GEOLOGY OF THE OWL HEAD MINING DISTRICT,
FINAL COUNTY, ARIZONA

by
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A Thesis Submitted to the Faculty of the
DEPARTMENT OF GEOLOGY
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF SCIENCE
In the Graduate College
THE UNIVERSITY OF ARIZONA

1962
STATEMENT BY AUTHOR

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GEOLOGY OF THE OWL HEAD MINING DISTRICT,
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ABSTRACT

The Owl Head mining district is located in south-central Pinal County, Arizona, within the Basin and Range province. Land forms, particularly pediments, characteristic of this province are abundant in this area.

Precambrian rocks of the Owl Head mining district include the Pinal schist; gneiss; intrusions of granite, quartz monzonite, and quartz diorite; and small amounts of Dripping Spring quartzite and metamorphosed Mescal limestone. These have been intruded by dikes and plugs of diorite and andesite, and are unconformably overlain by volcanic rocks and continental sedimentary rocks of Tertiary and Quaternary age. No rocks of the Paleozoic and Mesozoic eras have been recognized.

The structural trends of the Owl Head mining district probably reflect four major lineament directions. The dominant structural trends found in the area are north and northwest. Subordinate to these directions are northeast and easterly trends. The strike of the northerly trend varies from due north to N30°E and was probably developed during
the Mazatzal Revolution. The northwest trend has probably been superposed over the northerly trend at some later date.

Copper mineralization is abundant in the area and prospecting by both individuals and mining companies has been extensive. To date no ore body of any magnitude has been found, but evidence suggests that an economic copper deposit may exist within the area. The copper mineralization visible at the surface consists mainly of the secondary copper minerals chrysocolla, malachite, azurite, and chalcocite with chrysocolla being by far the most abundant. Copper minerals are found to occur in all rocks older than middle Tertiary age.

Placer magnetite deposits are found in the alluvial material of this area, and one such deposit is now being mined.
ACKNOWLEDGMENTS

This thesis was prepared under the direction of Dr. Thomas W. Hitcham, to whom I wish to express my appreciation for his guidance and helpful criticism given during the course of this study.

I am also grateful to other faculty members and graduate students of the University of Arizona and personnel of mining companies who have given time and assistance toward the completion of this problem.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>1</td>
</tr>
<tr>
<td>Purpose of the Study</td>
<td>1</td>
</tr>
<tr>
<td>Previous Study</td>
<td>3</td>
</tr>
<tr>
<td>Methods and Procedures of the Study</td>
<td>3</td>
</tr>
<tr>
<td>Climate</td>
<td>5</td>
</tr>
<tr>
<td>Topography and Drainage</td>
<td>5</td>
</tr>
<tr>
<td>Flora and Fauna</td>
<td>7</td>
</tr>
<tr>
<td>Present Use</td>
<td>9</td>
</tr>
<tr>
<td>GEOMORPHOLOGY</td>
<td>10</td>
</tr>
<tr>
<td>ROCK UNITS</td>
<td>16</td>
</tr>
<tr>
<td>Metamorphic Rocks</td>
<td>16</td>
</tr>
<tr>
<td>Gneiss</td>
<td>16</td>
</tr>
<tr>
<td>Pinal Schist</td>
<td>17</td>
</tr>
<tr>
<td>Igneous Intrusive Rocks</td>
<td>21</td>
</tr>
<tr>
<td>Owl Head Intrusives</td>
<td>21</td>
</tr>
<tr>
<td>Durham Granite</td>
<td>24</td>
</tr>
<tr>
<td>Antelope Quartz Diorite</td>
<td>26</td>
</tr>
<tr>
<td>Diorite and Quartz Diorite</td>
<td>26</td>
</tr>
<tr>
<td>&quot;Basalt&quot; Dikes</td>
<td>28</td>
</tr>
<tr>
<td>Effusive Rocks</td>
<td>28</td>
</tr>
<tr>
<td>Early Tertiary Volcanic Rocks</td>
<td>28</td>
</tr>
<tr>
<td>Late Tertiary or Quaternary Volcanic Rocks</td>
<td>34</td>
</tr>
<tr>
<td>Sedimentary Rocks</td>
<td>35</td>
</tr>
<tr>
<td>Mescal Limestone and Dripping Spring Quartzite</td>
<td>35</td>
</tr>
<tr>
<td>Pantano Formation</td>
<td>36</td>
</tr>
<tr>
<td>Late Tertiary and Quaternary Sedimentary Rocks</td>
<td>39</td>
</tr>
</tbody>
</table>
TECTONIC STRUCTURE .................................................. 40
Faults ................................................................. 40
Dikes and Veins ....................................................... 42
Foliation and Bedding ............................................. 45
Regional Setting ....................................................... 48

GEOLOGIC HISTORY .................................................... 49

ECONOMIC GEOLOGY .................................................... 52

Mining History ......................................................... 52
Mineralization and Mineral Deposits ......................... 53

Huerfanito Copper Deposit ....................................... 54
Big Nine and Related Prospects ................................. 55
Durham Hills Deposit .............................................. 57
San Juan Deposit ..................................................... 59
Blue Star Mine ....................................................... 61
Amygdule Copper Deposit ...................................... 62
Miscellaneous Deposits ........................................... 64
Placer Magnetite Deposits ..................................... 65

Future Possibilities .................................................. 69

BIBLIOGRAPHY .......................................................... 72
LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Index map</td>
<td>2</td>
</tr>
<tr>
<td>2. Vegetation types</td>
<td>8</td>
</tr>
<tr>
<td>3. Gravity profile</td>
<td>12</td>
</tr>
<tr>
<td>4. Aerial view from above the southernmost butte of the Owl Head Buttes, looking to the northeast</td>
<td>23</td>
</tr>
<tr>
<td>5. Fault contact of agglomerate and ignimbrite on eastern side of northernmost butte of Owl Head Buttes</td>
<td>30</td>
</tr>
<tr>
<td>6. Agglomerate at northernmost butte of Owl Head Buttes</td>
<td>32</td>
</tr>
<tr>
<td>7. Red tuff overlying recrystallized limestone, west of southernmost butte of Owl Head Buttes</td>
<td>32</td>
</tr>
<tr>
<td>8. Pantano Formation conglomerates south of Three Buttes</td>
<td>37</td>
</tr>
<tr>
<td>9. Mineralized quartzite outcrop at the San Juan property</td>
<td>60</td>
</tr>
<tr>
<td>10. Fault and vein at the Blue Star mine</td>
<td>63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Geologic map of the Owl Head mining district</td>
<td>in pocket</td>
</tr>
</tbody>
</table>
INTRODUCTION

Location

The area studied is located in Pinal County in south-central Arizona and includes approximately 180 square miles. This tract is bounded on the east and west, respectively, by the meridians 111°00' and 111°15'; on the north by the 32°45' parallel; and on the south by pipeline and powerline maintenance roads, as shown in Figure 1. Most of the area studied is within the Owl Head mining district, although the exact boundaries of the district have not been officially defined.

The primary access roads into the area are U.S. Route 89, State Route 84, and the Red Rock road, which is a dirt road maintained by the county. Secondary and mining roads exist on which it is possible to drive, during most of the year, to within one and one-half miles of any point in the area.

Purpose of the Study

At the present time almost no published information exists concerning the Owl Head mining district and its surrounding territory. The purpose of this study was to map the general geology of the area with emphasis being placed on the mineralization present.
Previous Study

The first known discussion of the Owl Head mining district is in a 1912 report by Pickard. In this report the history, general geology, and mineralogy of the Apache mines area was discussed and a deep drilling program was recommended.

Petth (1951), in a structural reconnaissance of the Red Rock quadrangle, mapped Desert Peak. Two, approximately north-trending, faults were mapped, and Desert Peak was described as being composed of metamorphic rocks.

In 1959 the Geologic Map of Pinal County, Arizona, was published by the Arizona Bureau of Mines. This map, though necessarily inaccurate in detail since it was published at a scale of 1:375,000, proved to be an invaluable source of information concerning the general geology of the area.

Halva (1961) made a study of the basalts of southern Arizona. This study included the basalt-like dike that composes a major portion of Three Buttes and other closely associated, low lying hills in the southeastern part of the problem area. Thin sections were made of the dike material, and it was found to be an augite andesite. Halva also approximated the age of dike as Plio-Pleistocene.

Certain mining companies have conducted exploration programs in this area. Some results of these studies were made available to the author.

Methods and Procedures of the Study

Data for this study were gathered by means of field mapping and the study of aerial photographs. Extensive use was made of U.S. Geologic
Survey high-altitude aerial photographs for locating faults, determining extent of outcrops, and tracing contacts. The information thus gained was then checked in the field for validity. Other data were acquired by direct mapping in the field, using as a base U.S. Geologic Survey advance topographic sheets with a scale of 1:24,000. The Tortolita Mountains 15-minute quadrangle map was used as a base for the final geologic map.

The following procedure was designed for mapping faults: (1) if no evidence could be found on the ground of a fault that seemed to exist on the photograph and if there was no negative field evidence of faulting, then this fault was listed as possible; (2) if there was some evidence on the ground of a fault indicated by the photographs, then this was listed as a probable fault; (3) if good evidence existed both on the photographs and in the field, then this was listed on the map as a certain fault.

The basis for interpretation of the concealed bedrock surfaces of the area is a gravity survey conducted by Dennis Peterson, a graduate student at the University of Arizona. Peterson used a Worden gravimeter with a sensitivity of 0.4994 mg. per scale division. The survey consisted of values taken at one mile intervals along the Red Rock road. A bench mark near Red Rock, Arizona, whose gravity value had been previously established by Peterson, was used as a local base. The assumed gravity value for the basement rocks of the area was 2.67. All values were calculated relative to the absolute gravity (G = 979.2429 gals) at the U.S.C. and G.S. magnetic observatory in Tucson. The author accompanied Peterson on the survey, but made no calculation of the gathered data. However, the geologic interpretation of Peterson's corrected values is that of the author.
Only the very common and the problematical rock types were studied in thin section. The remainder were described from hand specimens.

The study of the mineralization was limited to surface exposures and shallow workings. The general state of disrepair of underground workings prevented their investigation in detail.

**Climate**

The semi-arid climate which exists in this area is fairly typical of that common throughout the southern Basin and Range province. In summer the days are quite hot with much cooler nights, and the days during July and August are often brought to a close by a torrential type rainfall. A large portion of the annual rainfall occurs during these two months and from December through February.

Although no weather recording station exists in the area, temperature and rainfall data can be interpreted from the published information of nearby recording stations. The mean annual temperature is about 65°F, and the average rainfall is slightly more than 10 inches per year. Because of the large changes in elevation within the area, the temperature and rainfall vary rather markedly and the above figures are averages for the area as a whole (Smith, 1956).

**Topography and Drainage**

The general topographic form, broad alluvial valleys with intervening mountain ranges rising out of the alluvial cover, of the Owl Head mining district and surrounding area conforms to that common in the southern Basin
and Range province. The mountainous portion of the area lies approximately on a medial line and in general has a northerly trend, which partially reflects some of the major structure found in the area.

The western third of the area is essentially a featureless plain, which slopes to the west. The middle and southeastern sections of the area show more relief, these being the areas of bedrock outcrop and dissected bajadas of the Tortolita Mountains. The northeastern portion seems to be a continuation of the western plain, and in the extreme northeast corner bedrock is again encountered and the land surface begins to rise.

The high points of the area are in the southeast and northeast where the elevations are 3,770 feet and 3,730 feet, respectively. From these points the slope is rather gradual and to the west. This slope is interrupted by the central mountains, which reach a height of 3,369 feet, before continuing on to a low of 1,970 feet in the southwestern corner. The maximum relief is 1,800 feet.

All streams are intermittent and with few exceptions flow westward. In the western portion of the mapped area the stream pattern could best be described as parallel, presumably controlled by the westward sloping surface. In areas where outcrops exist or the bedrock is near the surface, there are local deviations from the westward flow pattern. Such streams are usually controlled by structural features as bedding and faulting.

All drainage is to the Santa Cruz River, which lies west of the area. The largest wash is Coronado Wash, which extends completely across the area and drains a large segment of the east-central portion of the Tortolita Mountains quadrangle.
Flora and Fauna

Two vegetation types are found in the mapped area. These are the southern desert shrub and the desert grassland. Almost all of the area is southern desert shrub with a small tract in the southeast corner consisting of desert grassland, as shown in Figure 2.

Shrubs, small trees, and cacti are the dominant types of growth found in the southern desert shrub type of vegetation. Near the washes, where moisture is more prevalent, certain trees are common that usually do not exist on adjacent higher ground. These are blue palo-verde, mesquite, and the tree-sized catclaw. On the uplands the more common plants found are creosote-bush, bur-sage, saltbush, and many types of cacti. Many of these plants are useful for distinguishing certain soil environments. For example, a pure stand of creosote-bush indicates a deep, fine textured, and slightly alkaline soil; bur-sage indicates a well drained, essentially neutral soil; and a combination of palo-verde, bur-sage, and a variety of other species indicate a shallow soil with appreciable amounts of caliche.

Within the mapped area the desert grassland type of vegetation is found above an elevation of about 3,200 feet on the dissected bajada north of the Tortolita Mountains. The more common plants in this type include mesquite, burrowweed, ocotilla, cholla cactus, and a number of grasses, which make the area valuable for grazing (Humphrey, 1960, p. 32-59).

The wildlife in the area includes most types that are common throughout the semi-arid Southwest. Game birds such as quail and dove abound along with cottontails and jack rabbits. Deer and javalinas are not an uncommon sight, their tracks often being seen in the dry washes. Although Gila
Vegetation Types

Figure 2

monsters and rattlesnakes are seldom seen, the smaller species of reptiles appear to be the most common type of wildlife in this region. Small burrowing mammals are also quite prevalent.

**Present Use**

The permanent population of the area probably never exceeds 25 people, and most of these are engaged in ranching. The part of the mapped area covered with southern desert shrub produces little forage and will support only three to six head of cattle per section. The small area of desert grassland will support approximately 20 head of cattle per section yearlong, and it is rather heavily grazed. Since no natural surface water exists in the area throughout most of the year, tanks and water wells are common sights. In at least two instances water for cattle is derived from some of the old mines, being pumped from approximately the 125 foot level.
GEOMORPHOLOGY

The geomorphology of this region is a product of the semi-arid climate, and its stage of development is governed by the fact that recent deformation has been relatively mild. The logical product of this set of conditions would be extensive pediments and associated land forms. Field observation, study of aerial photographs, and a gravity survey have lent some support to the existence of these land forms but have not definitely confirmed it.

Segments of pediments that show abundant outcrop are not uncommon within the mapped area. These segments can be found east of the central portion of the Durham Hills, west of the Owl Head Buttes, and possibly between Black Mountain and the Suizo Mountains.

The outcropping portion of the pediment east of the Durham Hills is limited in extent. It is cut on a granite whose outcrop is quite continuous over an area of approximately one square mile. There is no information available to the author as to the possible extent of this pediment under the alluvial cover to the east.

Probably the best example of a pediment in the area is found to the west of the Owl Head Buttes. The outcropping portion of this

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1 In this thesis pediments are defined as being "gently inclined planate erosion surfaces carved in bedrock and generally veneered with fluvial gravels." (Childs, 1948, p.369)
pediment is composed of granite, and the rock plain slopes gently to the west. The portion of this pediment that is visible in outcrop extends west of the Buttes for approximately three fourths of a mile and has a north-south extent of about three miles.

To the west of Black Mountain and east of the Suizo Mountains are some outcrops of schist and granite. These outcrops may represent portions of two pediments that have now been faulted or dissected by stream erosion.

North of the Tortolita Mountains is a rock plain, composed of granite, that has all but one of the characteristics of a pediment. No alluvial valley exists north of the approximately east-west trending mountain front. This rock plain has probably been formed by lateral erosion of east-west trending streams.

The study of the portions of the pediments that are covered by alluvium proved to be more difficult than the study of those portions that were exposed. Aerial photographs proved of little use, and field observation was of questionable value in this type of study. The only other information available to the author was the driller's logs of three wells in the southwestern part of the mapped area and the gravity survey. The wells all bottomed in alluvium below 500 feet, thereby limiting the possible extent of any pediment beneath the alluvium to the south and southwest. The gravity survey consisted of taking gravity values along the Red Rock road each time the road was crossed by a section line. These values were then corrected and plotted in profile, as shown in Figure 3. The gravity values seemed
For location of lettered points see Plate I

Gravity Profile

Vertical Scale: 1 inch = 1 mg.
to indicate that in the area between the Suizo Mountains and Desert Peak the basement rock was relatively shallow and possibly undulating. The author interpreted this bedrock surface to be a pediment. Three causes are proposed for the undulations found in the profile of gravity values: (1) the pediment has been dissected by stream erosion, (2) the pediment has been faulted, or (3) the pediment is carved on rock types with widely differing gravity values.

Further evidence that the area in question is a pediment is the presence of Desert Peak, the Huerfano, and other low lying hills. Desert Peak is composed of metamorphic rock, and its eastern most projection consists of schist quite similar to some found in the Suizo Mountains. The Huerfano and a few other small hills surrounding it are composed of an ignimbrite. Evidence seems to indicate that these volcanic rocks are not of great thickness and are supported by basement rock not far beneath the present surface.

The predominant land forms of this area are the pediments, but other land forms related to pediment formation do exist. A bajada can be seen on the northern side of the Tortolita Mountains and another at the foot of Black Mountain. Both of these bajadas are deeply dissected, and the Tortolita Mountains bajada is now partially disconnected from its source. The Huerfano and associated hills are erosional remnants and fit perfectly the definition of island hills or huerfanos. They are composed of volcanic rock surrounded completely by younger alluvial material. Desert Peak might also be called a huerfano.
Pediment passes also exist within this area of extensive pediments. If the rock plain north of the Tortolita Mountains can be called a pediment, then the area between the southern part of the Owl Head Buttes and the Tortolitas is a perfect example of a pediment pass. Between the northern portion of the Suizo Mountains and the southern part of the Durham Hills, another pediment gap probably exists.

The stream pattern within this area is predominantly parallel with the flow direction westward to the Santa Cruz River, which is the local base level. In the western part of the Tortolita Mountains quadrangle the pattern becomes slightly radial. The gentle westward slope of the surface is the most logical control for this pattern, but there is some evidence for east-west faulting, which may be an additional cause. Local deviations from this pattern are not uncommon, and usually they can be attributed to control by bedding or foliation in areas of bedrock outcrop. However, there is at least one example of a major deviation that is almost entirely within alluvial material. This deviation is a change in the trend of the usually dry channels of the two major streams of the area, Coronado Wash and Durham Wash, and the nearby and intervening smaller streams. The washes abruptly change direction from almost east-west to approximately N50°E. The abruptness of this change, the large number of streams that are affected, and the consistency of the change indicate that this deviation is caused by fault control of these streams.

The alluvium in the mapped area has undoubtedly been deeper in the past. Heindl (1959, p. 4) states that the valley fill of some
southern Arizona basins has locally undergone two or more stages of erosion. Within the general area of the Owl Head mining district, this statement seems to be confirmed by the multiple concordant levels of the summits of alluvial hills.\(^2\) Further work in this area may make it possible to correlate these surfaces with the erosion levels in the San Pedro Valley as defined by Bryan (1926).

Some of the streams within the mapped area are probably superposed over the lower bedrock hills. However, no evidence was found to indicate that the gaps formed by Coronado and Durham Washes, as they cut through the Suizo and Durham Mountains, respectively, were formed by a process of superposition.

\(^2\)This phenomenon is particularly evident in an area near Catalina, Arizona, which is slightly to the south and east of the mapped area.
ROCK UNITS

Metamorphic Rocks

Gneiss. Outcrops of gneiss with a high per cent of biotite are found on the western side of the Suizo Mountains, in the southern part of the Durham Hills, and in the bodies of quartz diorite between the Durham Hills and Black Mountain.

In the Suizo Mountains this gneiss lies below, and is also in contact with, other biotite-poor schists and gneisses, which have been mapped as older Precambrian by the author and on the Geologic Map of Pinal County. In this area the contact between the lighter-colored metamorphic rocks and the gneiss containing biotite, the foliation of this gneiss, and the foliation and relic bedding of the overlying lighter-colored metamorphic rocks are all parallel.

The outcrops of gneiss containing biotite in the southern part of the Durham Hills and in the bodies of quartz diorite found between the Durham Hills and Black Mountain have the appearance of inclusions, some of which are one-half acre in size. Throughout the granite complex of the Durham Hills, inclusions as small as one-half inch in length are found. These smaller inclusions are more schistose than gneissic, but in most cases the foliation of the larger outcrops of gneiss and the axes of elongation of the smaller inclusions are parallel to the ENE structural direction defined by the large k-feldspar crystals in the Durham granite.
The fact that this gneiss is found as inclusions within the Durham granite and that it lies below the Final schist indicates an older Precambrian age. It is possible that the gneiss containing biotite is a lower portion of the Final schist complex, but it is mapped as a separate unit on Plate I.

Most of Desert Peak is composed of a greenish gray gneiss. Conformably overlying this gneiss is a body of biotite-muscovite schist, which has been mapped as older Precambrian Final schist. Because of the probable similarity in age and in some cases a similarity of lithology, both the greenish gray gneiss and the gneiss containing a high per cent of biotite have been incorporated into one map unit on Plate I.

**Final Schist.** Schists, phyllites, and smaller amounts of gneiss crop out in much of the central portion of the Owl Head mining district. In general, these metamorphic rocks designated as Final schist can be put into two broad classifications, depending upon the type and intensity of metamorphism to which they have been subjected. An artificial division between the two types, which may have some structural significance, can be envisioned as an east-west line approximately defined by the Red Rock road. North of this dividing line the metamorphic rocks were subjected to a period of rather intense cataclastic deformation that was probably imposed on the product of an earlier
period of metamorphism.  

South of the Red Rock road the metamorphic rocks have undergone only mild metamorphism and show the characteristics of the greenschist facies.

In the southern part of the mapped area metamorphic rocks almost completely surround the Owl Head intrusive complex. The most common minerals found in these rocks are quartz and muscovite with smaller amounts of orthoclase, plagioclase, and chlorite. The contact between the intrusive and the metamorphic rocks can seldom be observed, but the attitude of the foliation of the metamorphic rocks usually suggests an intrusive contact along which both concordant and discordant relationships can be found. North and east of Owl Head Butte, where the contact can actually be observed, it is faulted. South of Chief Butte, where the contact of the schist and volcanic rocks is not covered, it is obvious that the volcanic rocks have flowed directly onto a relatively clean erosion surface formed on the schist, while in the general Owl Head Butte area faulting may account for the contact between these two rock types. East of the northernmost butte of the Owl Heads the volcanic-schist contact is definitely formed by a fault. Whether this relationship continues farther to the south is not known.

In the Suico Mountains the predominant rock type is a quartz-sericite schist with smaller amounts of augen gneiss. The most abundant minerals found in these rocks are quartz, sericite, and muscovite with

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3 For a further discussion, please see page 48.
an occasional grain of garnet. Both rock types show abundant evidence of cataclastic deformation. The foliation in the Suizo Mountains strikes NNE and is parallel to the relic bedding, a bedding that is well illustrated by alternating coarse- and fine-grained layers and occasionally by light and dark layers. This situation is also found to hold true in the outcrops of metamorphic rocks in the Durham Hills and in the northeastern portion of the mapped area.

Along the eastern side of the Durham Hills is an outcrop of schist and phyllite compositionally similar to that found in the Suizo Mountains. The outcrop is elongate along a northerly trend approximately conforming to the strike of the foliation, the strike of the relic bedding, and the western contact of the metamorphic rocks with the Durham granite. The eastern contact of this narrow body of schist and phyllite is shared by volcanic rocks of Tertiary age, the Panzano formation, and the Durham granite. This eastern contact with the granite is never visible from the surface, but it presumably is intrusive. The contact with the Tertiary volcanic rocks is probably a flow contact although it also can not be readily studied from the surface.

On the lower slopes of Black Mountain is found an outcrop of biotite schist and quartz-muscovite schist. The foliation of this outcrop strikes approximately N55°W and dips rather steeply to the north toward a coarse-grained, intrusive quartz diorite. This quartz diorite may be a border phase of the large intrusion that the Geologic Map of Pinal County indicates as making up the larger portion of Black Mountain. The contact between these two rock types is covered by a
dry wash filled with sands, which obscures its true nature. A study of the aerial photographs and the stream walls does not indicate faulting parallel to this contact, so it is tentatively called intrusive. To the south and west of Black Mountain the schist is covered by alluvial material.

Another small outcrop of biotite-muscovite schist is found on the eastern flank of Desert Peak. Here the schist overlies a gneiss, and the contact between these two rock types appears to be an erosional contact.

Lance (1939, p. 12) describes the Final schist of southeastern Arizona as being composed chiefly of muscovite quartz and chlorite-muscovite-quartz schist with textures ranging from aphanitic to coarsely crystalline and having in general a light, greenish gray color. He also states that the dominant minerals of the schist are quartz and sericite or muscovite with siren, tourmaline, hornblende, biotite, magnetite, and chlorite being the most common accessory minerals.

DuBois (1959, p. 108-109) describes the Final schist of the Santa Catalina Mountains as consisting of phyllite and quartz-sericite schist, whose major constituents are sericite and quartz with local muscovite, biotite, and chlorite.

The metamorphic rocks of the Owl Head mining district, excluding the greenish gray gneiss and the gneiss containing biotite, show a striking lithologic similarity to the Final schist as described by Lance and DuBois. Also, the northeast trend of the foliation and the fact that these metamorphic rocks are intruded by rocks of possible
older Precambrian age indicate that they may be Pinal schist. These observations, together with the lack of evidence for assigning them to some younger period, substantiate the older Precambrian dating given the metamorphic rocks of the Owl Head mining district.

**Igneous Intrusive Rocks**

Intrusive rocks of varying composition are probably the most abundant rock type of the Owl Head mining district. Only one of these intrusions can actually be dated with any absolute certainty. The remainder, the coarse- and medium-grained intrusives, could theoretically be of any age between older Precambrian and late Cretaceous. However, certain evidence suggests a more limited range of time for their intrusion. The subsequent names assigned to the separate intrusions are only to facilitate their discussion in this paper.

**Owl Head Intrusives.** In the general area of the Apache mines and extending to the north and west is a rather large intrusive complex consisting of three general rock types. These are a coarse-grained quartz monzonite, an aplite, and a quartz diorite. The main mass of the intrusion, which crops out in the general Apache mines area and to the west, shows rapid changes both in texture and composition, and its usual gray color may change to white or pink. Occasionally a directional trend of dark minerals can be observed in this main body, but the lack of good exposures precludes observing this phenomenon over any large area, if it indeed is widespread. Phenocrysts of plagioclase and perthite are the most striking feature of the rock. Their color
in outcrop is light gray and the composition of the plagioclase
is approximately that of oligoclase. This quartz monzonite weathers
to low rolling hills, which are covered with a very coarse sand of
feldspar and quartz derived directly from the quartz monzonite. In
one case, near the Apache mines, some of the biotite of this rock has
been altered to chlorite. Whether this effect is caused by the mineral-
izing fluids is not known.

To the north of the outcrop area of the quartz monzonite,
between the Owl Head Buttes and the volcanic rocks of Chief Butte, an aplitic
facies of this intrusion is found, as shown in Figure 4. The aplitite is
very fine-grained, bright pink in color, and usually does not occur
as dikes but rather as masses lacking any particular geometric form.
Spatially associated with this aplitic facies are a few pegmatites.
The pegmatites occur as masses of nearly 100 per cent quartz or a bright
pink potash feldspar and dikes of very coarse-grained rock probably
near a granite in composition.

The third rock found in association with this intrusive complex
is the quartz diorite. Outcrops of this rock type are found to the
north of the aplitic facies, near the contact of the intrusive and the
Pinal schist. The outcrops of this material are spotty and small and,
although they do not seem to be dikes, the exact relation of this
quartz diorite to the main intrusion is not certain. It may represent
a border facies of the main intrusive mass, or it may have been intruded
at some later date along the contact of the quartz monzonite and the
surrounding metamorphic rocks.
Aerial view from above the southermost butte of the Owl Head Buttes, looking to the northeast. In the lower left corner of the photograph the brownish gray color is caused by Pinal schist and the reddish brown color by the early Tertiary volcanic rocks. Slightly below the center of the photograph the pink color depicts the splite facies of the Owl Head intrusives, and the light gray color in the lower right corner is caused by the quartz monzonite. In the center of the photograph above the splite the brownish gray color is again caused by the Pinal schist, and above this schist the reddish brown hills are composed of early Tertiary volcanic rocks. In the distance is Black Mountain, and the three small hills between Black Mountain and the early Tertiary volcanic rocks are Three Buttes.
The contact between the Owl Head intrusives and the Pinal schist is almost always covered by alluvium. Unfortunately, faulting accounts for this contact in the few localities where it is visible. In other places the position of the intrusives and the direction of foliation of the overlying schist indicate a concordant relationship, while in some areas a discordant but intrusive relationship is indicated. Where the quartz monzonite is found in contact with the volcanics, evidence suggests that the volcanics have been extruded onto a relatively clean erosion surface formed on the older rock.

The author agrees with the older Precambrian age given for this intrusive complex on the Geologic Map of Pinal County because of the lithologic similarity of the quartz monzonite and its aplitic facies to the Oracle granite as described by Schwartz (1953, p.7-8), its intrusive relationship with the Pinal schist, and its geographic relationship to known outcrops of Oracle granite. The Oracle granite crops out approximately 12 miles to the east of the Apache mines.

**Durham Granite.** Granite is found to outcrop along the entire length of the Durham Hills. This granite is almost always the predominant rock type visible at this locality, but it is locally supplanted by relatively wide aplitic dikes. These dikes have been intruded along the faults striking N20°-30°W, which is the dominant structural grain of the area. From the standpoint of composition this rock is on the border line between a quartz monzonite and a
granite. Almost half of the rock is large crystals of perthite and orthoclase, which have a xenomorphic outline in thin section and which are surrounded by a matrix of strained and shattered quartz. These crystals of k-feldspar are oriented NNE and dip approximately 40° to 50° to the east. It seems evident that this rock has been subjected to the same metamorphism and deformation as the schists of the Suizo Mountains. The granite contains inclusions of biotite schist and biotite gneiss, which have been interpreted to be a portion of the Pinal schist complex. The granite is cut by numerous dikes of diorite and quartz diorite, and an occasional thin dike of andesite is encountered.

Along the eastern side of the central portion of the Durham Hills is found an outcrop of quartz-muscovite schist, which has been mapped as Pinal schist. This outcrop of schist superficially appears to be entirely enclosed by granite. The eastern contact of the granite and schist is covered by younger rocks, but the western contact is exposed by an open cut on a small hill west of the main portion of the central part of the Durham Hills. In this cut the contact is almost knife edge in character, and no evidence exists of a chill zone in the granite or of contact metamorphism in the Pinal schist. Faulting probably accounts for the contact at this cut. However, since this cut provides the only means of observing the contact between the schist and granite at the surface, it is not known if the faulting continues for any distance to the north or south.
Antelope Quartz Diorite. Coarse- to medium-grained biotite-quartz diorites are found cropping out exclusively in the northeastern portion of the mapped area. Antelope Peak, part of Black Mountain (in the extreme northeastern portion of the mapped area), and the outcrops located approximately three miles north of Antelope Peak are composed of this type of rock. At Black Mountain and in the outcrops located three miles north of Antelope Peak, the quartz diorite is in contact with, and appears to have intruded, the older Precambrian Pinal schist while the outcrop of the quartz diorite at Antelope Peak is completely isolated and is surrounded by alluvial material. The quartz diorite of Black Mountain appears to have undergone at least one period of metamorphism, but this effect is not particularly evident at Antelope Peak. From field evidence the only statement that can be made concerning the age of the quartz diorite is that it is post-Pinal schist and pre-alluvium, but the entire Black Mountain complex is mapped as older Precambrian on the Geologic Map of Pinal County. From lack of evidence to the contrary, the author has tentatively followed this older Precambrian dating.

Diorite and Quartz Diorite. Dikes ranging in composition from diorite to quartz diorite are numerous in both the Suizo Mountains and the Durham Hills. The dikes have been intruded across the foliation direction along pre-existing fractures. These rocks usually show the typical texture expected in diorite. In outcrop the dikes show a slightly negative relief and weather to a dark, greenish gray, which contrasts sharply with the lighter-colored rocks they have intruded.
Dikes and sills of this general nature are often noted in the geologic literature of southeastern Arizona, as in Ransome (1903, p. 53; 1919, p. 55-56), Short and others (1943, p. 35), Darton (1925, p. 254-255), Ludden (1950, p. 37), and Schwartz (1953, p. 11), and their age is widely disputed. In the Owl Head mining district the dikes are seemingly unaffected by the later stage of metamorphism, which has tentatively been assigned to the late Cretaceous or early Tertiary. One possible exception to this statement is the presence of a rather large amount of potash feldspar in at least one dike of the Durham Hills. Seemingly this mineral could be a product of metamorphism. However, Ransome (1919, p. 55-56) notes a similar rock within some of the diabases of the Ray-Miami, Arizona, area and describes them as a normal differentiation facies of the diabase. The latter process is proposed as having produced this type of rock in the Owl Head mining district.

In the Durham Hills the dikes show little evidence of primary mineralization but have been extensively silicified by the mineralizing fluids. The dikes are usually intruded along the predominant fracture direction that strikes N20°-30°W and has functioned as one of the controls of the mineralizing fluids. The fact that these dikes are not metamorphosed, that they have been intruded along the fractures which controlled the mineralizing fluids, and that they are probably older than some of the volcanic rocks of the area would seem to indicate an early Tertiary dating is correct for the time of their formation.

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For a further discussion, please see page 48.
"Basalt" Dikes. At Three Buttes and to the north and south of these prominences two basic dikes crop out. These dikes were studied by Halva (1961, p. 21) and from thin section studies were described as augite andesites. In hand specimen these dikes appear to be basalt. Phenocrysts of augite and plagioclase are visible in a black aphanitic groundmass. The plagioclase phenocrysts are prominent only in the upper of the two dikes. The weathering of this plagioclase has given the rock a vesicular appearance in outcrop. At Three Buttes the "basalts" are apparently dikes as they cut across the bedding of conglomerates in the Pantano formation, while further to the north, where they are exposed again in Coronado Wash, the attitude of the "basalts" and the sandstones and siltstones is parallel. The most logical explanation for this relationship is that the fault along which these dikes were intruded cuts across the bedding at Three Buttes and then becomes a bedding fault in the sandstones and siltstones where they are exposed in Coronado Wash. Halva (1961, p. 7) estimates the age of these dikes to be Plio-Pleistocene. This age seems reasonable as they intrude the Pantano formation and are covered by Recent alluvium.

Effusive Rocks

Early Tertiary Volcanic Rocks. A section of effusive rocks, estimated to be approximately 5,500 feet thick, is exposed in the general area of Chief Butte. This sequence of volcanic rocks consists
of andesite to basalt flows and acid to intermediate ignimbrites and tuffs. Slightly above the middle of this sequence is found a bed of arkose, which is approximately two to three feet thick. Light grays and browns are the dominant colors of the weathered surface of these rocks, but dark grays, purples, and reds are occasionally encountered. The strike of the layering in the volcanic rocks is consistently N40°W, but the dip varies from 45° to 85° to the northeast. Faulting has caused some repetition of units and in some cases has completely shattered the brittle flows.

The base of this volcanic sequence is in contact with the Final schist. South of the Big Mine where the contact can occasionally be seen, it is apparent that the basal unit of the volcanic sequence flowed onto a relatively clean erosion surface formed on the schist. Fragments of the schist have been incorporated into the flow and have been oriented parallel to its base. The upper units of the volcanic sequence are interbedded with the lower portion of the Pantano formation, but in some cases the contact between the two formations has been faulted.

The volcanic rocks of the Owl Head Buttes are somewhat similar in lithology to those occurring in the Chief Butte area. The uppermost part of the Owl Head Buttes is composed mainly of pink to gray ignimbrites. In at least one instance, at the northernmost prominence, the upper portion of the butte has been faulted into contact with an agglomerate, as shown in Figure 5. This agglomerate contains sub-rounded to sub-angular cobbles and boulders of volcanic rocks up to one and
on escarp side of northwestern butte and Oak Head Buttes
Fault contact of agaricoma (below) and agavimeta (above)

FIGURE 5
one-half feet in diameter, set in a white tuffaceous matrix. This is shown in Figure 6. Other volcanic rocks found in this general area of Owl Head Buttes seem to be composed of andesitic flows and breccias. Here the strike of the layering of the volcanic rocks is almost due north and the dip is approximately 30° to the west. West of the southernmost butte and north of the pipeline road are small outcrops of limestone, which contain large amounts of jasper and have been recrystallized to black calcite. This limestone appears to be interbedded with a red tuff (Figure 7), and these interbedded units are probably faulted into contact with the granitic rock to the west. The outcrop of this limestone is too small to be shown on the geologic map (Plate I), but it has tentatively been dated as early Tertiary in age because of its apparent interbedded relationship with the red tuff, which is of a probable early Tertiary age. The western contact between the Owl Head Buttes volcanic rocks and the basement rocks is usually covered; but in the one locality where the contact is visible (due west of the northernmost butte), it does not appear to be a fault contact. Along the eastern side of the Buttes the volcanic rocks are in contact with the Final schist. The northernmost part of this contact is a fault contact, but the relationship to the south is not known.

To the east of the Owl Head Buttes is an outcrop of dark red to gray volcanic flows and tuffs. These volcanic rocks have been dated
FIGURE 6

Agglomerate at northernmost butte of Owl Head Buttes

FIGURE 7

Red tuff overlying recrystallized limestone, west of southernmost butte of Owl Head Buttes. Only a small portion of the red tuff, the upper six to eight inches of the outcrop, is shown in the photograph.
by the author as early Tertiary because of their lithologic similarity to the volcanic rocks occurring in the Chief Butte area.

The Huefano and the low hills that surround it are composed of a volcanic rock that the author has interpreted to be crystal ignimbrite. This volcanic rock is similar to the ignimbrites found at the Owl Head Buttes and so has been dated early Tertiary.

An attempt was made to correlate the volcanic rocks of the Owl Head mining district with volcanic rocks occurring in other areas in southeastern Arizona. In general, this literature study met with little success due to a lack of accurate lithologic descriptions of the volcanic rocks of the Owl Head mining district and those of other areas. In only one case was any particular lithologic similarity noted between a volcanic sequence of known age and the volcanic sequence in the mapped area. This similarity was found in Brown’s (1939, p. 729-738) description of the Tertiary sequence of volcanics in the Huacson Mountains. Brown’s (p. 713-714) description of the weathered outcrops of both the Cretaceous and Tertiary volcanic rocks also proved interesting. He states that the Cretaceous volcanic rocks weather dark purplish gray to purplish black while the Tertiary volcanic rocks weather various shades of brown. Many of the volcanic rocks of the Chief Butte area also weather to various shades of brown.

An early Tertiary dating for the volcanic sequence is indicated by the fact that the upper part of the sequence in the Chief Butte area is interbedded with the Miocene Pantano formation. Also,
the volcanic rocks in the mapped area are unaffected by the latest stage of metamorphism, which supposedly occurred during post-Cretaceous times. Most of the volcanic rocks of the Owl Head mining district were mapped as Tertiary on the Geologic Map of Pinal County.

*Late Tertiary or Quaternary Volcanic Rocks.* Tuffs and an occasional flow of vesicular basalt and andesite, whose outcrops are rather widely separated from the Tertiary volcanic sequence, are found at certain localities within the mapped area. East of the Suizo Mountains is an outcrop consisting mainly of tuff. As this outcrop is completely surrounded by alluvium, field relations are of little use in determining their age. Their lithology does not indicate that they are part of the early Tertiary volcanic series, and they are mapped as being of Quaternary age on the Geologic Map of Pinal County.

A short distance to the west of Antelope Peak is an outcrop of vesicular basalt that has been tilted to the east. This basalt and the aforementioned tuff are probably of the same approximate age as the augite andesite dikes outcropping at Three Buttes, which Halva (1961, p. 7) dated as Pleistocene.

Other small outcrops of volcanic rocks are found in the northeastern portion of the mapped area. Neither field relations nor the lithology of these rocks have provided sufficient evidence to indicate if they are related to the Fantano, the early Tertiary, or the late Tertiary volcanic rocks. On Plate I they are listed as late Tertiary.
West of Desert Peak is a small, elongate outcrop of reddish brown tuffaceous sandstone. The bedding, which strikes N20°W and dips approximately 12° west, is quite pronounced in this outcrop. Spatially this rock type is near the early Tertiary volcanic rocks. However, its lithology suggests that it is late Tertiary, and it is mapped as such on Plate I.

**Sedimentary Rocks**

**Mescal Limestone and Dripping Spring Quartzite.** One-half mile south of the Red Rock road and two miles west of Three Buttes is an outcrop of quartzite. The quartzite is gray to reddish brown, fine-grained and shows excellent bedding. Its maximum exposed thickness is approximately 30 feet. Nearby, exposed only in a shallow prospect pit, is found a white, coarsely-crystalline marble. At two other localities very small outcrops of these two rocks were found.

Directly to the west of the main quartzite outcrop Pinal schist is encountered; but, because of the alluvial covering occurring in this area, the contact of the quartzite and the schist could not readily be studied. Quartz diorite of the Apache intrusive complex is also found near the quartzite, but here again the contacts were obscured by alluvial cover.

All of the outcrops of the quartzite appear similar to the Dripping Spring quartzite as described by Ransome (1919, p. 41-42). This likeness and the occurrence of marble near the quartzite suggest...
that these two rocks represent the Mescal limestone and the Dripping Spring quartzite of younger Precambrian age. The relationship of the quartzite and the marble to the schist suggests that they may have been faulted into their present position.

**Pantano Formation.** North of Chief Butte and along U.S. Route 89 a series of red to tan sandstones, siltstones, and conglomerates crops out. The lower portion of this series of sedimentary rocks locally is interbedded with the upper flows of the Tertiary volcanic sequence, and these lower units tend more to a light brown color than the red and purples usually encountered. These sedimentary rocks are thin-bedded and show a poor degree of sorting. The roundness of the pebbles, cobbles, and boulders seems to depend on their size—the bigger the rock the greater the roundness—and the distance they were transported. The pebbles that were derived from an acid to intermediate igneous intrusive rock were probably transported farther than the volcanic rocks and therefore show a greater degree of roundness. The lowest units are mainly sandstones, which grade rapidly into bright red and purple conglomerates whose pebbles, cobbles, and boulders are mainly from the Tertiary volcanic sequence. Higher in the sequence at Three Buttes, the pebbles are still of the Tertiary sequence, but the predominant rock type found in the boulders and cobbles is an acid to intermediate igneous intrusive rock (Figure 8).

Sandstones and siltstones crop out again in Coronado Wash where it is crossed by U.S. Route 89. At this locality the sedimentary rocks are both red and tan, and it is not certain exactly where these
FIGURE 3

Pantano formation conglomerates south of Three Buttes
clastic rocks lie in the stratigraphic sequence. To the east of the
Durham Hills red conglomerates containing cobbles derived from an acid
to intermediate igneous rock are again found outcropping above a
thin series of volcanic flows, which may be some of the Pantano
formation volcanic rocks or the upper portion of the early Tertiary
volcanic sequence. West of U.S. 89, near Panther Butte and north,
these sedimentary rocks can rarely be seen in outcrop, but their pres-
ence is confirmed by bright red residual soil. Throughout the sequence
an occasional red or gray volcanic flow is encountered. The
lower beds of the Pantano formation strike parallel to the layering
in the Tertiary volcanic rocks and stand almost vertical, while in
the Three Buttes area a more gentle dip is encountered. Here the
strike is north to N30°W and the dip varies from 10° to 30° to the east.
These sedimentary rocks are covered by Tertiary and Quaternary alluvial
material and in some cases probably by tuffs and basalt flows.

Brennan (1957, p. 14) and Chew (1952, p. 10-14) each described
a sequence of continental sedimentary rocks, which they called
the Pantano formation and the Minata formation, respectively. The
red beds of the Owl Head mining district show a resemblance to both of
these formations. The upper portion of the Minata formation has
been dated as middle Tertiary on fossil evidence (Chew, 1952, p. 21).
The similarity of these continental sedimentary rocks and the fact
that in the Owl Head mining district they lie stratigraphically above
a sequence of volcanic rocks of probable early Tertiary age have influenced
the author to call them Pantoño formation—the older term used for
these beds in southern Arizona—of middle Tertiary age.

**Late Tertiary and Quaternary Sedimentary Rocks.** The youngest
sedimentary rocks of the area are predominantly tan conglomerates
with a few coarse-grained sandstones and arkoses. The oldest of
these rocks are partially compacted and show a rude stratification
while the younger deposits are almost completely unconsolidated.
These alluvial, valley-fill deposits are younger than any other rocks
in the area with the exception of some of the youngest volcanic
rocks. Within the Owl Head mining district the relationship of
the youngest volcanic rocks and the older valley fill is obscured by
a covering of Recent alluvium. However, at numerous other localities
in southern Arizona field work has proved that the latest volcanic
rocks are younger than the oldest portion of the valley fill, as
shown on the Geologic Maps of Pinal and Pima Counties.
TECHNICAL STRUCTURE

Faults

Four general directions of faulting were recognized either in the field or on the aerial photographs during the course of this study. Faults trending northwest and northerly were found to be dominant with faults trending northeast and easterly being subordinate.

The strike of the northwest faulting direction varies between N20°W and N45°W. Numerous examples of this trend were found in both Durham Hills and the Suino Mountains where the faults have often been filled with dikes. Northwest faulting also exists at The Huerfano where the entire northeastern portion of the outcrop is a fault breccia zone, and at the Big Hine where a fault striking approximately N40°W is indicated by a gouge and shatter zone from two to six feet wide. Another example of this trend is found in the southern portion of the Owl Head Buttes. Here faults striking N30°W have set the trend of outcrop for the volcanic rocks and may have moved them into contact with the granite. This trend of faulting is important not only for its frequency of occurrence but also for the fact that it has at least partially controlled much of the copper mineralization found in the area. Faulting along this general trend probably began before early Tertiary times since many of the faults striking N20°W of the Durham Hills have been filled with diorite dikes tentatively dated as early Tertiary.
There is even some indication in the presence of northwest striking
aplite dikes associated with the Durham granite that this northwest
direction was active in older Precambrian time. Since many of these
northwest fractures do carry mineralization and are found cutting
through the sequence of Tertiary volcanic rocks, it is evident that
northwest faults were active after the early Tertiary period of vol-
canism.

Examples of the north-trending fault direction are widespread.
Such examples are found at Desert Peak, in the northern portion of the
Suizo Mountains, and at Owl Head Buttes. The strike of these faults
varies from due north to N15°E, and they are either vertical or dip
steeply to the west. The longitudinal axis of the Suizo Mountains
and the Durham Hills trends generally NNE and may be reflective of
faulting. In the northern portion of the Suizo Mountains is a fault
that strikes N15°E and carries copper mineralization. The presence
of mineralization in this fault suggests that the fault at least
functioned as a conduit during the time of mineralization and may
have been active during this time.

The northeast-faulting trend has a single representative,
which is the probable fault that cuts through the Suizo Mountains
at the gap formed by Coronado Wash. Some evidence for the existence
of this fault—the change in direction of the washes—has been pre-
viously presented on page 14. Other evidence is found in the dis-
ruption of the foliation of the schist and gneiss found in outliers
of Black Mountain and the Suizo Mountains. The strike of this probable
fault is N55°E. On the southern side of Coronado Wash, where it cuts through the Suise Mountains, a body of gneiss outcrops that is not present on the northern side of the wash. This gneiss is probably older than the schist complex of the Suise Mountains. This evidence would indicate that the north side of the fault has moved down in relation to the southern side.

Faults with an approximate due east strike have been mapped at three localities within the Owl Head mining district. In the workings of the Apache mines east-striking faults with a dip of 65° to 85° south seem to be the dominant direction and have partially controlled the emplacement of dikes and mineralizing fluids. Between the two southernmost prominences of the Owl Head Buttes another fault with a general easterly strike was encountered. Here, faulting has affected both the schists and the early Tertiary volcanic rocks and has controlled the copper mineralisation. The third and most obvious member of this trend is found north and east of the Owl Head Buttes where it has faulted the Owl Head intrusives into contact with the metamorphic rocks of the area. Here again no time can be set for the inception of faulting, but the fact that it has affected the early Tertiary volcanic rocks indicates that faulting along this easterly trend was active after early Tertiary time.

Dikes and Veins

Both acidic and basic dikes abound within the mapped area. They are found not only in intrusives and schists, but also cutting
across the bedding and flow directions of the sedimentary and volcanic rocks mapped as the Fantano formation.

The majority of the dikes in the Durham Hills are aplitic in nature. These dikes are associated with the Durham granite, which has intruded the schist complex of the area. Where the aplite is found in the Final schist it has occasionally been intruded parallel to the foliation, but more commonly these acidic dikes follow the northwest-faulting trend, as do most of the diorite dikes. Although both the aplite and diorite dikes are often found intruding parallel fractures, occasionally the younger of the two, the diorite, is found to cut across the aplite.

In the Suizo Mountains basic dikes are common along many small fractures. No particular direction seems to be dominant, but it appears that a flood of magma at one time has intruded and filled all available open fractures.

In the area south of the Red Rock road and west of Chief Butte dikes of pegmatitic granite are found in the schist and gneiss. These dikes have generally been intruded along faults that strike N20°-40°W.

The largest dike in the area is the augite andesite or "basalt" intrusion, which forms a prominence at Three Buttes. Portions of this dike outcrop both north and south of Three Buttes and can be observed just north of the Palo Verde Ranch road and north of the Red Rock road where its outcrop approximately parallels U.S. Route 89. A careful study of the rock types indicates that there are actually
two separate dikes that are parallel and probably were intruded about
the same time. The upper dike is rich in plagioclase phenocrysts while
the lower one is poor in this component. These dikes have been in-
truded into the sequence of volcanic rocks and continental sedimen-
tary rocks of the Pantano formation. At Three Buttes they cut across
the strike of the conglomerates at a 30° angle, while north of the
Red Rock road the dikes appear to be parallel to the strike and dip
of the sedimentary rocks. Halva (1961, p.7) states that these dikes
were probably Plio-Pleistocene in age and represent the last magmatic
activity in the area.

Outcrops on the lower slopes of Black Mountain, in the north-
eastern corner of the mapped area, are composed of Fidal schist and
a quartz diorite, both of which were cut by a number of pegmatite
dikes. The main constituent of the pegmatite is quartz with small
amounts of potash feldspar and muscovite. Where these dikes are
found in the schist, they seem to have been intruded parallel to the
foliation and continue to follow this direction into the quartz dio-
rite except for an occasional small dikelet, which may be transverse
to the general pattern.

The Owl Head intrusives are cut by numerous andesite and dia-
base dikes. These dikes form small, more-resistant knobs in the
gently rolling topography, but their outcrop can never be traced for
any distance because of the extensive cover of the area. The dikes
have been intruded along pre-existing east and northeast fractures.
It is often possible to chip the dike material from the granite wall and observe a slickensided surface attesting to the presence of faulting. The andesitic dikes may be a connection between some of the volcanic rocks of the area and a parent magma at depth. A few andesitic dikes are found in the Durham Hills where they are only a few inches wide, while those at the Apache mines are up to six feet in width.

Two types of veins are encountered in the Owl Head mining district. Quartz veins, which are the most common of the two types, are found at the Blue Star claim on the northern end of the Suizo Mountains and in the workings at the Apache mines. In both cases the vein material is massive and somewhat shattered and appears to have been formed earlier than the copper mineralization for which it often serves as a host. The other type of vein is found at the Big Mine and in the small exposure of tuffaceous sandstone between the Owl Head Buttes and Desert Peak. At these two localities the vein material is barite. The veins could not be readily studied from surface outcrops, but dump specimens indicate that most of the barite is massive. A few specimens showed vugs suggesting open space filling. The age of the barite with relation to the other mineralization is not known.

**Foliation and Bedding**

Foliation and bedding within the Owl Head mining district follows two major trends, N25°-55°W and N20°-30°E. Deviations from
these trends seem to be controlled by local conditions except at Black Mountain, where the strike of the foliation in the Final schist is approximately N65°W. Foliation and relic bedding are parallel in all cases where both are discernible in the metamorphic rocks of one locality.

The northeasterly trend of foliation, which is found in the Suizo Mountains, in the Durham Hills, and at Desert Peak, is typical of older Proterozoic metamorphic rocks and supposedly was formed during the Mesotral Revolution (Lance, 1959, p. 13). Foliation with a northwest strike is dominant throughout the remainder of the Owl Head mining district, but in nearly all cases a northeasterly trend is present. It is possible that the northwest trend is superimposed over the northeast trend.

Elongate vesicles and autocratic texture often lend a directional trend to the volcanic rocks in which they are found. These directional trends are quite consistent within each of the two major outcrops of volcanic rocks in the Owl Head mining district. The volcanic rocks occurring in the Chief Butte area strike N40°W and dip 45° to 85° to the northeast, and the Owl Head Buttes volcanic rocks strike almost due north and dip approximately 30° to the west. There is some correlation of individual units in these two localities, but it does not seem that they are opposing limbs of a large anticline. The exact nature of the deformative stress acting upon the
volcanic rocks is not known, but it is probable that their attitude has been changed by local faulting.

Racial bedding found in the metamorphic rocks of the Suizo Mountains and Durham Hills has a NNE strike and dips to the east, away from the Durham granite. The attitude of the Pantano formation sedimentary rocks constitutes the only other instance where bedding was studied in any detail during the course of this investigation. The lower beds of the Pantano formation in their outcrop directly north of Chief Butte strike N40°W and dip steeply to the north. Moving to the north and east, presumably higher in the stratigraphic column, the attitude changes to a due north strike and the dip is approximately 25° to the east. Still farther to the north, where U.S. 89 crosses Coronado Wash, another outcrop of Pantano sediments is encountered. Here the strike of the bedding planes is approximately N20°W and their dip is 20° to the east. The Pantano formation probably has been affected by at least one period of faulting, and it may have been subjected to mild folding. Rather large and rapid variations in the primary strike and dip would be expected in the Pantano type of sedimentary rocks; and this, rather than folding or faulting, might account for some of the less radical changes in the strikes and dips now found in the Pantano formation. A more detailed study, which is beyond the scope of this investigation, would be necessary before a complete structural understanding of the Pantano formation could be achieved.
Regional Setting

Mayo (1958) shows four different lineament directions that might have had some effect on the structural trends existing within the mapped area. These are: (1) a combination of two lineaments, the southwest Arizona belt and the central Arizona belt, that trend approximately N30°W, (2) the Morenci belt that trends approximately N55°E, (3) the Texas lineament that trends approximately N75°W, with its possible east-trending branch, and (4) the north-trending Utah-Arizona belt. A study of the geologic map of the Owl Head mining district (Plate I) indicates the possibility that all four lineament directions have affected the structure, with the effects of the north and northwest trends being dominant. Evidence of these two trends can be seen in faulting and in the attitude of the bedding, the layering of the volcanic rocks, and the foliation. The effect of the Texas lineament could possibly be represented by the east-trending faults in the southern portion of the area, while the theoretical northeast-trending fault cutting through the Suise Mountains might represent the Morenci belt.
GEOLeOGIC HISTORY

The geologic record within the Owl Head mining district is quite incomplete. This situation has made it necessary for the author to rely heavily upon the work of other geologists in southeastern Arizona for determining a sequence of events and for dating the rock units within the area. Many of the rock units have been dated relative to the periods of metamorphism, which the author has assumed are nearly the same age as the two main stages of metamorphism in the Santa Catalina Mountains. These two periods of metamorphism have been dated as older Precambrian and post-Cretaceous (DuBois, 1959, p. 116).

The oldest rocks found in the mapped area are the schists, phyllites, and gneisses, which are probably the metamorphosed equivalents of sediments deposited in older Precambrian time. The Masatzal Revolution brought to a close this period of sedimentation and metamorphosed the older Precambrian rocks, imposing upon them a NE structural trend. Contemporaneous with or immediately following this period of deformation the Final schist was intruded by granitic rocks, which are represented in the Owl Head mining district by the Owl Head intrusives and the Durham granite.

Pye (1959, p. 6) indicates that the mapped area was once covered by younger Precambrian seas. This statement is tentatively confirmed by the presence of a small outcrop of quartzite and marble.
within the Owl Head mining district. These rocks may be Dripping Spring quartzite and metamorphosed Mescal limestone.

Evidence of the Paleozoic and Mesozoic eras are completely lacking within the mapped area, but the Geologic Maps of Pima and Pinal Counties show that the Owl Head mining district is almost completely surrounded by Paleozoic sedimentary rocks. This fact would seem to indicate that Paleozoic sediments were deposited within this area but were later eroded away. This was probably not the case during the Triassic and Jurassic periods. Heindl (1959, p. 3) states that this span of time was characterized by uplift and erosion. There is some possibility that Cretaceous sediments were deposited in this area, but if they do exist they have not been recognized by the author. Very late in Cretaceous time or during the early Tertiary, the area was again metamorphosed and the rocks of the northern portion of the area were cataclinically deformed. Shortly after the metamorphism and before the period of volcanism numerous diorite and quartz diorite dikes were intruded along pre-existing fracture directions.

Early Tertiary time was characterized by volcanic activity that formed the extensive flows and pyroclastic deposits of the Owl Head mining district. During middle Tertiary time these volcanic rocks and surrounding highlands were eroded, and the resulting material was deposited in a basin. The product of this phase of continental sedimentation is the Pantano formation. Near
the end of the volcanic activity of early Tertiary time there was extensive faulting along a northwest trend and shortly afterward the copper deposits of the area were formed.

Continental sedimentation and intermittent volcanic activity continued through Tertiary time and possibly into the Quaternary when the latest andesite and basalt dikes and flows of the area were formed, and the area was faulted into its present basin- and range-like topography. Extensive erosion of the resulting uplands filled the valleys with alluvial material and began to carve the present land forms. Subsequently, the valley fill was subjected to at least two major stages of erosion.
ECONOMIC GEOLOGY

Copper mineralization is quite common throughout the mapped area, and all rock types except the Tertiary sediments and alluvial material show abundant evidence of primary or secondary mineralization. Most of the mineralization existing at or near the surface is composed of secondary copper minerals with chrysocolla being by far the most abundant. Primary sulphides of copper are almost nonexistent in near-surface workings, but in some cases the presence of gossan prove that they once existed. As is to be expected in an area containing so much copper mineralization, prospecting has been extensive by both individual prospectors and by numerous mining companies. As a result most of the area contains numerous prospect pits and shafts.

Two other types of mineral deposits within the Owl Head mining district have merited the interest of the miner. At one time, silver ore was mined in the district. During recent years, alluvial material has been prospected for deposits of placer magnetite, and one such deposit is now being mined.

Mining History

The history of mining in the Apache mines area dates from pre-1900 when gamboines, Indians, and roving prospectors removed approximately $130,000 worth of silver ore, which was treated at a small mill operating in the district. The property then came into
the possession of a Captain Jeffords, sometimes known as the white chief of the Apache Indians. About 1894 Captain Jeffords gave some twenty claims to Count and Mme. Morajeska, who then resided in Red Rock, Arizona. The Count and Mme. held title to the claims until at least 1912 when the State Engineer of Mines visited the property. He stated that gold, silver, copper, and some lead were found on the property. It is evident from his description of the workings that little development took place from that time to the present (Pickard, 1912).

The only other mention of the Apache mines in the literature was a letter found in the Arizona Bureau of Mines files, dated October 13, 1931, and addressed to Dean G. M. Butler of the University of Arizona. This letter was an inquiry into the status of the Owl Head Copper Company, which had apparently acquired the property from the previous owners. Dean Butler replied as follows: "I am sorry to be forced to tell you that the Owl Head Copper Company has been inactive since 1917, and it is my conviction that it is completely defunct and that the stock is worthless."

**Mineralization and Mineral Deposits**

The mineral deposits in the mapped area vary widely in mineral content, type of deposit, origin of the minerals present, and location. With this wide divergence it seems necessary to discuss the more important deposits separately.
Huerfanito Copper Deposit. A small, but possibly important, copper deposit is located two miles east of Desert Peak. Here an outcrop of tuffaceous sandstone rises out of the alluvial covering. The outcrop is about one acre in size and is elongate N20°W, parallel to the strike of the bedding. This small outcrop is quite isolated, as the alluvial covering extends unbroken in all directions for at least two miles. The workings consist of a single adit, which seems to run for only a short distance into the hill.

Small amounts of gossan indicate that primary mineralization once existed in this deposit. At present mineralization consists mainly of the copper oxides, chrysocolla, malachite, and a little azurite along with an occasional blob of chalcocite and some barite. The underground workings were not studied during the course of this investigation, but a study of the dump samples as well as the surface features suggests that mineralization was localized along one and possibly two fractures. These mineralized fractures were never actually observed because the mineralized portion of the tuffaceous sandstone is covered by either alluvium or dump material. The extent of mineralization under this covering is not known, but three or four feet to the north, where outcrop is encountered, no effect of mineralization can be seen.

Alteration of the tuffaceous sandstone consists of bleaching and some kaolinization. The original rock was dark reddish brown before being exposed to the mineralizing fluids, but locally it has now taken on a cream to tan coloring where it does not contain a large
amount of copper oxide or limonite. Both alteration and mineralization are of low intensity, and it is assumed that the deposit is quite small.

The presence of hot waters in a well one mile south of Desert Peak must be considered when searching for a source for the mineralizing fluids. There is a distance of only two miles separating this well and the mineralized outcrop, and it is quite possible that some correlation exists between the two. If so, the fact that the waters are still fairly hot, being 115°F plus (verbal communication, Richard Shaw, Assistant Agricultural Engineer, University of Arizona), may suggest a fairly recent date for the time of mineralization.

**Big Nine and Related Prospects.** The Big Nine and associated shafts and prospect pits are located south and southeast of Chief Butte within the early Tertiary volcanic sequence. The Big Nine, three other shafts, and several prospects mark a fault that carries much of the mineralization in the area. This fault strikes approximately N35°W and has a variable dip that averages about 65° to the south. The fault, as exposed in the mine workings, consists of a gouge and shatter zone, which is three to five feet wide.

Mineralization at the Big Nine now consists of the copper oxides, malachite, chrysocolla, and azurite, along with limonite and rather large amounts of berthierite. Gossan indicates that primary minerals of copper were once present throughout much of the gouge and shatter zone. Fluids carrying the secondary minerals spread somewhat from the main fault along smaller joints and fractures to points
that never had primary minerals deposited in them. Waste on the dump
of the Big Mine is composed mainly of schist, which would indicate
that a great thickness of volcanic rocks does not exist at this point
and that the main fracture zone almost surely extends into the basement
material.

The only effect of alteration at the Big Mine that is visible
in hand specimen samples is bleaching, and even this effect is quite
limited in extent. Other alteration phenomena may exist at the Big
Mine, but a rather extensive thin section analysis of the aphanitic
volcanics found in this area would be necessary to determine their
nature and extent. An investigation of this type is beyond the scope
of this study.

Smaller fractures, probably associated at least in time to
this main fault, exist in the area and carry small amounts of copper
oxides. Usually the smaller fractures show no evidence that they once
contained primary mineralization, and it may be that the copper now
showing in the very limited workings along these smaller fractures
was first deposited as primary material in the underlying basement
complex.

The volcanic rocks at the Big Mine are early Tertiary in age
and are some of the youngest rocks showing evidence of primary minerali-
ization within the mapped area. This fact would tentatively extend the
time of mineralization within the Owl Head mining district to at least
pre-middle Tertiary.
**Durham Hills Deposit.** The Durham Hills copper deposit is located on the eastern side of this relatively low range of hills and contains the highest grade of copper ore yet developed in the entire mapped area. Two groups are presently working copper deposits in the Durham Hills area. One group has driven a tunnel westward into a hill to the western granite-schist contact where they have encountered high grade secondary copper ore consisting of chalcocite and chrysocolla. One shipment of flux ore from this development assayed approximately 3.5 per cent copper (verbal communication from owner). The second development presently being worked in this area consists of a small pit entirely within the granite. Here again the copper bearing minerals are mainly secondary chalcocite and chrysocolla. The quality of the ore is approximately the same as that found in the other development.

The country rock on the eastern side of the Durham Hills consists of older Precambrian schist intruded by a granite. Both of these rocks have subsequently been cut by several quartz diorite and aplite dikes. The remaining small amount of schist forms an elongate north-trending body whose western contact with the granite was a major control of both the primary and secondary mineralizing fluids. The high concentration of secondary copper minerals along the schist-granite contact seems to have resulted from a leaching of the primary copper values from the schist and the movement of the resulting copper-rich solutions downward until they encountered the granite. The second major control of the primary copper bearing solutions is well illustrated in the small open pit. Here a fault zone that strikes
N20°-30°W has extensively fractured the granite. Evidence of primary mineralization is found along these fractures, and they have apparently exerted some control on the secondary mineralization.

Other development in the area consists of two old shafts, numerous prospect pits, both shallow and deep drilling, and some surface work in the schist. This development has been conducted by a number of individuals and mining companies, and even though the amount of work has been rather extensive, little information gathered by these companies was readily available to the author.

Mineralization in the Durham Hills copper deposit consists of chrysocolla, malachite, azurite, and secondary chalcocite. Associated with the chalcocite is an occasional blob of chalcopyrite. Evidence of primary mineralization exists in both the granite and the schist, but no goosan was found to occur in either the quartz diorite or the aplite although both show the effects of alteration and carry secondary copper values. From the tunnel mineralization extends some distance to the south along the contact of the schist and granite but apparently diminishes somewhat in intensity in this direction. To the east the visible mineralization is limited by the alluvial cover, the volcanic rocks, and the Pantages formation. To the west the effective limit of ore seems to be the granite-schist contact, but the granite contains some mineralization west of this contact. To the north visible mineralization is again limited by the alluvial cover. However, the northern portion of the Durham Hills shows little evidence of mineralization, indicating that mineralization does not extend far in this direction.
Alteration near the Durham Hills copper deposit consists of
kaolinitization of the feldspars of the granite near the main fracture
zone and widespread silicification, which affects all rocks older than
the Tertiary volcanics. Silicification is quite intense along the
northern part of the schist-granite contact and extends some 1,500
feet eastward into the granite. However, the effect of silicification
is much less intense and sometimes entirely lacking along the southern
part of the schist-granite contact.

San Juan Deposit. The San Juan and associated claims are
located approximately one-half mile south of the Red Rock road and
two miles west of Three Buttes. Mineralization is found in three
of the rock types—quartz diorite, quartzite, and schist—present
at this locality. Figure 9 shows a typical mineralized outcrop
of quartzite on the San Juan claim. The marble and volcanic rocks
seem to be completely lacking in copper values. Even though the
volcanic rocks carry no copper mineralization, the effect of mineral-
izing fluids is indicated by the large amounts of secondary quartz
that are present near the mineralized outcrops of the other rock
types. This quartz is thought to be secondary because it is found
in the vesicles and fractures in the volcanic rocks and occasionally
appears to have replaced them.

Abundant evidence of primary mineralization exists in both
the schist and the quartz diorite as disseminated blobs of gossan,
but the quartzite contains no such evidence. The present copper
Mineralized quartzite outcrop at the San Juan property
mineralization consists mainly of the copper oxides, chrysocolla, and malachite, along with small amounts of cuprite, azurite, and secondary chalcocite. Assays of shallow drilling have indicated an average copper content of somewhat less than .10 per cent, but some assays in the quartzite run as high as .36 per cent copper (mining company reports). Alteration of the country rock is almost entirely lacking near this deposit.

The outcrops on the San Juan property are typical pediment outcrops, small, low, numerous along the washes, and sparse on the uplands. Development by numerous prospect pits, one older shaft, and the shallow drilling has been entirely within the outcrops. The extent of these mineralized outcrops is limited on the east by volcanic covering and on the west, south, and north by alluvium. Exactly why the volcanic rocks near this deposit show no copper mineralization is not known, since it is felt that the presence of the large amounts of secondary silica in the volcanic rocks, along with information from other nearby properties, indicates that the volcanic rocks were present at the time of mineralization. The possibility of the continuation of mineralization in the basement rocks under the volcanic rocks is considered to be good.

Blue Star Mine. The Blue Star mine is located on the northern end of the Suizo Mountains. Workings at this property consist of a tunnel and a few prospect pits. Most of these prospects are along one line formed by the outcrop of a vein that strikes N15°W and in which
almost all of the mineralization is located. (Figure 10). The country rock is augen gneiss and schist, and the vein filling consists of a basic dike rock and quartz.

Mineralization consists of chrysocolla and azurite with smaller amounts of malachite. The present owner of the mine has stated that the dike rock contains some copper values, but the presence of these values has not been confirmed by the author. Some evidence of primary mineralization exists, but gossan is rare. The primary mineralization was apparently localized along fractures in the quartz, as is the secondary mineralization. The gneiss and schist appear unaltered, but the dike rock, which is highly weathered, may be in part chloritized by the mineralizing fluids. Limonite staining is common in most places along the strike of the vein, which is one and one-half to two feet wide.

At present the property is being mined for the low grade gem stones found in the vein, but at one time it was apparently mined for its copper values. The initial attempts at mining this property seem to have been unsuccessful, and the mine probably has little future worth if mined for copper values. It is well suited for its present use. This usage consists of periodic mining of quartz colorfully stained with chrysocolla and copper carbonates, which is sold to mineral and rock collectors.

**Amygdale Copper Deposit.** Another copper deposit is found south of Chief Butte and west of the Big Mine, near the contact between the schist and the volcanic rocks. Here chrysocolla has been deposited in the scoriaceous top of a dark brownish gray volcanic flow. A few
FIGURE 10

Fault and vein at the Blue Star mine
small fractures cutting across the flow also contain copper minerals. Some of the vesicles have been elongated parallel to the flow direction. The larger of the vesicles measure three fourths of an inch in length. In some cases the first mineral to be deposited in the vesicles was quartz, which was later covered by the chrysocolla. Occasionally a third mineral, calcite, completely filled the remaining open space. The outcrop of the mineralized portion of this flow can be traced some 750 feet along its strike, and it is located approximately 80 feet above the schist-volcanic contact. Mineralization is not continuous along the entire outcrop of the flow.

The source of this mineralization is uncertain as no evidence of primary mineralization has yet been found in the flow itself. The copper may have come from the Big Mine deposit from which it could have been carried by ground water. Another possibility is that the quartz, chrysocolla, and calcite were deposited by hot spring action.

**Miscellaneous Deposits.** Throughout the Owl Head mining district there are numerous occurrences of small amounts of copper. Most of these contain the copper oxides and little else. Alteration is generally nonexistent, and the copper usually is found along small fractures.

The three deposits in the general Owl Head Buttes area fall into this category. Two of these deposits are found in volcanic rocks and are located on the western side of the Buttes. Both are fracture controlled and actually contain very little copper, though development on the southernmost one has been rather extensive. In both cases
some evidence of primary mineralization exists. The third deposit is located between the two southernmost prominences of the Owl Head Buttes. Here again mineralization occurs along a small fracture, cutting both the schist and volcanic rocks. Some evidence of primary mineralization was found to exist, but the rocks appear to be unaltered. At this locality development consists of a rather shallow shaft and three prospect pits.

Copper is often found in quartz pegmatites, particularly around the Suise Mountains. Both sulphides and oxides of copper are found in three or four of these small pegmatites. At other times pegmatites in this area carry some magnetite and ilmenite.

**Placer Magnetite Deposits.** The Arkota Steel Company, which now has control of some 60 square miles of placer mineral rights within and north of the mapped area, is conducting a mining operation centered at the eastern foot of the northern portion of the Durham hills. The mineral deposit at this property consists of placer magnetite that has been concentrated in the alluvial sands of the area. At present only the sands with a relatively high magnetite content in Bogard Wash, Durham Wash, and their tributaries are being mined. The method of mining and concentrating the ore is quite simple and consists of loading the material into a magnetic concentrator that produces a crude concentration. The material may or may not undergo further treatment at the mine before being shipped to the company's new $1,500,000 plant and smelter, where it is further concentrated and smelted into iron.
In a recent issue of the *Arizona Engineer and Miner*, the Arkota Steel Company's placer magnetite operation was discussed. The article stated that the deposit of placer magnetite covers over 40 thousand acres and contains enough ore, which averages 7 per cent iron, to produce more than 500 million tons of iron. It has been drilled to 800 feet and increases in richness with depth (Clark, 1962).

The placer magnetite now found in the sands at this property almost surely has been derived from the granitic rocks of Black Mountain, which is where such magnetite bearing washes as Bogard originate. The fact that the valley fill in this area has undergone more than one stage of erosion might explain the high concentration, up to 25 per cent, of magnetite in some streams, as this concentration would be at least a secondary and possibly a tertiary rather than a primary one.

The placer magnetite now visible in the dry washes of the area varies in size from a fine to a very coarse sand with the majority of the material falling within the classification of a coarse sand. The magnetite grains are sub-rounded to sub-angular, and some of the larger pieces contain silicate minerals. The alluvial material in which it is found is very poorly sorted and varies in size from boulders to silt. Some of the black metallic material found in these placer deposits is ilmenite or titaniferous magnetite, much of which can be separated by the magnetic concentrator being used at the mine location. One physical property of the sands that hampers concentration
either by screening or by magnetic methods is its wetness. This factor becomes quite important when mining material from the washes during the rainy season.

During the course of this study the author visited the offices of the Arkona Steel Company north of Coolidge, Arizona. Certain reports were made available for study, but other, more detailed reports could not be obtained at this time. The reports contained some assay values, representative samples of which are presented here exactly as they appeared in the company's report.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Assay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit 5 sample 1</td>
<td>5.9% magnetite</td>
</tr>
<tr>
<td>Pit 5 sample 2</td>
<td>6.9% &quot; &quot;</td>
</tr>
<tr>
<td>Pit 5 sample 3</td>
<td>6.4% &quot; &quot;</td>
</tr>
<tr>
<td>Pit 6 sample 4</td>
<td>7.3% &quot; &quot;</td>
</tr>
<tr>
<td>Pit 6 sample 5</td>
<td>6.2% &quot; &quot;</td>
</tr>
<tr>
<td>Pit 7 sample 6</td>
<td>8.6% &quot; &quot;</td>
</tr>
<tr>
<td>#1&lt;sup&gt;5&lt;/sup&gt; Top three feet, NE&lt;sub&gt;1&lt;/sub&gt; Sec. 23, Coon 17</td>
<td>15.1% Magnetite</td>
</tr>
<tr>
<td>#2 Taken from N wall of the wash cut 1 foot back from and across one foot cut. Cut 5.6 feet vertical</td>
<td>10.4% &quot; &quot;</td>
</tr>
<tr>
<td>#2a From wash 15 feet from #2</td>
<td>10.6% &quot; &quot;</td>
</tr>
<tr>
<td>#2b 25 feet from 2a, Hole 3 feet</td>
<td>11.8% &quot; &quot;</td>
</tr>
<tr>
<td>#3 3/4 mile west of 1</td>
<td>9.2% &quot; &quot;</td>
</tr>
<tr>
<td>#3a 200 feet north of #3, Hole 4 feet</td>
<td>16% &quot; &quot;</td>
</tr>
<tr>
<td>#3b 400 feet north of #3, Hole 3 feet</td>
<td>22.7% &quot; &quot;</td>
</tr>
</tbody>
</table>

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<sup>5</sup>Sample locality is approximately two miles east of the point where Durham Wash is crossed by U.S. Route 89.
600 feet north of #3. Hole 3 feet 25.1% magnetite

NE ¼ of Coon 13. Hole 3 feet deep 6.8% " "

Taken from the bottom of #4 plus 3 feet 5.0% " "

The author has little information other than that given above as to how the samples were obtained or the assay was determined. It does not seem that this high average would continue over a large percentage of the area, as these amounts of magnetite would be quite obvious to the naked eye but were seldom observed by the author except in certain washes. From another portion of the reports examined, this author estimated that the magnetite concentrate contained 60 per cent iron and 6½ per cent titanium oxide.

One statement from the reports of the Arkota Steel Company indicated that approximately six per cent magnetite in the sands would be necessary to make the mining profitable. However, the cursory investigation conducted at this property by the author has not confirmed the occurrence over any large area of this percentage of magnetite.

In view of the limited, as well as conflicting, information available to the author, it was not possible to come to any definite conclusions as to the present worth of the placer magnetite properties.
Future Possibilities

Only two known copper deposits seem to merit even a passing comment in this discussion. These two are the San Juan claims and the Durham Hills deposit.

Some evidence would suggest that no copper deposit of significant magnitude exists within the area of mineralized outcrop of the San Juan claims. The low assay values obtained from the drill cuttings and the fact that no evidence of alteration exists at this locality constitute the two main arguments against the existence of a large mineral deposit. But other factors seem to add to the attractiveness of the area around the San Juan property. The drilling was shallow and never encountered the zone of primary mineralization or the zone of secondary enrichment, so the assays indicate only the minimum copper values that could be expected in any theoretical ore body existing within this general area. Mineralization is almost continuous between the Big Mine and the San Juan claims, so there is no reason to believe that the center of the mineralized area has been drilled. Also, the extensive cover, both volcanic rocks and alluvium, leaves a very large area unexplored. The author feels that to date nothing definite has been proven in this area. However, the fact remains that exploration in this area involves a very high risk.

The Durham Hills copper deposit seemingly has little potential for any large mining operation. In both mines now working
within this area the zone of secondary enrichment has been encountered and what probably constitutes the highest grade of copper found in the deposit is now being mined. Both of these ore bodies seem to be small, limited laterally and at depth. Additional pockets of high-grade ore with good fluxing qualities may exist in this area either along the schist-granite contact or along the main fracture direction. These should prove attractive to the individual miner, but both the limited extent and the weak intensity of alteration would appear to limit the possibility of a major deposit existing in this area.

Even though the Owl Head mining district has been rather extensively prospected without such success in the past, the author feels that some possibility still exists for finding an economic copper deposit in this area. This presumption is based on a number of facts. One of the most important is the abundance of copper in outcrops throughout the mapped area. The second consideration is the location of the Owl Head mining district with relation to lineaments. It lies within the area included in the Texas lineament, while the Morenci and Utah-Arizona belts intersect within the limits of the mapped area.

Another positive factor for the existence of an economic copper deposit within the Owl Head mining district is the presence of hot waters, Tertiary flows, and ignimbites, which seem to indicate the presence of Tertiary magmatic activity either within or near
the mapped area. Considering all of these facts it seems that the Owl Head mining district would have some possibility of containing an attractive copper deposit.
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