STRUCTURES AT THE NORTHERN END OF
THE SANTA CATALINA MOUNTAINS, ARIZONA

by

Roberts Manning Wallace

A Thesis
submitted to the faculty of the
Department of Geology
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in the Graduate College, University of Arizona

1954

Approved:  
Director of Thesis

Date
This thesis has been submitted in partial fulfillment of requirements for an advanced degree at the University of Arizona and is deposited in the Library to be made available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the dean of the Graduate College when in their judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED:

[Signature]
TABLE OF CONTENTS

ABSTRACT

INTRODUCTION
Location
Purpose of the Study

ACKNOWLEDGMENTS

GENERAL GEOLOGY ..............................................
Rocks ............................................................ 1

STRUCTURAL FRAMEWORK ...................................

EARLY PRECAMBRIAN ROCKS IN THE STRUCTURAL FRAMEWORK .

The System, Pinal Schist, Mogul Fault, Oracle Granite ..... 5

Pinal Schist .............................................. 11
Deformation of the Pinal Schist ............................. 11
Structure of the Samaniego Granite .......................... 12
The Pinal-Samaniego Contact ................................ 13
Petrography of the Samaniego Granite and Aplites .......... 14
Metamorphism of the Pinal Schist ............................ 16
Early Precambrian Rocks as Sources of Later Sediments ..... 16

LATER PRECAMBRIAN ROCKS AND STRUCTURES .............

The Pinal-Apache Unconformity .............................. 18

Apache Group .............................................. 18

Pioneer Shale ............................................... 18
Barnes Conglomerate ......................................... 20
Dripping Spring Quartzite ................................... 21
Mescal Limestone ............................................. 22
<table>
<thead>
<tr>
<th>Illustration</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate 1</td>
<td>Pocket in Back</td>
</tr>
<tr>
<td>Plate 2</td>
<td>Pocket in Back</td>
</tr>
<tr>
<td>Plate 3</td>
<td>Pocket in Back</td>
</tr>
<tr>
<td>Plate 4</td>
<td>Pocket in Back</td>
</tr>
<tr>
<td>Plate 5</td>
<td>6A</td>
</tr>
<tr>
<td>Plate 6</td>
<td>8A</td>
</tr>
<tr>
<td>Plate 7</td>
<td>10A</td>
</tr>
<tr>
<td>Plate 8</td>
<td>13A</td>
</tr>
<tr>
<td>Plate 9</td>
<td>18A</td>
</tr>
<tr>
<td>Plate 10</td>
<td>19A</td>
</tr>
<tr>
<td>Plate 11</td>
<td>20A</td>
</tr>
<tr>
<td>Plate 12</td>
<td>26A</td>
</tr>
<tr>
<td>Plate 13</td>
<td>27A</td>
</tr>
<tr>
<td>Plate 14</td>
<td>28A</td>
</tr>
<tr>
<td>Plate 15</td>
<td>32A</td>
</tr>
<tr>
<td>Figure 1</td>
<td>7A</td>
</tr>
<tr>
<td>Figure 2</td>
<td>7B</td>
</tr>
<tr>
<td>Figure 3</td>
<td>7C</td>
</tr>
<tr>
<td>Figure 4</td>
<td>7D</td>
</tr>
<tr>
<td>Figure 5</td>
<td>7E</td>
</tr>
<tr>
<td>Figure 6</td>
<td>18B</td>
</tr>
</tbody>
</table>
ABSTRACT

The northern end of the Santa Catalina Mountains, Pinal County, Arizona, is made up of granites, sedimentary rocks, and intrusive bodies ranging in age from early Precambrian to Recent, that fit into a structural framework with four dominant trends: west-northwest, northwest, northeast, and nearly north-south. These trends, developed in the oldest Precambrian rocks, have influenced, directly or indirectly, the deposition and the deformation of all younger rocks. Metamorphism where present is of low to medium rank, even on the schist-granite contacts. Of the late Precambrian Apache group, the Pioneer shale, the Barnes conglomerate, and the Dripping Spring quartzite, in part, were derived from the surrounding earlier formations. Only a thin remnant of the final Precambrian Mescal limestone survived the pre-Paleozoic erosion controlled by uplift on northwest trending structures.

The Paleozoic Era was a time of general slow sedimentation followed in early-Cretaceous (?) time by accumulation of coarse debris, possibly a local expression of the Nevadan Revolution. At this time the four trends in the structural pattern again became active, and subsequent erosion removed much of the Paleozoic rocks. The resulting debris, plus a large amount of volcanic material, collected in basins to form the Lower Cretaceous (?) conglomerates.

The structural framework was again active sometime in the Tertiary
period, when a large dioritic mass was intruded and subsequently meta-
morphosed. Debris from the erosion of this uplift formed part of the
Gila conglomerate and Rock Dump material. Ten-inch high scarplets,
trending north-south along the western boundary of the Santa Catalinas,
indicate that the mountain mass has recently sunk.
INTRODUCTION

Location

The map area is located at the northern end of the Santa Catalina Mountains in south central Arizona about thirty miles north of Tucson. The town of Oracle is in the northern part (Plate 1). Most of the mapped area lies in southern Pinal County; it occupies parts of the Winkleman and Tucson quadrangles, United States Geological Survey. It is bounded by latitudes 32° 30' and 32° 35' N. and longitudes 110° 41' to 110° 51' W.

The region is divided into two parts by a high north-northwesterly trending spur of the Santa Catalinas. The western part is drained by the Canada del Oro, a small pirated stream that eventually empties into the intermittently draining Santa Cruz River. This section, referred to as the Canada del Oro section, may be reached from Tucson via U. S. Highway 84 to Oracle Junction, then northeast 7.5 miles on Arizona Highway 77, then south on the Burney Mines road.

The eastern section is drained by intermittent eastward flowing streams that empty into the San Pedro River. This is the San Pedro section and is reached from Oracle via the graded Mount Lemmon road.

Purpose of the Study

The objective of this study is to reveal the structures at the northern end of the Santa Catalina Mountains as examples of the
deformation likely to be found elsewhere in the general region. The area studied is only one per cent of the total of the Santa Catalina Mountains and, of course, is a much lesser portion of the surrounding region. Nevertheless, it is thought that certain principles derived from this study may have a rather broad application. Even in this small area, the study is obviously not final. The structures found are so complex that the following account is only a report of progress.
ACKNOWLEDGMENTS

The writer wishes especially to acknowledge the help of Dr. B. S. Butler and Dr. Evans B. Mayo of the Department of Geology and Mineralogy, University of Arizona, Dr. Eldred Wilson of the Arizona Bureau of Mines, and Dr. Andrew Schride of the U. S. Geological Survey, for suggestions that aided in the preparation of this report. The Kennecott Copper Corporation generously financed the study. Calvin S. Bromfield of the U. S. Geological Survey made available his geological map of the Peppersauce Canyon area. Professors E. D. McKee and A. A. Stoyanow kindly determined the age and species of Trilobites from the middle shaly member of the Cambrian Troy quartzite. The hospitality extended by Mr. and Mrs. Robert Burney of Burney Mines, Inc., during the field work is greatly appreciated.

And lastly, special acknowledgments are due to my wife for her untiring assistance, without whose aid the preparation of this manuscript would have been impossible.

STRUCTURES AT THE NORTHERN END OF
THE SANTA CATALINA MOUNTAINS, ARIZONA

GENERAL GEOLOGY

Rocks

The rocks are regarded as units of the structural pattern, and, indirectly, as the products of tectonic events. In conformity with this concept, the geologic formations are, as far as possible, introduced directly into the discussion of the structure.

The oldest rock is the early Precambrian Pinal schist, which in the northwest part of the area is situated on either side of a curved belt of younger sediments, and locally is pushed up through the floor of younger sediments (Pl. 2, K,L-14,16). Associated with the Pinal is, on the north, the Oracle granite, in the south a similar granitic rock with different structure for which the writer proposes the name Samaniego granite.

Separated from the older Precambrian rocks by a pronounced unconformity is the later Precambrian Apache group, consisting, in descending order, of:

- Mescal limestone
- Dripping Spring quartzite
- Barnes conglomerate
- Pioneer shale

The Scanlan conglomerate, which should appear at the base of the section, and the Apache basalt that overlies the Mescal limestone at some
localities\textsuperscript{1} are lacking in this area.

The Paleozoic section rests on the latest Precambrian Mescal limestone in the northwestern part of the area (Pl. 2, Secs. B-B', C-C') and on the late Precambrian Dripping Spring quartzite in the northeast. The contact, therefore, is an unconformity, although at most exposures the unconformable relation is not apparent.

The formations in the Paleozoic section are:

- Lower Mississippian: Escabrosa limestone
- Upper Devonian: Lower Ouray formation
- Upper Devonian: Martin limestone
- Upper Cambrian: Abrigo formation
- Middle Cambrian: Troy quartzite

The Mesozoic rocks include a Pre-Cretaceous (?) breccia, overlain by Cretaceous (?) conglomerates and red beds, all mapped as one unit.

Some of the above rocks have been invaded by Tertiary (?) intrusions of meta-diorite; one of these intrusions is the large meta-diorite, centrally located in the area of sedimentary rocks. The minor diabase and rhyolite bodies are of unknown age, but are thought to be post-Miocene. The same may be said of the andesites.

The late Tertiary and (or) early Quaternary Gila conglomerate, and a coarse clastic rock termed "rock dump material", are locally exposed. Extensive areas are concealed by Quaternary alluvium.

\textsuperscript{1} Bansome, F. L., 1903, pp. 25-28.
STRUCTURAL FRAMEWORK

Within the area (Pl. 1), there appear to be four dominant structural trends:

1. The west-northwest structure, as exemplified by the Mogul fault zone.

2. The northwest, as revealed by the trend of the Tertiary (?) meta-diorite and accompanying parallel faults located within the Apache group and later rocks on either side; by the northwest trending andesitic and pegmatitic dikes in the Oracle granite (Pl. 3) and dioritic dikes in the Paleozoic rocks of the San Pedro or eastern section (Pl. 1, U, Z-13, 19). The contact of the Samaniego granite with the Apache group follows this trend near the Charoleau Gap, as do certain planar structures in the Samaniego granite in that vicinity.

3. The northeast trends are revealed by the Charoleau fault and a series of minor northeasterly faults cutting all Precambrian and Paleozoic rocks of the area; by the general trend of the planar structure in the Oracle granite and by minor folds and shears in the Pinal schist (Pls. 1, 4).

4. Nearly north-south trends are shown by the Pirate fault and by planar structures in the Samaniego granite near the Pirate fault (Pl. 1). North and south trending joint
sets are present in the sedimentary rocks in the vicinity of the Pirate fault, while similarly trending quartz veins are exposed directly north in the Oracle granite (Pl. 3).

In every case some of the features that reveal these directions seem to be primary elements in early Precambrian rocks, and, similarly, some of these features reappear in younger rocks, as though the structural framework is geologically very ancient and has controlled the later deformation.
EARLY PRECAMBRIAN ROCKS IN THE STRUCTURAL FRAMEWORK

These oldest rocks are the Pinal schist, the Oracle granite and the Samaniego granite. The Pinal schist was named by F. L. Ransome in 1903 from the Pinal mountains near Globe, Arizona. The Oracle granite was named by Professor C. F. Tolman, Jr., in 1914. He used the name to denote the Precambrian granite found at Oracle Hill (Pl. 1, N-5). He also used the name Oracle granite to include all granite bodies older than the Carboniferous. In this report it has become necessary to distinguish the Oracle granite in the northern section of the mapped area from a structurally, texturally, and mineralogically different granite found in the southwestern portion of the map. The author proposes the name Samaniego granite for this latter granite, which is found in the vicinity of the Samaniego ridge.

These rocks occur in two places as associations or systems of rocks and structures: first in the northwestern corner of the map area, along the Mogul fault, where Pinal schist and Oracle granite are in contact; secondly, along the southwestern side of the belt of sediments (Pl. 1) where Pinal schist contacts Samaniego granite.

The System, Pinal Schist, Mogul Fault, Oracle Granite

Nature of the Pinal Schist: The Pinal schist in the Mogul fault zone is composed of at least two rock types. The original materials

appear to have been: (1) rather thick, massive, light gray sandstones, separated by (2) layers of fine-grained, thinly-laminated siltstone or mudstone. Because of deformation, the finer-grained layers are now intensely contorted, although cleavage is not strongly developed. Megascopically, the former sandstones appear almost structureless. The fine-grained rocks vary in color from greenish black, or dark red where iron stained, through greenish gray to light gray, and the massive-appearing sandy members are predominantly light gray.

In thin section the fine-grained rocks show sporadic, sand-sized, detrital quartz grains and rare plagioclase grains in a matrix of sericite and fine-grained, brownish secondary mica (Pl. 5, Fig. 1). There are a few ragged nests of carbonate. The quartz shows strain shadows, and some of it has been granulated and "smeared out" into lenses and streaks. The matrix is traversed by many parallel microshears. Some sections show euhedral pyrite, altered to limonite. In one observed case a green, actinolitic amphibole had grown in the "pressure shadow" of a pyrite euhedron, and had partially altered to chlorite. Unless there was retrogressive metamorphism, of which there is practically no evidence, this rock never attained the metamorphic grade of schist; it is at best a low-rank phyllite. The penetrative deformation, however, has been severe, and it is strange that cleavage was not better developed.

The massive-appearing sandy phase in thin section appears to contain abundant detrital quartz grains (Pl. 5, Fig. 2), usually not in contact, set in a matrix of fine-grained recrystallized quartz, sericite, a little fine-grained, secondary brown mica, fairly abundant
Plate 5.

Plane polarized light (x 5)

Figure 1. Pinal schist, fine grained phase. Near Copper Hill Mine (Plate 2, F-10).

Crossed nicols (x 4.5)

Figure 2. Pinal schist, sandy phase near Copper Hill Mine.
secondary magnetite, and accessory apatite and zircon. The detrital quartz shows strain shadows, and the margins of some of the grains are granulated in a manner that suggests the origin of some of the matrix quartz as debris from mechanical abrasion. Some of the detrital quartz has deformed into lenses. Microshears weave through the rock and elements of the matrix are strongly oriented. This sandy phase has probably suffered less penetrative deformation than have the finer-grained types; yet it is surprising that the sandy rock is megascopically so nearly structureless.

Deformation of the Pinal Schist: The structural behavior of the Pinal schist is well displayed in an arroyo below the Copper Hill mine (Pl. 4 and F-10, Pl. 2). In order to gain some idea of the nature of the deformation, these outcrops were mapped at ten feet to the inch. On the resulting map (Pl. 4) the most impressive features are the nearly east-west strikes of the Pinal schist and strands of the Mogul fault, and the folding of the finer-grained members of the schist (Fig. 5) and of many of the fault strands. Coarser-grained, sandy members do not fold closely; where intensely deformed they are reduced to masses of breccia (Figs. 3, 4). This folding, together with other minor features, suggests that the hanging wall of the southward-dipping Mogul fault zone has moved relatively eastward. Sections (Figs. 1, 2, 3 and 4) of these exposures indicate also that the hanging wall has moved relatively downward. The exact manner in which this eastward and downward movement was accomplished is not known. Because this type of deformation occurs in
Figure 1

A "knee" fold in resistant sandy phase of Pinal schist, (light gray) in contact with thin-bedded, silty phase (dark gray). West side of first wash east of Copper Hill Mine, near entrance. Looking westward. The fold suggests downward movement of the hanging wall of the Mogul fault zone.
Located a few yards north of Figure 1 on same side of wash, looking west. Shows drag folding near contact between sandstone member (light gray) and siltstone member (dark gray) of final schist. The folding records the downward motion of the hanging wall of the mogul fault zone. Light gray fragments at left represent thin sandstone beds disrupted by flowage of the siltstone.
On north side of wash about 700 feet east of Copper Hill Mine (Plate II, H-11) looking eastward. A brecciated "knee" fold in the sandstone member of the Pinal schist. The higher beds have gone downward and southward (right) in the hanging wall of the Mogul fault zone.
Northern side of the wash (Plate II, I-11). Looking eastward. Shows a further stage of the same type of drag folding as in Figures 1, 2, and 3. In this case the fold has broken and the brecciated upper limb has ridden southward (right) and downward across the lower limb.
On north side of wash 20 feet north of Figure 4, looking north. Sine-grained phase of Pinal schist with thin, sandy layers sharply folded and overturned eastward.
the Pinal schist only, it is supposed that the deformation began in early Precambrian time. However, the presence in these exposures of poorly cemented tectonic breccias and gouge suggests geologically young movement. The solution appears to be that these structures were active at various times.

Many shears in directions other than east-west are exposed; relative movements on these are shown (Pl. 4). From these exposures one gains the impression that the Pinal schist is here the material expression of the Mogul fault zone. This suggestion appears to be substantiated by the more extensive mapping in this zone (Pl. 2, Pl. 3). In plan, of course, the relative eastward motion of the southern block is the most obvious.

Relation of the Pinal Schist to the Oracle Granite: Approaching the Oracle granite from the Pinal schist of the Mogul fault zone, the first notable structural change at the contact is the disappearance of the many drag folds (Pl. 2), with apparent simplification and intensification of structure. Accompanying this change is a slight coarsening of the grain of the rock and the appearance in it of small but recognizable feldspar porphyroclasts and bands and lenses of quartz. In thin section this material now appears to be mylonite. The specimen taken nearest the contact with Pinal schist (Pl. 6, Fig. 1) shows most plainly the mylonite structure, the quartz and feldspar porphyroclasts being small and inconspicuous. At about 150 feet from the contact (Pl. 6, Fig. 2) larger and more abundant porphyroclasts express the gradually coarsening grain of the rock. A southeastward-plunging lineation (Pl. 2, J, K, and R-11)
Figure 1. Transition zone mylonite, about 50 feet from contact with Pinal schist, (Pl. 2, K-12). Looking west-northwest.

Figure 2. Transition zone mylonite, about 150 feet from contact with Pinal schist, (Pl. 2, K-12). Looking northwest. Remnant porphyroclasts of quartz and plagioclase.
was found in this mylonite.

Farther toward the granite the feldspars become larger and more abundant, and among them potash feldspar becomes increasingly important; the strike begins to turn northward, away from the Mogul fault zone; evidence of mylonization fades, and the rock gradually assumes a more granitic texture. Although the intense planar parallelism of the mylonite weakens northward, an obvious planar structure marked by oriented potash feldspar porphyroblasts, Pinal schist inclusions and oriented femic minerals, persists to the limits of the detailed mapping. This structure gradually swings into a northeasterly direction. The planar parallelism of the granite, the foliation of the transitional mylonite, and the drag folded stratification of the Pinal schist - all appear to be related parts of one large, turned structure. The turn itself is the Mogul fault zone.

The early Precambrian age of the Oracle granite seems to be established by its structural relations to the Pinal schist. It is always in fault contact with younger formations - never in structural continuity with them. The possibility exists that studies of a more regional character may furnish evidence that the Oracle granite is much younger than now thought, but until such evidence is forthcoming it seems best to follow precedence and the local evidence.

Petrography of the Oracle Granite: From the above discussion it is inferred that the Oracle granite was somehow made from the Pinal schist. The very low metamorphic grade of the Pinal schist and the general structural relations seem to favor such an assumption. The presence within the
Oracle granite of thousands of variously recrystallized inclusions of Pinal schist, and the fact that the mineral orientations within cross-cutting aplites and pegmatites fit the regional structural pattern are additional evidence.

The fresh Oracle granite is a handsome rock in which microcline porphyroblasts 8 to 10 centimeters long appear in a groundmass, mainly of coarse quartz anhedral, biotite, and smaller feldspars. In the field the microcline porphyroblasts are found well within the granite mass, while plagioclase feldspar porphyroblasts are found closer to the transition zone. In fact, deep within the granite mass the plagioclase feldspars are no longer porphyroblasts but merely one of the essential minerals.

Only one thin section of the Oracle granite was prepared. In this section the rock is a mosaic of quartz, plagioclase, microcline and biotite (Pl. 7, Fig. 1). By the Tsuobi method the plagioclase was determined as sodic oligoclase. It has been partially altered to sericitic, and some of the plagioclase crystals have myrmekitic outgrowths. The biotite is altered in part to chlorite and is locally replaced along cleavage by sphene. The quartz shows strain shadows, is fractured, contains many rows of dust-like inclusions, and shows a fine network of minute, hair-like inclusions. Much magnetite, probably secondary, appears to have entered along strained and ruptured crystal boundaries. Apatite, in small clear crystals is closely associated with the magnetite. There is a little accessory zircon, most of it as minute
Crossed nicols (x 5)

Figure 1. Oracle granite near Oracle Hill.

Crossed nicols (x 37)

Figure 2. Myrmekite in the Oracle granite or Figure 1.
inclusions in biotite.

Crushed samples of large microcline porphyroblasts showed nearly all of the minerals seen in the thin sections of the granite. This suggests that these large porphyroblasts crystallized late.

In the residue from another crushed sample of Oracle granite, schorlite was identified. This mineral, seen at many places in the field, appears to be a late comer. It may have arrived in Tertiary time, with magnetite and other secondary minerals.

The System Pinal Schist, Samaniego Granite

**Pinal Schist:** Along the southern border of the strip of sediments this early Precambrian rock is, in general, like the Pinal schist on the northern border. On the south there seems to be even more of the light-gray, sandy phase and correspondingly less of the darker, finer-grained phase. As was true at the north, the rock scarcely merits the term schist.

**Deformation of the Pinal Schist:** No detailed study has been made of the structure of this area of the Pinal; therefore, the structure is not definitely known. In general there seems to be a broad arc concave southwestward, beginning at the Canada del Oro on the west, and ending near Charoleau gap on the southeast. Measurements of the attitudes of bedding, particularly near the contact with the younger Precambrian Apache group, help to outline this arc. In detail, however, the Pinal is closely folded on northeasterly axes, and at some places a definite axial plane cleavage is developed in the finer-grained phases. All
observed folds plunge rather steeply southwestward, and it seems that the measurements recorded in the Pinal near the contact with the Apache group may coincide with crests or troughs of these southwestward-plunging folds. Many exposures show faint, crinkled bedding, striking northwesterly, or west-northwesterly, and crossed by cleavage that strikes northeasterly. At some exposures, on the flanks of folds, bedding and cleavage are parallel.

Future work may disclose that the northeasterly folds have a fan-like arrangement such that their trends, beginning at the west, are little east of north, and gradually change to little north of east near Charoleau Gap. Several weeks of detailed field work would be required to confirm this.

Structure of the Samaniego Granite: South of the Samaniego-Pinal contact and east of the Canada del Oro, feldspar phenocrysts, dark inclusions and black biotite flakes of the Samaniego granite lie in planes that strike nearly east-west and dip very steeply northward. This planar structure is approximately parallel to the Pinal-granite contact, and could logically have resulted in the flow of a viscous mass past this border. It was surprising, however, to find that many inclusions, crystals, and even some schlieren are arranged in planes that trend slightly east of north and dip very steeply eastward. In other words, the Samaniego granite in this area has two planar structures approximately at right angles.

In the Charoleau gap area, again, the Samaniego granite was found
to have two steep planar structures approximately at right angles. One of these had a northwesterly strike and a very steep northeasterly dip; the other an east-northeast strike and a very steep northwesterly dip.

It is difficult to account for these two directions of planar structure by any theory of magmatic flow; however, these features recall the two structures, bedding and cleavage, seen in the Pinal schist. In a thin section, oriented to serve as a map, the Samaniego granite shows two parallelisms at right angles to each other. Unfortunately, a good photomicrograph of this thin section could not be obtained, but a photomicrograph, showing mineral alignments in two directions, was obtained from Samaniego granite in a piece of float (Pl. 8, Fig. 1). Probably these are planar structures and are the same as seen in the field. In the Samaniego granite, as in the schist, the northeasterly trending structural planes may have a fan-like arrangement, and the northwesterly ones may form arcs. If future work shows this to be the case, it will appear that the structure of the Samaniego granite is a relic of the Pinal structure.

The Pirate, Charoleau, and other faults shown in this granite (Pl. 1) fit the ancient structure plan, yet weakly cemented gouge and breccia on the trace of these fractures indicate geologically young movements. Just east of the Pirate fault, the Samaniego granite is intensely sheared and reddened over a width of perhaps 200 or 300 yards.

The Pinal-Samaniego Contact. The trace of this contact forms an arc, as previously described. The contact itself is sharp, steep, and irregular, and the contact zone contains abundant aplite. The contacts near
Crossed nicols (x 22)

**Figure 1.** Samaniego granite, float, (Pl. 1, V-20). Shows two directions of mineral orientation like that shown in field. Not oriented.

Plane polarized light (x 4)

**Figure 2.** Final schist near contact with Samaniego granite (Pl. 1, M-1). Horizontal section, arrow points N 50 W. A biotite porphyroblast nearly touches shaft of arrow.
the granite and aplite enclose sharply bounded slabs of Pinal schist. Approaching this margin from the Samaniego granite, one notices that narrow seams of aplite appear parallel to the northerly or northeasterly planar structures. Locally these seams are aplitic schlieren bundles. As the contact is further approached, the aplite seams grow in size and number and turn very abruptly westward to parallel the schist border (Pl. 1, C.F.-11).

The impression gained in the field is that the shears parallel to the northeasterly granite structure have been dragged and bent into parallelism with the schist border and replaced by aplite.

The Samaniego granite, therefore, is related structurally to the Pinal schist. Apparently the later Precambrian Apache series was deposited on the eroded surface of this granite. In the area mapped the Apache is separated from the granite either by the Pinal schist or by a rhyolite dike, but south of the area the Scanlan conglomerate is said to rest directly on "Oracle granite," which seems to be what is herein termed the Samaniego granite. In this case, again the weight of evidence seems to favor an early Precambrian age for the granite, but future studies farther within the Santa Catalinas may bring about a revision of this assignment.

Petrography of the Samaniego Granite and Aplites: In the field the Samaniego granite resembles somewhat the Oracle granite except that the former granite appears significantly coarser-grained, lighter greyish in color, is less weathered, and contains distinctly larger pink feldspar porphyroblasts.
In thin section the minerals of the Samaniego granite differ from those of the Oracle granite in the following respects: plagioclase is more abundant in relation to microcline, and the composition of the plagioclase, as determined by extinction angles on crystals twinned on both carlsbad and albite laws, is slightly more calcic. The plagioclase seems to contain rather less than 80 percent of the albitemolecule.

No myrmekitic outgrowths were seen. The biotite shows a tendency to cluster into nests of medium sized crystals, and it is joined in this rock by hornblende. Sphene appears in abundant sharp euhedral crystals. There is less magnetite, and the mineral appears to be primary rather than secondary, as in the Oracle granite. Both quartz and feldspar are charged with minute dust-like inclusions, but these are not arranged in lines, and no net-like arrangement of fine needles, such as are seen in the Oracle granite, was noticed. Apatite appears in elongated prismatic crystals that are probably also primary. Zircon, which usually appears associated with biotite, occurs in somewhat larger crystals in the Samaniego granite.

The presence of the hornblende, plus the slightly higher anorthite content of the oligoclase, suggests that the Samaniego granite crystallized at a somewhat higher temperature than the Oracle granite.

The aplite is a fine-grained assemblage of potash-feldspar, quartz, and plagioclase, with a little muscovite, biotite, magnetite, apatite, and zircon. The zircons occur in the biotite and are enveloped by pleochroic halos. The amount of plagioclase feldspar is much less than that of quartz or potash-feldspar. A small amount of the quartz occurs as drop-like
inclusions in both feldspars. The boundaries of the essential constituents are sutured, and the texture is hornfels-like.

Metamorphism of the Pinal Schist: As might be expected from the evidence of somewhat higher temperatures associated with the formation of the Oracle granite, the Pinal schist near the granite contact, and locally at some distance from the contact, is obviously recrystallized, and at many places is a garbenschiefer. In thin section there is little to suggest the original detrital origin of the rock. The texture approaches that of a hornfels. The thin section shows essentially a mosaic of quartz and untwinned feldspar in which occurs abundant biotite, andalusite, magnetite, and muscovite, all oriented in bands or layers. Some of the biotite occurs as porphyroblasts. The recrystallization has not destroyed all of the structure of the original sediment (Pl. 8, Fig. 2).

Early Precambrian Rocks as Sources of Later Sediments: Sometime after the initial deformation of the early Precambrian rocks, these materials were eroded and re-deposited. If the younger Precambrian of this area contains debris from the local older Precambrian, one would expect to identify in the Apache series such features as quartz grains with trails of dust-like inclusions and networks of fine needle-like inclusions, as observed in the Oracle granite. The Oracle granite also could have supplied myrmekite grains to accumulating sediments. The Samaniego granite could have furnished quartz and feldspar grains charged uniformly with dust-like inclusions, and both granites would have supplied abundant feldspar unless chemical weathering was intense. The only stable primary
accessory minerals likely to reach the Apache sediments are the Zircon and magnetite of the Samaniego granite.

The Pinal schist could have furnished second-cycle quartz and much fine, paste-like material for matrices. Such pastes could also have been furnished by the decomposition of the feldspars of the granites. It is just possible that some of the andalusite of the metamorphosed Pinal survived an erosion cycle.
LATER PRECAMBRIAN ROCKS AND STRUCTURES

The Pinal-Apache Unconformity

At two places (Pl. 2, K-14, F-11; Pl. 9; Fig. 6) the oldest exposed member of the later Precambrian Apache group was seen to rest on the eroded surface of very steeply-dipping Pinal schist. In both places, and especially at the first one, the Pinal, for a distance of two feet or more below the unconformity, is intensely reddened. Apparently this oxidation occurred before deposition of the Apache group.

The lower part of the Pioneer shale is purplish red, as though this part of the Pioneer were composed of very fine debris from an intensely oxidized surface. These observations suggest that only the stabler constituents of the early Precambrian land survived in the lowest Apache sediments.

Apache Group

Pioneer shale: The oldest exposed member of the Apache group, the Pioneer shale, is in scattered exposures in the central and western parts of the mapped area. (Colored heliotrope on Pls. 1 and 2). The lower part of the formation is banded with alternating purplish-red and light grey, often contorted, beds. The upper part is light grey to dark greenish-grey and massive-appearing. Close inspection shows un­ contorted thin dark laminae. Weathered surfaces are brownish-grey.
Figure 1. On south side of wash (Pl. 2, H-11) looking south. Contact (dark line) between Pinal schist below and Pioneer shale above. A and B are portions shown enlarged Fig. 2 and 3.

Figure 2 (left). Contact shown at A, Figure 1. Laminae of Pioneer shale wedge abruptly at contact.

Figure 3 (right). Contact at B, Fig. 1. Steep dips and sharp fold in Pinal schist overlain unconformably by Pioneer shale.
On eastern side of wash at A-14, Plate II looking eastward. Unconformity between Pinal schist (steep, below) and Pioneer shale (flat, above.) Small amount of breccia along the contact and curvature of beds in Pinal schist suggest relative motion of Pioneer shale toward the south, or southwest (right).
In thin section the lower, or purplish-red colored part, of the Pioneer shale consists of abundant fine angular quartz grains that show strain shadows and contain dust-like particles usually scattered haphazardly in the interior of the grains. At times the dust particles form short hazy lines. Fine hair-like inclusions are present but rare. Other essential minerals are fresh-appearing grains of plagioclase feldspar and microcline, together with some detrital plagioclase, altered almost beyond recognition. Accessory constituents are apatite, zircon, and myrmekite. The matrix appears to be mostly fine-grained silica. Much of the matrix, in local sheared laminae, appears to be crushed and recrystallized detrital grain borders. Very fine black opaque material, probably hematite, occurs throughout the matrix and is especially abundant in certain layers. Secondary calcite is in thin veinlets, and in nests between detrital grains. The original constituents are oriented in bands that must represent original laminae (Pl.10, Fig. 1).

In thin section, the upper part of the Pioneer shale shows rectangular quartz grains oriented to probable primary lamination. The quartz is charged with dust-like inclusions. The grains show strain shadows and are set in a matrix of fine debris in which is much sericitic mica. Locally the micaceous material appears sheared, and the laminae may even be folded. Other detrital grains are plagioclase, microcline, and myrmekite (Pl.10, Fig. 2). Some of the feldspar grains are fresh, others moderately altered and still others intensely altered. Apatite and zircon are accessories.
Plane polarized light (x 4)

Figure 1. Lower part of Pioneer shale (Pl. 2, J-16). Laminae in the fine-grained sediment.

Crossed nicols (x 37)

Figure 2. Upper part of Pioneer shale, (Pl. 2, A-19). Coarser, granitic debris with grains of myrmekite.
The mineral assemblages of both upper and lower parts of this formation indicate that granite was contributing heavily to the sedimentation. Myrmekite and quartz with hair-like inclusions suggest the Oracle granite as the parent. The angularity of the microcline, plagioclase and quartz grains suggests a near-by source. It seems probable that the Pinal schist contributed to some extent, although there is no strong confirmatory evidence.

Association of fresh and intensely weathered feldspars suggests that a weathered surface was being destroyed, and its products mixed with fresher material derived from the places of deepest dissection.

**Barnes Conglomerate:** This, a multi-colored conglomerate, made up of elliptical pebbles and cobbles of quartzite, varying from white through red to purple and dark grey, lies with apparent conformity on the Pioneer shale. Cobbles resembling silicified Pinal schist are rare; pebbles of blood-red jasper somewhat more common. The coarse sandy matrix appears silicious and varies from black in the San Pedro sections, where the formation may be as much as 60 feet or more thick, to greyish-yellow in the Canada del Oro section, where the unit thins to 18 inches. A thin section of the matrix shows the majority of grains to be quartz, of coarse sand size (Pl. 11, Fig. 1), with trails of dust-like inclusions and occasional hair-like inclusions. The quartz grains are angular to subangular and show strain shadows that are obviously related to present grain boundaries. Locally the quartz grains have sutured boundaries that indicate marginal crushing and recrystallization. There are a few chalcedony (jasper) grains, a few that appear
Figure 1. Matrix of the Barnes Conglomerate, (Pl. 1, K-14). Very fine debris is almost lacking in this well-washed sediment.

Figure 2. Dripping Spring quartzite, (Pl. 2, G-16). Angular fragments in abundant matrix of "poured in" sediment.
to be small pieces of sandstone, micropegmatite, and others that suggest fragments of lava. There is some variation in grain size toward fine sand, but almost no very fine-grained material, the grains being cemented by minor amounts of recrystallized silica, sericite, and carbonate. The Barnes conglomerate appears to be a well-washed sediment that has been worked over by waves or currents.

One might postulate the formation of this unit by the action of a transgressing sea, the ellipsoidal pebbles and cobbles being shaped in the surf action. The source of the pebbles is unknown.

**Dripping Spring Quartzite:** The dripping Spring quartzite apparently conformably overlies the Barnes conglomerate. In some places the contact is quite sharp, yet in other places there may be a gradual intertonguing of the two formations obscuring any definite contact. The quartzite is predominantly massive, pale red and fine-grained. It weathers from a light brown to a dark reddish brown. Variations in both color and texture make distinction of this quartzite from younger quartzites difficult. Cross-lamination in Dripping Spring quartzite was not seen in the mapped area. Fossil ripple marks were found in the Canada del Oro section, suggesting deposition in a shallow sea.

The thin section shows the dominant constituent to be very angular quartz in medium to fine sand-size grains. This quartz shows strain shadows and is very locally crushed. It contains a few trails of dust-like inclusions. Other large detrital grains are angular, fresh microcline, chalcedony, and slightly altered plagioclase. Accessory detrital grains are zircon, rutile, sphene, epidote, opaque grains with whitish "fuzzy"
surfaces, probably ilmenite altering to leucoxene, and a few grains doubtfully identified as chloritoid.

The recrystallized matrix is fairly abundant (Pl. 11, Fig. 2). It consists of sericite, which has locally been thrown into micro-folds, and possibly a little fine-grained silica. This sediment is obviously less well washed than the Barnes conglomerate. It also contains some elements foreign to known local source rocks, yet the extreme angularity of the larger grains and freshness of the microcline suggest that much of the material came from no great distance. Possibly the accessory detrital grains, which are comparatively well-rounded, have travelled far.

This is the last indication noted of the Oracle granite contributing to sedimentation until Cretaceous times.

**Mescal Limestone:** The youngest member of the Apache group within the mapped area is the lower cherty unit of the Mescal limestone, which is present only in the Canada del Oro section (Pls. 1 and 2). Where not separated from the underlying Dripping Spring quartzite by a fault, it apparently lies conformably with a gradational contact on the older rock. The lower part of this member is dark grey, weathering to reddish-brown. The upper part is light grey, as though the seas in which deposition took place had become deeper and the water less silty. The upper part, a medium grained limestone with abundant nodules of chert, weathers light grey. Thin sections show small and medium-sized calcite grains and a little secondary quartz in veinlets. Nothing suggesting detrital origin is preserved in the section.
Inferences Regarding Sedimentation of the Apache Group

After the Pinal schist had been reduced to a surface of low relief, and been intensely weathered and finally brought below sea level, deposition began in the Apache sea. The character of the Pioneer shale suggests that products derived from erosion of the weathered Pinal surface were dumped into the sedimentary basin, but the flood of little-altered detritals accompanying the oxidized materials suggests that erosion quickly bit below the weathered zone. The chief contributor to this sedimentation seems to have been the Oracle granite, but some material may have been supplied by the Pinal schist, and there is no definite evidence either for or against the Samaniego granite as a source.

The existence of the Barnes conglomerate as a thin, extensive, well-washed layer, consisting of beautifully rounded pebbles in a coarse sandy matrix, suggests a deposit formed by the destruction of low sea cliffs by an advancing sea. This supposes that the Pioneer shale was overlain by a quartzite member, that supplied the Barnes conglomerate, and the Barnes should now rest on the Pioneer with erosional non-conformity. This is apparently not the case, so the source of the conglomerate remains a mystery.

After deposition of the Barnes conglomerate, poorly washed materials now composing the Dripping Spring quartzite were rapidly poured into a deepening sedimentary basin. Much of this sediment seems to have been transported a relatively short distance, which points to rapid erosion
of a nearby highland, but some of the accessory constituents may have travelled far.

That infilling of the sedimentary basin did not keep pace with sinking is suggested by the upward gradation of the Dripping Spring sediments into the Mescal limestone, a calcitic deposit characteristic of comparatively deep, quiet water. There is both a sedimentational and a structural break between these quiet water deposits and the incoming sands of Cambrian time.

Tectonic Significance of the Distribution of the Mescal Limestone

As mentioned previously, the Mescal limestone is lacking in the San Pedro section, where the Cambrian Troy quartzite rests with erosional unconformity on the Dripping Spring quartzite. In the Canada del Oro section the Mescal remnants are very thin and represent only the lower member of the formation. This condition suggests that the Mescal has been differentially eroded, a condition that in turn suggests differential uplift prior to Troy deposition.

If uplift had been along the northeasterly elements of the structural framework in such a manner as to tilt the final Apache surface southwestward, the Mescal limestone might easily be stripped off the San Pedro section and carried southwestward, beyond the area. This erosion might also be expected to remove the upper part of the Mescal limestone in the Canada del Oro section. However, some Mescal remnants might logically be expected in the San Pedro section, where none have been found. There is a
sharp boundary between the area of no Mescal remnants on the east and the area where some Mescal is preserved, on the west (Pl. 1).

This difficulty is overcome if northwesterly elements of the regional framework, situated in the zone now occupied by the meta-diorite, became active in final Apache time to create some sort of northwest-trending structural terrace on the southwestward-sloping surface. Erosion would remove all of the Mescal from the upper block to the very lip of the terrace. In fact, erosion has bitten into the Dripping Spring quartzite on the upthrown block, destroyed the terrace, and removed the upper part of the Mescal from the downthrown block (Fig. 7 A).

The destruction and subsequent burial of the terrace did not mean the end of the structures that formed the terrace. These primary elements, mildly rejuvenated in final Precambrian time, again play their part in later structural events.
PALEOZOIC ROCKS

Excepting the Middle Cambrian Troy quartzite, the Paleozoic rocks of the mapped area are found only in the San Pedro section. In general the siliceous rocks have suffered little or no metamorphism except induration, and the limestones contain well preserved fossil faunas.

Middle Cambrian Troy Quartzite: The Troy quartzite consists of several distinct members, of which three have been recognized in the mapped area, but mapped as one single unit (Pl. 1). The lowest member is a reddish-brown massive impure quartzite displaying no bedding or laminae. The middle member is a fine sandy and shaley unit containing well-preserved fragments of trilobites tentatively identified by Stoyanow as of the Elrathia-Elrathiella group and also a few specimens close to the Bolaspis groups showing a reduction of the preglabellar boss.1

The upper member of this formation is a greyish pink, medium to coarse-grained, cross-laminated quartzite that weathers from a moderate red to pale reddish brown. This upper member of the Troy quartzite is readily identified in the field, while the two lower members may easily be mistaken for the Dripping Spring quartzite.

The thin section shows the lower member to have been a very well-washed quartz sand (Pl. 12, Fig. 1). It now has a very sparse sericitic-hematitic cement with some secondary silica. There are a few small nests of apparently secondary biotite. The quartz grains have sutured boundaries

Figure 1. Lower member of Troy quartzite (Pl. 2, 4-16). Fine grained, well sorted orthoquartzite.

Figure 2. Middle member of Troy quartzite (pl. 1, x-11). Trilobite spine (?) in fine angular quartz debris with some recrystallized matrix.
are somewhat fractured, and show strain shadows. There is no detrital feldspar. Zircon in subrounded grains is a very minor accessory. A few fragments were seen with structures suggesting organic origin. A small amount of a colorless, apparently secondary mineral with moderately high relief and very low birefringence may be apatite.

The chief detrital constituent of the middle member is angular quartz in fine sand to silt-sized grains. Other detritals are minor amounts of microcline and plagioclase, with some zircon and sphene. Recrystallized cement consisting of chlorite, sericite, some carbonate and hematite is fairly abundant. A few elongated objects, possibly trilobite spines, appear now to be apatite (Pl. 12, Fig. 2).

The upper member consists of subangular quartz grains and a few minute detrital zircons, with a very sparse hematitic cement. Obviously, the original sand was extremely well-washed (Pl. 13, Fig. 1).

**Upper Cambrian Abrigo Formation:** This formation has been mapped as a single unit (Pl. 1), that apparently conformably overlies the Troy quartzite. It is in the San Pedro section only, as are all the younger Paleozoic rocks. It is a thick-to-very-thin bedded, often cross-laminated, hard red and yellow dolomitic limestone that weathers unevenly, with cross laminae emphasized in dark reddish-brown. The rock is surprisingly tough and strong.

In thin section (Pl. 13, Fig 2), the rock consists of dolomite with interstitial chalcedony. The rock is quite porous, evidently as a result of dolomitization. In addition to the chalcedony, the interstices contain an opaque mineral that appears to be limonite after original pyrite.
Figure 1. Upper member of Troy quartzite (Pl. 1, L-11). Very well washed orthoquartzite.

Figure 2. Abrigo formation, (Pl. 1, W-16). Mostly dolomite rhombs with few well rounded quartz grains. Trace of bedding from upper left to lower right.
Upper Devonian Martin Limestone: The Martin limestone unconformably overlies the Abrigo formation with a sharp contact, and no apparent angular disconformity. It is a grey, silty limestone containing many chert nodules and a few fossils characteristic of the upper Devonian period, such as crinoid stems, *Atypa Reticularis* (Linne), and *Spirifer Hungerfordi* Hall.¹ This impure limestone weathers yellowish grey with the iron stained, more resistant chert nodules and silicified fossils protruding from the surface.

A thin section (Pl. 14, Fig. 1) cut through a fossil coral, that proved to be structureless, showed the rock to consist mainly of calcite and quartz in silt-sized grains, a small amount of secondary chalcedony, and some secondary hematite. The Martin appears to be an extremely silty limestone formation.

Upper Devonian Lower Ouray Formation: This formation, called the Lower Ouray by Stoyanow,² conformably overlies the Martin limestone without gradation. It is a friable pink to red sandstone that weathers light reddish-brown. The outcrops of the Lower Ouray formation are quite limited, and no fossils were observed.

The rock, in thin section, is a fine-grained sandstone composed mainly of clear angular quartz grains with a few grains of plagioclase feldspar, zircon,apatite and tourmaline, in a very sparse cement of hematite and siricite.

Apparently upwarping caused the silty, limy sediments of Martin time

---

¹ Stoyanow, A.A., 1953, personal communication.
² Stoyanow, A.A., 1936, p. 489.
Figure 1. Martin limestone. Ragged crystals of carbonate separated by chert. Trace of bedding from upper left to lower right.

Figure 2. Matrix of green Cretaceous (?) conglomerate, (Pl. 1, X-15). Altered plagioclase and quartz (whole) grains in fine grained matrix.
to be followed by the fine, clean sands of the regressive Lower Ouray sea.

*Lower Mississippian Escabrosa Limestone:* The youngest Paleozoic rock found in the area is the Escabrosa limestone which overlies either the Devonian Lower Ouray or Martin limestone. The contact must be unconformable, but no good contact exposures were seen. The Escabrosa is a light grey to white, clean looking, fine-grained limestone that weathers medium grey. Stoyanow has assigned this formation to the Lower Mississippian by the fossil assemblages found in Peppersauce Canyon.¹

---

MESOZOIC ROCKS

The Mesozoic rocks lie nonconformably and disconformably on the Paleozoic formations. Regional uplift in the Triassic and Jurassic periods in southern Arizona "resulted in the sedimentation being confined to the northern half of the state."¹ McKee, describing the Lower Cretaceous deposits of southern Arizona, states:

"The sedimentary record in southern Arizona gives clear evidence of widespread crystal disturbance and uplift between the end of the Paleozoic and the early stages of the Cretaceous. Extensive, thick conglomerate deposits in which gravels locally are of boulder size occur at the base of Cretaceous strata and above Paleozoic rocks in many localities. It is not certain that all such conglomerates are of the same age, for although in some areas the overlying sedimentary sequences are known to be of Early Cretaceous age, in others the dating is open to question and the deposits may be of Late Cretaceous age.

"Best known of the late Mesozoic conglomerates of southern Arizona is the Glance conglomerate, . . . It is the basal unit of a conformable sequence of rocks determined on paleontological evidence to be of Early Cretaceous age."²

As the sediments in the mapped area above the Mississippian Escabrosa limestone are conglomeratic, and often of boulder size, it is supposed that they represent the Glance conglomerate of early Cretaceous age. In the field these sediments show several variations in lithology. The lowest member exposed is a thin bed of red conglomerate

¹. McKee, E. D., 1951, p. 493.
². Ibid, p. 495.
containing limestone fragments of Escabrosa aspect. This is followed by green conglomerates also containing Escabrosa-like limestone pieces. Nonconformably above these two thin conglomerate members is a silty red bed member. The largest and uppermost member of the formation overlies the red bed member with an angular unconformity, and is a poorly sorted, usually green colored conglomerate consisting of angular fragments from several millimeters to several meters in diameter. This uppermost member within the area weathers from a dark greenish brown to dark brown and in places shows spheroidal weathering. No diagnostic fossils were seen.

The various members show great variety in thin section. The matrix of the oldest member, the red conglomerate, consists of sand-sized grains of carbonate debris, some with probable organic structures, in a fine, web-like base of flaky crystals. Some of the flaky crystals are sericite, but most show very low birefringence and may belong to the kaolin group. Magnetite is abundant in .25 mm. grains, some of which are included within the carbonate grains. Many grains are bordered by semi-opaque brown material.

Some of the carbonate grains may represent carbonatized olivine, in which case the included magnetite is explained. One is impressed that much of this debris is of volcanic origin, although there seem to be some sedimentary admixtures. The rock is strikingly different from any of the older formations, and seems to record the onset of new conditions.

The matrix of the green conglomerate shows many coarse carbonate
grains, some obviously derived from limestone, sub-angular quartz grains with hair-like inclusions and trails of dust-like inclusions, moderately fresh to badly altered microcline grains, angular chert, partially carbonatized plagioclase grains, antigorite grains with associated magnetite granules, altered pieces of basic lava, and fragments of sandstone (Pl. 14, Fig. 2). The sparse fine-grained binding material varies in nature from place to place, being locally carbonate, sericite, or chalcedony. The rock seems to record the growing importance of tectonic unrest.

A thin section of the unconformable red bed member (Pl. 15, Fig. 1) shows fine, silt-size, and a few fine, sand-size, quartz grains in a sericitic matrix stained nearly opaque by hematite. The material appears to have undergone soft rock deformation. There are a few bleached spots in which hematite is almost completely lacking.

This striking lithologic change may indicate a period of quiescence, when fine, oxidized sediments accumulated on a flood plain.

Three thin sections of matrices of the stratigraphically highest, thick, massive member of the Cretaceous (?) sediments show the following: In the lower part, grains in the matrix are largely of volcanic origin, together with pieces of schist, some organic fragments and large quartzes, possibly derived from granite, pieces of quartzite and grains of little altered potash feldspar and perthite. Pieces of mafic minerals have altered to a striking, bright green chlorite. A thin section from rock higher in this member shows much less volcanic material, and many more grains that could have been derived from a granitic source. Much of the
Crossed nicols (x 29)

Figure 1. Red bed member of Cretaceous (?) sediments, (Plate 1, A-15). Soft rock deformation in oxidized (dark) and bleached (light) portions.

Crossed nicols (x 10)

Figure 2. Upper part of Cretaceous (?) sediments (Pl. 1, 2-14). Angular, poorly sorted quartz and feldspar in fine-grained matrix traversed by quartz veinlets.
finest debris is now sericite. The thin section from the upper part of
the member (Pl. 15, Fig. 2) shows again important amounts of volcanic
material with much granitic debris. Alteration minerals are epidote,
sericite, dull green chlorite and carbonate.

All matrices in the coarse Cretaceous (?) sediments are practically
unsorted. With the exception of the red bed member, the Cretaceous rocks
are "poured in" sediments with volcanic admixtures. The presence of
granitic debris in these sediments indicates that areas of granite, bur­
ied since the Precambrian, were again exposed.
POST CRETACEOUS SEDIMENTS

The interval of approximately 75,000,000 years between the Cretaceous period and upper Miocene epoch is little known in Southern Arizona. Recent work, however, suggests that the gap may eventually be bridged. In a paper concerning mid-Tertiary deposits in the San Pedro Valley, some 15 miles east of the area under study, R. T. Chew\(^1\) described four sequences of rocks: From oldest to youngest, and also from west to east, he found debris of metamorphosed sediments consisting of conglomerates, sandstones, schists and marbles; secondly, a series of fresh-water limestones and fine conglomerates which he named the Mineta formation; a third sequence of rocks is andesite porphyry intrusive and extrusive which is overlain finally by a fourth group of three distinct units resting on alluvial fan material. This group forms what has been called "Gila conglomerate" in other parts of Arizona.\(^2\) He has field named these units, from oldest to youngest, the Soza beds, the Bar LY beds, and the Banco beds.

Within the Mineta beds Dr. J. F. Lance of the University of Arizona found a few teeth and part of a jaw from a young Rhinoceros, indicative of the upper Oligocene or lower Miocene epochs.\(^3\)

Gila Conglomerate: Within the mapped area (Pl. 1, Z-12-21) is a conglomeratic formation consisting of well consolidated angular pebbles,  

\(^1\) Chew, R. T. (in press).
\(^2\) Ibid.
\(^3\) Lance, J. F., 1954, personal communication.
cobble and boulders of granite, limestones, sandstones, and especially remnants of the disconformably and nonconformably underlying Cretaceous (?) formation. This deposit has been tentatively identified in the field by L. A. Heindl as probably a member of the Gila conglomerate. At one place (Pl. 1, Z-15), a high angle normal fault dropped the Gila conglomerates against the Cretaceous (?). A five foot bed of white volcanic tuff within the Gila conglomerate is present at this exposure. No Gila conglomerate lake bed deposits were seen in the immediate area but are present deep in the San Pedro valley to the east. Correlation between this member of the Gila conglomerate and those studied by Mr. Chew is not now possible.

Rock Dump Material: The rock dump area (Pl. 1, F-8), is probably only a remnant of a much more extensive conglomerate that once covered the Cretaceous (?) surface. It consists of angular rock fragments ranging in kind from the Precambrian Apache group to Cretaceous-like siltstones. Several sedimentary rock types found in the rock dump are not exposed elsewhere in the area. It is not known whether this formation correlates with the Gila conglomerate.

Recent Alluvial Deposits: Alluvial deposits cover a Pinal schist pediment in the extreme western section of the area, and are present in all stream beds and washes. They consist mainly of decomposed granite admixed with weathered pebbles, cobbles and boulders of the Apache group, the Paleozoic quartzites, and a minor amount of all other exposed formations.

Near Oracle Junction the alluvium contains boulders of younger Paleozoic limestones now known to crop out only on the eastern side of the mountains.
LATER DEFORMATIONS

Evidence of the post-Paleozoic deformations is recorded in the Cretaceous (?) rocks, the Gila conglomerate, the Rock Dump material and even in the alluvium. For the purpose of discussion these deformations are somewhat arbitrarily divided into three stages.

Stage I: In pre-Cretaceous (?) time, possibly during the Navadan orogeny, it seems that the northeasterly structures (Fig. 7, B) were tilted about north-west axes, elevating the western part of the area and depressing the eastern part (Fig. 7, C). Possibly the western limit of this tilted block was the Pirate fault (Pl. 1, D-11 to 18). Because of this tilting the Paleozoic section may have been beveled in the west where erosion cut perhaps to the bottom of the upper Cambrian Abrigo formation. The erosional debris of these rocks, plus volcanic and granitic material from bordering areas, may have been transported eastward collecting in basins to form the Cretaceous (?) deposits. It seems that as a result of this stage the upper Paleozoic rocks are not found in place in the Canada del Oro sections.

Stage II: After an interval little known as to nature and duration deformation became active again. Field observations suggest at this stage a relative eastward movement of the entire Santa Catalina mountain block. This movement seems to have been accomplished by a differential eastward shift of many fault­bounded block-like sections, resulting in
Erosion surface at end of Precambrian Era.

(A) Precambrian Apache Group

Section showing possible conditions at end of Paleozoic Era.

(B) Stage I

Tilting of section to the east with subsequent erosion.
the formation of a great arc, concave westward (Fig. 9). The mapped area is located in the northern end of this great arc, and contains three of these differentially eastward moving blocks, namely, the Oracle granite, the sedimentary septum, and the Samaniego granite. Of the three blocks, the Oracle granite had the least relative eastward movement and the Samaniego granite the most.

The Mogul fault, located between the Oracle granite and the sedimentary rocks, being an ancient zone of weakness, now became active again. At this time the hanging wall moved relatively eastward and downward (Figs. 5, 1-4). The mylonites (Pl. 6, Figs. 1,2) of the transition zone were generated as frictional products where the Precambrian swing of the northeasterly Oracle granite structure into parallelism with the Mogul fault zone was tightened. The rock transitions behaved as brittle materials, between the relatively rigid granite and the yielding schist.

The force causing the eastward movement of the sedimentary section must have been deep seated, as the bottom rocks (the early Precambrian Pinal schist) moved eastward relatively farther. Thus the Pioneer shale appears to have moved westward in relation to the Pinal schist (Pl. 9) and the hanging walls of flat thrusts in the Apache series (Pl. 2) seem to have moved relatively westward. If this view is correct, the younger rocks were dragged eastward by the motion of the underlying basement.

As the thinner strata of the Canada del Oro section moved towards the thicker, more resistant Paleozoic and later rocks of the San Pedro section, buckling and upwarping took place in the zone of Precambrian north-west trending structures (at the present site of the meta-diorite)
and motion on these structures was rejuvenated (Fig. 8, D). Probably
the emplacement of the meta-diorite began at this time (Fig. 8, D and E),
as did the intrusion of dikes and sills of andesite and rhyolite. Possibly also the north-west trending dikes of aplite, pegmatite, and
quartz veins in the Oracle granite were emplaced at this time. Diabase
appears to have served as a lubricant for both low-angle thrusts and in
high angle normal faults. It is also found as thick sills in the Apache
group, apparently unrelated to tectonic processes.

The emplacement of the meta-diorite seems to be closely related to
the eastward crowding of the rocks of the Canada del Oro section and to
up-buckling along the ancient northwesterly structures. It seems that
the relative eastward motion has tended to force the meta-diorite into
the growing cross buckle. Obviously, the emplacement of the meta-diorite
was largely controlled by northwesterly structures, but the northeasterly
structures were not dormant at this time. The east-northeastward projection of the meta-diorite (Pl. 1, U 6-17A) suggests that the structures
having this trend were moving also.

In the field the meta-diorite has a light olive green colored matrix
containing light grey feldspar porphyroblasts, and a few dark mafic min-
erals. It weathers from a dark yellowish-brown to a pale olive and is
an extremely tough rock.

The thin section (Fig. 10) shows large subhedral porphyroblasts of
microcline with unsutured boundaries, fresh fragments of sodic plagio-
clase and sodic plagioclase partly altered to sericite, biotite, and
epidote. Sphene is well represented, and a few grains of olivine rimmed
by antigorite and sparse secondary magnetite were seen. Minor amounts of
Above and below: 2 phases of Stage II. A, below, shows accumulation of Rock Dump material to the west.

Stage III. Section suggesting present conditions after continued uplift of meta-diorite and subsequent erosion.
apatite and zircon are associated with the biotite. Quartz is present, but sparse, and usually shows strain shadows.

The field mapping reveals some interesting results of the interplay of northeast and northwest trending structures. For example, on Plate 1, T-13-14 there is an obvious northeast-plunging anticline that, followed northeastward, reverses its plunge to form a basin-like structure (Pl. 1, V-12) that probably marks an intersection with a northwesterly trending down warp. Beyond this basin (Pl. 1, W,X-12) the initial form and plunge of the northeasterly anticline is resumed. Section D-D' approximately follows the axial plane of the northeasterly fold.

In the southeastern corner of the area, a sharp, northeasterly anticline is broken by an axial plane fault. The northwest-trending meta-diorite sends a minor prong along this broken structure.

During the eastward movement of the sedimentary rocks and subsequent up-buckling, erosion stripped much of the Paleozoic and Cretaceous rocks from the upwarped areas and deposited the debris as Rock Dump material in the Canada del Oro section and as Gila type conglomerate on the San Pedro side (Fig. 8, E).

Stage III: In this last stage, which may not yet be closed, there was continued uplift of the sedimentary rocks, especially along the north-west-trending structures in the vicinity of the meta-diorite intrusion. With a few minor exceptions, erosion has stripped this igneous body of nearly all of its sedimentary cover (Fig. 8, F). The Rock Dump material was stripped off the Canada del Oro section, except in one small area (Pl. 1, G, 6-8) and redeposited to the west as pebbles, cobbles, and
SKETCH OF SANTA CATALINA MOUNTAINS
boulders in solidated Recent alluvium.

After the Rock Dump material was stripped from the Canada del Oro section and the Gila type conglomerate was consolidated, most of the area was dropped with relation to the eastern and western borders. The border fault is not exposed in the San Pedro section, but boulders from the Apache group in Recent alluvium east of the fault are topographically much higher than any exposures of the Apache group to the west.

The border fracture in the Canada del Oro district is undoubtedly the Pirate Fault which appears to have a large throw. Some boulders of Barnes conglomerate, weighing several tons, are west of Oracle Junction seven miles away. The later movements on the Pirate fault, therefore, seem to have been reversals of the earlier ones. The relative down drop of the central area also caused the piracy of the main drainage, which once flowed northward and then northeastward into the San Pedro River but now swings about 160 degrees to nearly due south, following the trace of the Pirate fault and exposing in places a fault-line scarp.

Small fault scarps, a foot or less in height, may be seen in little consolidated material in the extreme southwestern section of the area. These scarplets parallel the buried Pirate fault and indicate a continued depression of the eastern side of the fault. Their age may be a matter of a few hundred years.

It seems, then, that whereas the total uplift of the Catalina mountains area was accomplished by synthetic faulting in stage 2, this was changed to antithetic faulting of the central portion of the northern end in the final stage. W. M. Davis\(^1\) recognized the synthetic faulting in

\(^{1}\) Davis, W. M., 1931, pp. 289-317.
Crossed nicols (x 10)

Figure 10. Meta-diorite (Plate 1, m-17). Mostly plagioclase crystals in fluxion arrangement in fine, altered groundmass.
stage 2 in his studies of the Santa Catalinas in 1931. He thought that
during the last stage of faulting the northern end of the mass was
raised. Field evidence does not support this.
MINERALIZATION

In 1954 only one mine, Campo Bonito (Pl. 1, T-9), is in operation within the mapped area. Sphalerite is the main ore, found within the Mogul fault zone where the Oracle granite is in fault contact with a displaced block of Mississippian Escabrosa limestone. No study was made of the mine area because access is prohibited.

The Burney Mines area in the Canada del Oro section (Pl. 1, L-11) was active until recently, when the price of lead and zinc dropped below the economic limit. Lead was mined as galena and cerrusite; zinc as sphalerite; and copper as chalcopyrite, malachite and azurite. Minor gold and silver were found with the ores. The gangue minerals were pyrite, arsenopyrite, calcite, barite, psilomelane, and pyrolusite or wad. Four small mines are located within this area, each having a different set of minerals, yet the mineralization of all being structurally controlled by the intersection of northeast and northwest trending fracture patterns. Northeast trending quartz monzonite dikes that intrude Precambrian Mescal limestone are within or near the mine workings. Although the dikes are essentially barren of ore minerals, their contacts could have served as mineralization channels, especially at intersections with northwest fractures. Mineralization within the mined area appears weak and the ore occurs in pods.

Copper mineralization in the form of malachite, chrysocolla, and azurite is in the transition zone between Pinal schist and Oracle granite at the Copper Hill mine (Pl. 1, F-6) and can be traced southeastward along
BIBLIOGRAPHY


10 pieces
FRACTURES
ALONG A PART OF THE
MOGUL FAULT ZONE

EXPLANATION

SYMBOLS

QTZ VEIN
API APLITE DIKE
Peg. PEGNATITE DIKE
AND. ANDESITE DIKE
RH. RHYOLITE DIKE
DB DIABASE DIKE
GEOLOGICAL RECONNAISSANCE MAP
OF THE
NORTHERN END
OF THE
SANTA CATALINA MOUNTAINS,
ARIZONA

GEOLOGY BY ROBERTS M. WALLACE
UNIVERSITY OF ARIZONA, 1954

PLATE I.

MOGUL FAULT

MAGNETIC DECLINATION
14° EAST

TOPOGRAPHY FROM WINKLEMAN QUADRANGLE
U.S. GEOLOGICAL SURVEY
SCALE 1:24,000

CONTOUR INTERVAL 100 FEET
STRUCTURAL DETAILS
ALONG A PART OF THE
MOGUL FAULT ZONE

SCALE, 1/6000
APPROXIMATELY 1 INCH EQUALS 500 FEET

TOPOGRAPHY & GEOLOGY BY ROBERTS M. WALLACE
UNIVERSITY OF ARIZONA, 1954

EXPLANATION

ALLOUVIAL OVERBURDEN
QUATERNARY

INTRUSIVE
UNKNOWN AGES
DISEASE SILLS & OXES
MIDDLE CAMBRIAN

TROY QUARTZITE
PRECAMBRIAN

MESCAL LIMESTONE
APACHE GROUP

DRIPPING SPRING QUARTZITE
EARLY PRECAMBRIAN

BARNES CONGLOMERATE

PIONEER SHALE

ORACLE GRANITE

FINAL SCHIST

SYMBOLS

PLANAR PARALLELISM IN GRANITE

LINEATION IN PLANAR PARALLELISM, TREND AND PLUNGE

STRIKE AND DIP OF BEDS IN SEDIMENTARY ROCKS

THRUST FAULT, TRIANGLES ON UPTHROWN BLOCK

TRACE OF THRUST FAULT

APPROXIMATE ELEVATION

SMALL MINE OR PROSPECT Pt

ENDS OF CROSS SECTIONS

LITHOLOGIC CONTACTS

FAULTED CONTACTS

INTERMITTENT STREAM DRAINAGE

CONTOUR LINE
MAP OF
STRUCTURAL DEFORMATION
OF THE
PINAL SCHIST
IN THE
MOGUL FAULT