipped either to the smelter at Hayden, Arizona, or to that at El Paso, Texas.

Property and Workings.

The Indiana-Arizona Mining Company owns 15 patented mining claims north of Silver Hill. Mining and development work have been done on three veins: the Indiana vein, the Waterman vein, and the Burro vein.

Development.

Indiana vein

The main shaft is on the Indiana vein. This is a vertical, well-timbered shaft about 350 feet deep with a small hoist and ore bin. Besides the shaft, there is an entrance through the stopes.

The mine has four main levels; the 92-foot level, the 169-foot level, the 214-foot level, and the 350-foot level. The last was flooded at the time of this examination. The 92-foot level has about 190 feet of drifting; the 169-foot level has 250 feet; the 214-foot level has 230 feet; and the 350-foot level is reported to have about 350 feet of drifting. On the surface about 65 feet southwest of the main shaft there is a 92-foot vertical shaft that connects with the 92-foot level.
Waterman vein.

The workings on the Waterman vein consist of short adits which intersect the vein. There is about 250 feet of drifting on the vein which has also been prospected by winzes and stopes for a vertical distance of about 150 feet.

Burro vein.

Two adits on the Burro vein prospect it for about 200 feet.

There are several other prospect pits and adits on the Indiana-Arizona Mining Company claims that show little mineralization.

Mineralization

Indiana vein.

The Indiana vein strikes about north 55 degrees east and dips about 85 degrees to the northwest. The vein crops out for about 1,000 feet and varies from two to 15 feet in width. It is resistant to erosion and forms bold outcrops five or more feet above the surrounding surface.

The ore minerals are galena, cerussite, chalcopyrite, chalcocite, malachite, azurite, and sphalerite. Some ore is high in silver, but no silver mineral has been determined. The silver content does not seem to bear any relation to the content of lead, so the silver probably occurs as a separate ore mineral rather than being combined in the galena.
The gangue minerals are quartz, pyrite, calcite, fluorite, barite, limonite, and hematite.

The vein is chiefly quartz and contains the other minerals in sparse amounts except in high-grade ore shoots. The quartz in many places has a vuggy and comb structure. The vein minerals are both carbonates and sulfides with carbonates predominating for 100 feet below the surface. On the third level, 214 feet below the collar, there is little, if any, carbonate.

Pyrite is abundant between the first and second level, and considerable galena is found between the second and third level. The presence of primary sulfides between these levels indicates that there is little chance of secondary enrichment below.

The wall rocks of the vein are the Waterman alaskite, the Troy quartzite, the Lower and Upper Cochise formation, the Abrigo formation, and, probably, the Martin limestone. All the wall rocks except the Martin limestone are favorable ore formations. The wall rocks are silicified to some extent and impregnated with iron oxides, but otherwise show little alteration.

A few small post-ore faults displace the vein but are of minor importance because of their small displacements.

Waterman vein

The Waterman vein strikes about north 20 degrees east and dips about 65 degrees to the northwest. The outcrop is about
1,500 feet long and follows a fault zone which in places shows shattering of the wall rock for a width of over 20 feet. The vein varies in width from one to 10 feet. The outcrop of the Waterman vein is less resistant to erosion than the Indiana vein because the Waterman vein has less solid quartz.

The ore minerals are principally cerussite and galena with minor chalcopyrite, malachite, and azurite. Some ore specimens have high silver content. The gangue minerals are fluorite, quartz, calcite, pyrite, barite, limonite, and hematite with fluorite and quartz most abundant. The quartz is vuggy with many leached boxwork cavities. The most common leached minerals are pyrite and fluorite. Some cubic boxworks in the quartz show the characteristic striations of pyrite. In these boxworks the pyrite has been entirely leached leaving a light boxwork of quartz. Impressions of leached fluorite are also present in the quartz. The fluorite occurs as octahedrons, and in many specimens part of the fluorite is still in the boxworks. Specimens showing unleached fluorite grade into those in which the fluorite has all been leached.

A large amount of soft yellowish iron oxide at the end of the Lower adit probably results from the leaching pyrite - an original mineral in the vein.

The wall rocks of the vein are the Waterman alaskite, the Troy quartzite, the Lower and Upper Cochise formation, the Martin limestone, and Escabrosa limestone, and the Naco
limestone. The limited development on the vein does not expose the mineralization well enough to indicate which wall rocks are most favorable to ore deposition. But the Escabrosa limestone seems to be a very poor ore horizon.

Burro vein.

The Burro vein strikes about north 45 degrees east and dips about 70 degrees to the southeast. The vein is narrow and varies from a thin seam to two feet wide. There is little surface outcrop except a very weakly mineralized fracture, but the vein widens underground. The vein is opened for 200 feet in the Burro adit level.

The ore minerals are cerussite and galena with good silver content in local enriched portions of the vein.

The gangue minerals are quartz, calcite, limonite, hematite, and minor pyrite.

The wall rocks of the vein are the Lower Cochise formation and the Escabrosa limestone. A pre-ore low angle normal fault causes the Escabrosa limestone to rest on the Lower Cochise quartzites and limestones. The mineralization is strong only in the Lower Cochise formation and does not continue into the Escabrosa limestone. At the Escabrosa-Cochise contact the mineralization widens and continues upward and downward in a chimney like body. Here, there is strong mineralization, but it is not commercial as it consists almost entirely of
coarse calcite and soft iron oxides. Only a few cars of ore have been shipped from this vein.

Temperature of Mineralization.

The mineralogical composition of the veins can be best classified as the mesothermal type according to Lindgren's classification. Although barite, quartz, fluorite, and pyrite may occur at any temperature, sphalerite, chalcocite, and galena with a little chalcopyrite are best placed in the mesothermal class. No characteristically high or low temperature minerals were found in any of the veins.

Age of Mineralization.

The following are the youngest formations cut by the veins: The Indiana vein cuts the Martin limestone; the Waterman vein cuts the Naco limestone; and the Burro vein cuts the Escabrosa limestone. The mineralization is probably all about the same age and according to the above field evidence is at least post-Pennsylvanian time. Although the veins show no age relationships with younger sediments, the mineralization probably took place during Tertiary time.

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CHAPTER IV

SUMMARY

This report covers an area of about three square miles in the northern part of the Waterman Mountains, Pima County, Arizona. The Indiana mine is at the north end of this area.

The sedimentary series includes formations of the Paleozoic and Mesozoic eras. The paleozoic sedimentary rocks are the Troy quartzite, Cochise formation, Abrigo formation, Martin limestone, Escabrosa limestone, Naco limestone, and undifferentiated Permian. The Mesozoic rocks include only the undifferentiated Cretaceous beds.

The oldest igneous rock in the area is the Precambrian Waterman alaskite. During Precambrian time the Waterman alaskite was intruded by the Waterman granite. After the intrusion by the granite, the Apache series may have been deposited and eroded, but there is no record of this series. The Troy quartzite rests with an erosional contact on the Waterman alaskite and granite.

Late rhyolite and porphyritic granite dikes intrude the Cretaceous sediments. The Waterman alaskite has been intruded by dacite dikes which are probably closely related to the rhyolite and porphyritic granite.

Probably during the Cretaceous-Tertiary interval (Laramide) the region was subjected to northeast-southwest forces which
produced folds with northwest-southeast strikes.

The faulting in the area can be classed in two general types, pre-ore and post-ore. The pre-ore faults can be divided into two systems, those which strike northwest and those which strike east to northeast. The main northwest fault is a high angle fault with minimum displacement of 1,400 feet. This northwest system has been cut by later east to northeast faults with displacements of 50 to 100 feet. The post-ore faults generally strike northeast and have displacements of 10 to 50 feet.

The mineralization is the vein replacement type and probably took place in Tertiary time. At the Indiana mine are three veins, the Indiana vein, the Waterman vein, and the Burro vein. The mineralizing solutions traveled up the east to northeast faults and fractures because they were more permeable than the northwest faults. The best mineralization took place in the Troy quartzite, lower Cochise, and Abrigo formations. There is little mineralization in the more pure limestones such as the Escabrosa and Martin limestones.

The mineralogy and structure of these veins suggest relatively near-surface mesothermal mineralization.

The Waterman vein has not been thoroughly prospected, and although the footwall will probably remain in alaskite, the hanging wall should remain in sediments to some depth. Despite the fact the pipe-like body of limonite in the Lower adit indicates an oxidized pyrite body, the mineralogical composition
may change with depth to more valuable ore minerals. The vein is a large structure and should continue to depth.

The Waterman and the Indiana veins are roughly parallel. The Waterman vein dips about 65 degrees toward the Indiana vein. The projected intersection of these veins is a good place to prospect for an enriched primary or secondary ore shoot.
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Fig. 1.

Panoramic view looking south from Indiana mine. Et Troy quartzite, Ecl Lower Cochise formation, Ecu Upper Cochise formation, Ce Escabrosa limestone, Pre Ga Waterman alaskite.
PLATE VII

Fig. 1.

Panoramic view looking north from Indiana mine. St Troy quartzite, Scl Lower Cochise formation, Scu Upper Cochise formation, Sa Abrigo formation, Cn Naco limestone.
PLATE VIII

Fig. 1.

Permian section east of Indiana mine looking south. Two Permian limestone cliffs with Permian quartzite between. In foreground are alluvium covered cretaceous beds.

Fig. 2.

Silver Bell drilling camp. American Smelting and Refining Company.
(5 pieces)
PLAN

INDIANA MINE

GEOLOGIC MAP 92-FOOT LEVEL

SCALE 1' - 20'

GEOLoGY BY A.W.RUFF
1950
PLAN

INDIANA MINE

GEOLOGIC MAP 169-FOOT LEVEL

SCALE 1" = 20'

GEOLOGY BY A.W. RUFF
1950
SECTION A-A'
LOOKING N.W.

SECTION B-B'
LOOKING N.W.

VERTICAL SECTIONS
SCALE 1" = 700'

EXPLANATION

SEDIMENTARY ROCKS
CRETAEOUS
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
UPPER CAMBRIAN
MIDDLE CAMBRIAN

IGNEOUS ROCKS
TERTIARY
PRECAMBRIAN

UNDIFFERENTIATED BEDS
NACO LIMESTONE
ESCABROSA LIMESTONE
ABRIGO FORMATION
COCHISE FORMATION upper unit
COCHISE FORMATION lower unit
TROY QUARTZITE
RHYOLITE
WATERMAN ALASKITE

BY A.W. RUFF, 1950