GEOLOGY OF THE PALO VERDE RANCH AREA,
OWL HEAD MINING DISTRICT,
PINAL COUNTY, ARIZONA

by

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DEPARTMENT OF GEOSCIENCES
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1975
STATEMENT BY AUTHOR

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

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JOHN M. GUILBERT
Professor of Geosciences

[Date]
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ABSTRACT

A quartz diorite intrusion of probable early Tertiary age that crops out over at least 6 square miles in the Palo Verde Ranch area in Pinal County, Arizona was mapped as a distinct intrusion. The quartz diorite intrudes an area comprising Pinal Schist, Oracle granite, andesitic flows, gransaplite, and dike rocks including both pegmatite and diabase. Two major physical features, the Owl Head Buttes and Chief Buttes volcanic areas, both remnants of an extensive early Tertiary series of flows of intermediate composition that covered the area, now remain as lava-capped buttes above the pediment.

Weak but persistent fracture-controlled copper mineralization is found in the quartz diorite and the Pinal Schist at or near their mutual contacts in the form of chrysocolla, malachite, black copper oxides, chalcocite, chalcocyprite, and bornite, in decreasing order. Pyrite is rare.

Alteration related to northeast and northwest-trending fractures increases in intensity from the common propylitic to argillic to the northeast toward the San Juan claims area. A barely discernible increase in copper sulfides mirrors the alteration zoning, although geochemical sampling showed background copper in the quartz diorite to be more uniform away from fractures.
INTRODUCTION

Work was undertaken in the area lying between the Owl Head Buttes and Red Rock Road in southern Pinal County, Arizona, with the hope of establishing the source as well as potential of the weak but widespread mineralization in the district. Prior to this study, no geologic mapping had been done at a scale larger than 1:62,500, consequently substantial areas of mineral outcrop were either designated as alluvium or interpreted as one complete continuous rock unit. It was considered that a scale of 1:12,000 might allow presentation of a more complete picture, including age relationships, structure, rock alteration, and possible mineralization.

Previous Work

The earliest geologic discussion of the Owl Head mining district was by Pickard (1912), and this discussion affords some interesting geographic and mining history. Pickard spoke in glowing terms of the silver and gold mines of the area, citing $500,000 worth of silver ore shipped from the Jesse Benton mines. He reported a "true" gossan with copper stains in and around it and recommended at least several drill holes. The actual existence of such a gossan has not been substantiated.

The Arizona Bureau of Mines published a geologic map of Pinal County, Arizona (Wilson and Moore, 1959) at a scale of 1:375,000. Barter (1962) mapped the Tortolita Mountains quadrangle, excluding the
Tortolita Mountains proper, at a scale of 1:62,500. His work includes all of the area mapped in my study. Although Barter's scale is too small to show detail in areas of spotty outcrop, his work is very accurate and has been most useful as a reference.

Iles (1967) mapped a northwest strip east and north of the study area, which also overlaps 2.5 square miles of the study area in the vicinity of the San Juan claims (Fig. 1). His work provides an accurate outcrop map at a scale of 1:12,000, which has been most useful.

**Methods and Procedures**

The base map used for geologic mapping was constructed by enlarging 1:48:0000 aerial photographs taken by the U.S. Geological Survey to 1:12,000. Because much of the outcrops consisted of small scattered exposures, thorough study required an outcrop map. Contacts were mapped either as actual, as in the case of outcrop-alluvium or outcrop-outcrop contacts, or as approximate (Fig. 2, in pocket). Clusters of small outcrops connected by apparently authigenic, lithologically homogeneous float were mapped as single outcrops. High-altitude NASA color photographs were used where feasible to locate major features, especially faults, and to obtain a broader picture of the surrounding areas.

The following procedures were used to map faults: (1) where a fault could be found on the ground as well as on the aerial photographs in the form of a photolineation or by visible displacements of outcrop along lineations, it was mapped as a definite fault; (2) where the fault was not exposed but was suggested by topography as well as by
Figure 1. Location map of the Palo Verde Ranch area
photographs, the fault was mapped as probable; and (3) where the photographs indicated faulting not found on the ground, the fault was mapped as possible, unless the ground mapping showed enough outcrop to deny the fault.

Thin-section study involved samples of each unit mapped. Most of the work consisted of a study of alteration of the quartz diorite unit, while the remainder was directed at establishing accurate petrographic and lithologic descriptions of the other units mapped. A geochemical study, using both rock-chip as well as stream-sediment samples, was undertaken in the northern part of the study area where copper is the dominant form of mineralization.

Mapping consisted of traversing roads, washes, and fence and power lines. Since the area is low in relief, many compass and pace traverses were made. Traverse frequency was in direct proportion to outcrop frequency as well as apparent alluvial cover, so some small outcrops may have been missed.

Dip and strike of planar features, such as faults, joints, veins, dikes, contacts, and bedding were measured wherever clear expressions of the elements were encountered. However, due to the poor exposures and rubble-covered and heavily weathered outcrops, structure was not easy to describe.

**Size, Location, and Access**

The mapped area is about 14 square miles (36.26 km²) and is located within the Palo Verde Ranch (Fig. 1) in south-central Pinal County, Arizona. The study area is irregularly shaped and is situated
within an area bounded by lat 32°34'30" N. and 33°39' N. and long 111°05' W. and 11°08' W. Access is by Red Rock Road (Fig. 1), now officially Park Links Drive, a wide, well-graded dirt road connecting Interstate 10 near Red Rock and U.S. Highway 90, 10.3 miles (16.6 km) north of Oracle Junction and 34 miles (54.6 km) north of Tucson.

The northern boundary of the mapped area is Red Rock Road, while the southern boundary is irregular, extending south of Owl Head Buttes to the southern limit of conspicuous outcrop west of Owl Head Buttes; the eastern boundary lies at the western edge of the Chief Butte volcanics and avoids the area mapped by Iles (1967). The two study areas overlap at the northeastern edge in the San Juan claims area where the quartz diorite has its eastern margin.

Access to the area is adequate, with poor ungraded jeep trails in the northern part and both a power line and pipe line road across the southern part. A motorcycle was used for travel in some areas, but with only partial success. While it was made for trail riding, the motorcycle could not be used in most washes, and a four-wheel drive jeep was found to be more suitable. Travel cross-country on the motorcycle was not attempted for many reasons. Vegetation, especially heavy stands of cholla, mask the geology and can make motorcycling very dangerous to vehicle and driver.

**Climate**

Climate in the area is typical of that of the lower Sonoran Desert, with hot summers and generally mild winters. The average elevation of the mapped area is about 2,800 feet (853.7 m). Although there
are no weather stations within the area, the approximate temperature and precipitation may be determined by averaging data from two nearby reporting stations at Cortaro at 2,155 feet (657.0 m) elevation, 13 miles (20.9 km) south of Owl Head Buttes, and at the Willow Springs Ranch at 3,690 feet (1,210.2 m) approximately 10 miles (16.1 km) to the northeast. Record temperatures are 107°F (41.7°C) in June and July and 12°F (-11.1°C) in February at Willow Springs and 113°F (45°C) in June, July, and September and 13°F (-10.6°C) in January and February at Cortaro.

Humidity is normally low, except during January and February and July and August, when rains occur quite regularly. The low humidity accounts for an extremely large diurnal variation in temperature, commonly near 60°F (15.5°C). Yearly precipitation averages 10.39 inches (26.4 cm) at Cortaro and 11.40 inches (29 cm) at Willow Springs Ranch. The months with the greatest precipitation are January to March and July to September, with an average of between 2 and 5 inches (5.1 and 7.6 cm) reported for both stations for July, a monthly high for the year. Summer rains are commonly of short duration and may be violent, often closing access into much of the area. First and last dates for frost at Cortaro are November 5 and February 10, respectively, giving an average growing season of 268 days. Light snowfalls in winter are common, but snows are rarely over one foot (30 cm) in depth and rarely are on the ground for more than one day.

Flora and Fauna

A description of southern Arizona vegetation types is beyond the scope of this research, and the reader is referred to Humphrey's
(1958) study. The whole study area lies within the southern vegetation shrub type, which is composed of small shrubs, cacti, and low but commonly large trees of the phreatophytic type. Grasses are a minor constituent of this vegetation type. Areas of alluvial cover commonly have a high density of tall cholla and palo verde, as in the area between Red Rock Road and the San Juan Road. The observation has been made that areas having deep alluvial cover and little or no outcrop are endowed with abundant creosote shrubs. Prickly pear are ubiquitous, but saguaro are commonly restricted to areas underlain by siliceous rocks and are thus a guide to outcrops. This phenomenon may be attributed to the fact that saguaro seeds take root in fractures in the rock. Since the less resistant fractured rock weathers more rapidly, "islands" of more resistant rock are left accompanying the saguaros.

Along washes with alluvial-filled channels, phreatophytes are the dominant vegetation, with mesquite, palo verde, and ironwood present in that order. Catclaw and prickly pear are also abundant near washes. The area lies just below the zone in which yucca is found, but several were observed south of the mapped area in the foothills of the Tortolita Mountains at about 3,400 feet elevation.

The area is heavily populated with desert fauna. Gambel's quail are found in most medium-size washes, as are dove, jackrabbits, and cottontail. Other animals observed included mule deer, javelina, hawk, owl, vulture, Gila monsters, rattlesnakes, tarantulas, and numerous small lizards and burrowing animals. A wild horse was recently observed by a local rancher just south of the mapped area in the northernmost Tortolita Mountains. Mountain lion tracks, 3.5 inches (8.9 cm)
across were measured by me in Parker Wash just south of the Red Rock Road.

**Present Use**

The only permanent residents of the area live at the Palo Verde Ranch headquarters between the northern and southern Owl Head buttes in sec. 5, T. 10 S., R. 12 E. The mapped area lies entirely within the boundaries of the Palo Verde Ranch. Cattle raising is the prime economic use of the land at present, and the area is a popular locality for quail and javelina hunting.

Although various programs of mineral exploration have been and are being undertaken, the only ore shipped in recent years is a small number of tons of high-grade silver-gold ore (W. R. Ewing, oral commun., 1975).
GEOMORPHOLOGY

Regional Geomorphology

The semiarid climate, in which evaporation exceeds rainfall, and the elevation of the area studied are important factors in the production of the present arid landscape. Short torrential rains producing sheetwash and a fairly wide diurnal range in temperature are major factors contributing to physical weathering in the area.

The region in which the mapped area is situated is part of a large, north- to N. 200 W.-trending mountain mass, which drains and slopes to the west and is in the middle stages of erosion, as defined by Thornbury (1954). Drainage in the Tortolita Mountains quadrangle, excepting the extreme southeastern part, is generally in the form of parallel to subparallel ephemeral streams, either ending in relatively flat areas or reaching the local base level, the Santa Cruz River.

According to King (1959), the Tortolita Mountains are in a "fan-bayed" or "fan-frayed" stage, with the Suizo Mountains to the north being in a "fan-bayed" stage. Limiting Basin and Range fault scarps have been eroded, and the ranges are thus placed in a middle stage of erosion.

Thornbury (1954, p. 288) lists three processes for pediment formation: backweathering, sheetwash or sheetflood erosion, and lateral planation. These processes are all in evidence in the Tortolita Mountains area, backweathering and lateral planation by the retreat of the western edge of the Tortolita Mountains and the latter two by the gentle but constant pediment slope west of the Tortolita-Suizo Mountains area.
**Local Geomorphology**

The area mapped is part of a large pediment surface, as shown by a spotty but ample occurrence of outcrop throughout. Differing lithologies have varied geomorphic expression. The volcanic rocks in the area are easy to discern on aerial photographs by their color and are found in outcrops ranging from several feet to several hundred feet above the pediment surface, as in the Owl Head and Chief Butte areas. The quartz diorite is recognized by its light-gray to whitish color and sandy texture. The best exposures are along washes where the only unweathered outcrops are found. The more resistant granite pegmatite forms parallel ridges west of the Chief Butte volcanics and small to large mounds and hills throughout the area. The quartz monzonite, mostly in the southern mapped area, forms subdued, coarse-grained, rubbly hills, with bedrock at or below the ground level. Exposures are often difficult to find due to deep weathering.

Barter (1962) noted that the pass between Owl Head Buttes and the northernmost Tortolita Mountains is a perfect example of a pediment pass. Several washes drain through this pass, although one wash in the northern part of sec. 9, T. 10 S., R. 12 E. makes an abrupt northwest turn and drains through a gap half a mile wide (0.8 km) that separates the Owl Head Buttes in that area. Although Barter suggested a superposition of streams in the region, this stream runs subparallel to local structure through a structural gap. Further to the east, washes in secs. 22, 23, and 27, T. 9 S., R. 12 E. make similar changes in trend from westerly to northwesterly upstream. These streams again appear to follow
local structure, providing negative evidence for superposition in the area.
ROCK DESCRIPTIONS

For descriptive purposes, the rocks mapped on Figure 2 (in pocket) are classified as metamorphic, intrusive, extrusive, and sedimentary.

Metamorphic Rocks

Pinal Schist

Phyllites, schists, quartzites, gneisses, and hornfels have been included under the classification of Pinal Schist. The unit appears to be the local basement rock and is found west of the mapped area in drill holes to depths exceeding 2,500 feet (762.2 m). Within the mapped area, the unit is abundant and is found in contact with all other major units.

The Pinal Schist, named for the Pinal Mountains near Globe, Arizona, was first described by Ransome (1903). Erickson (1962) concluded, after studying a number of well-known localities of the Pinal Schist, that the schist was originally deposited as a series of argillaceous to quartzose sediments intercalated with beds of minor intrusive and extrusive rocks. The series underwent regional metamorphism during the Mazatzal Revolution, although a later, possibly thermal type of metamorphism has been superposed locally by later intrusive rocks. During the Mazatzal Revolution, the sediments were compressed into tight, isoclinal folds, which were shown by Erickson (1962, fig. 2.1) to be
characterized by axial planes trending generally northeast. Deviations from this trend are common (Barter, 1962, plate I; Schmidt, 1967).

In outcrop, the Pinal Schist is commonly found to be a silver-gray or brownish silver gray phyllite, yielding talus mounds of small schistose chips. In several areas, for example, an area just south of the San Juan Road at the eastern edge of sec. 15, T. 9 S., R. 12 E., the schist is actually a quartzite. Three thin sections of Pinal Schist were studied to examine both typical and unusual samples of the schist. The first thin section, 2-30, is of a typical gray phyllite exposed in a wash in the northern part of sec. 28, T. 9 S., R. 12 E., while the second thin section, OH-1, came from a dull, spotted, and weakly foliated phyllite that resembles a hornfels in outcrop. The sample location lies on the eastern side of the southernmost Owl Head butte near some prospects where the rock is mineralized. The third thin section, NW-27A, is for a rock sampled in a contact aureole around a small dike or lens of quartz diorite similar in color to the enclosing Pinal Schist. The quartz diorite contains xenoliths of more mafic and chloritic rock, disseminated sulfides, and oxide copper mineralization. The sample location is in the northeastern corner of sec. 28, T. 9 S., R. 12 E. The compositions for the three rocks represented by thin sections of Pinal Schist are given in Table 1.

Studies of the thin sections of the first two rocks show strong schistosity, while that of the third displays a granoblastic or hornfelsic texture, usually an indication of contact metamorphism but, in this case, a product of retrograde metamorphism superimposed over contact metamorphism. Thin section 2-30 is a chlorite-sericite-quartz phyllite and
Table 1. Composition of samples of Pinal Schist

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<td>60%</td>
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<td>2</td>
<td></td>
</tr>
<tr>
<td>rutile</td>
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<td>1</td>
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<tr>
<td>anthophyllite</td>
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<tr>
<td>calcite</td>
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<td>apatite</td>
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<td>tr</td>
<td></td>
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<tr>
<td>xenotime(?)</td>
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</tbody>
</table>

OH-1 is a sericite-quartz phyllite, both members of the greenschist metamorphic facies. The hornfels, according to Williams, Turner, and Gilbert (1954) fits most closely into the pelitic mineral assemblage of the amphibolite hornfels facies. Assuming the schist to have been remeta-morphosed during the intrusion of the adjacent quartz diorite, biotite in both rocks was altered to chlorite by hydrothermal fluids after the intrusion and metamorphism had taken place. Secondary muscovite appears to have been formed during or after this stage, because textural relationships show the muscovite to be younger than the chlorite and to have been formed at its expense.

Although no actual contact between the Pinal Schist and quartz monzonite was found, one large boulder of float contained a xenolith of Pinal Schist enclosed within the quartz monzonite (Fig. 3).
Figure 3. A blocky hand specimen of quartz monzonite showing an enclosed xenolith of Pinal Schist

The gray xenolith is 17 cm across.
Foliation of the Pinal Schist in the area strikes either northeast or northwest and usually dips steeply. Many small outcrops in the San Juan claims area have foliation deviating from these trends, showing a possibility that these outcrops may be roof pendants in the quartz diorite intrusion. However, the most cursory study of foliation attitudes shows that foliation of the Pinal Schist in that area is quite irregular and only at a larger scale could the structure of the schist be accurately mapped. A study of this nature is beyond the scope of this work.

An older Precambrian date is given for the Pinal Schist on the "Geologic Map of Pinal County," by Wilson and Moore (1959). Six Rb-Sr isotopic age dates from Pinal Schist taken near Ray, Arizona, indicate a date of $1500 \pm 50$ m.y. (Damon, 1966). Silver and Deutsch (1963) obtained a U-Pb date of $1650 \pm 20$ m.y. on zircons from the Johnny Lyon Granodiorite in southeastern Arizona that intrudes the Pinal Schist. This date pushes back the date of the Pinal Schist considerably, to perhaps before 1700 m.y.

**Intrusive Rocks**

**Quartz Monzonite**

A porphyritic quartz monzonite crops out in most of the study area, most extensively in the southern part. Much of the outcrop there is obscured by float from aplite and pegmatite dikes, which intrude the quartz monzonite. The rock is light to dark gray brown, depending on mafic content; it locally displays an olive green hue where the content of chlorite is sufficient. Phenocrysts of plagioclase, perthite, or flesh-colored orthoclase as large as 3 cm are characteristic, while the
phaneritic matrix is composed of grains averaging slightly above 5 mm, making the rock a coarse-grained porphyritic quartz monzonite. Locally, the rock has been weakly metamorphosed and has a gneissic texture. One thin section of typical quartz monzonite was studied. The rock has a holocrystalline, hypidiomorphic–granular texture, with euhedral plagioclase crystals, subhedral microcline and perthite, and anhedral quartz grains. The microcline commonly exhibits a poikilitic texture, hosting small euhedral crystals of plagioclase. A representative composition, in percentages, is: quartz 38, microcline 20, plagioclase 22, perthite 5, biotite 8, magnetite 1, chlorite less than 1, and traces of rutile and zircon. The plagioclase has a composition of oligoclase, with approximately 5 percent of the biotite altered to chlorite. Plagioclase crystals are zoned, with the calcic cores dusted with kaolinite and traces of sericite, leaving clear rims around the edges of crystals. The K-feldspar is fresh and unaltered. Barter (1962) noted biotite alteration to chlorite near the Apache mines and suggested that the alteration was the result of hydrothermal fluids. The sample studied was collected several miles west of the Apache mines in an unmineralized area, which may suggest that weak deuteric alteration is a characteristic feature of the quartz monzonite. A similar description of the alteration is given by Schmidt (1967) for the Ruin Granite, some 40 miles to the north, which was mapped by Wilson and Moore (1959) as one unit with the Oracle granite, which crops out 15 miles east of the Palo Verde Ranch area.

The quartz monzonite appears physically and compositionally very similar to the Oracle granite. This similarity was first mentioned by Barter (1962). The Oracle granite is actually a quartz monzonite
(Banerjee, 1957), and age determinations made by Thomas (1966) using Rb-Sr and K-Ar methods on samples taken in the Oracle, Arizona area allow dates of 1420 to 1450 m.y. to be inferred. An Rb-Sr date on biotite (Damon, 1961) concurs with the 1450 m.y. age. A K-Ar date for the Ruin Granite in the Sierra Ancha Mountains indicates 1500 m.y. (Damon, Livingston, and Erickson, 1962), while an Rb-Sr date for the Ruin Granite from northern Arizona indicates 1450 m.y. (Wasserburg and Lamphere, 1965). Since all three rocks appear to be the same unit, a 1450-1500 m.y. date for the quartz monzonite seems reasonable.

**Diabase**

Numerous small exposures of diabase were mapped throughout most of the study area. Only quartz monzonite and Pinal Schist are found in direct contact with the diabase. Outcrops are highly weathered and are surrounded by alluvium. Outcrops appear mostly in quartz diorite areas, possibly as roof pendants, as is thought of many Pinal Schist outcrops.

The diabase is dark greenish gray to black, and medium-grained laths of plagioclase are visible. The diabase weathers to large spheres, usually about one foot in diameter. This weathering feature, although common to diabase, is similar to weathering characteristics observed in the Salt River Canyon–Globe area. Although very few of the diabasic outcrops exhibited any structure, the few observed showed north-south and N. 45° E. contacts.

Diabase units are tentatively placed in the younger Precambrian age group due to similarities with diabases intruded into much of Arizona
during the Grand Canyon Disturbance. Other small and rare outcrops of basalt and diorite are believed to be separate and later intrusions, but only an extensive dating program can give credence to these beliefs.

Quartz Diorite

A medium-grained, gray, dark greenish gray to pinkish gray rock is found in small but abundant outcrops in the northern part of the area (Fig. 2). Drilling records examined by me from a number of shallow drill holes in sec. 31, T. 9 S., R. 12 E. west of Owl Head Buttes describe a medium-grained, grayish-white, granitic rock, locally reddish brown and biotite rich, from depths of 10 to 100 feet (3 to 30.5 m). The deepest hole was 100 feet. No core was taken, and no definite identification can be made from examination of the cuttings. This information suggests the possibility of extensions of the quartz diorite to the south. The total area of the intrusions ranges from 6 to 10 or more square miles (15.5 to 25.9 km²).

Quartz diorite was not mapped as a separate unit by either Wilson and Moore (1959) or Barter (1962). Barter described the Owl Head intrusive rocks as having a quartz monzonite facies to the south, followed to the north by an aplitic and then quartz diorite facies. This is a generalized picture, both spatially and petrographically. Barter's aplitic facies is found to intrude the quartz monzonite, quartz diorite, and Pinal Schist. Williams and others (1954) describe the diorites as of hybrid origin, being formed either through assimilation of sialic material by basic magma or through digestion of basic country rocks by a more acidic magma. The latter may have been the case, as shown in the
contact aureole with the Pinal Schist, where xenoliths of a mafic (diorite?), chloritic rock with indistinct boundaries are found within the quartz diorite in the northeast corner of sec. 28, T. 9 S., R. 12 E. The assumption that Barter's Owl Head intrusive complex is a single differentiating magmatic mass formed in Precambrian time is contradicted by field relationships where the quartz diorite has intruded the andesites and where the granoaplite facies has intruded the quartz diorite facies. Close examination of a contact between the volcanics and quartz diorite exposed in a prospect pit, 1.25 miles (2 km) N. 10° W. of Chief Butte, showed an inclusion of volcanic rock within the quartz diorite (Fig. 4), illustrating the intrusion of at least part of the volcanics by the quartz diorite. Fragments of the volcanics are also found in brecciated quartz diorite (Fig. 5) next to a contact exposed in Parker Wash in the NW1/4 sec. 23, T. 9 S., R. 12 E. In the NW1/4 sec. 15, T. 9 S., R. 12 E., an unmineralized volcanic breccia is found about 50 feet (15.25 m) south of Suizo Wash. This volcanic breccia contains fresh quartz diorite xenolith fragments (Fig. 6) with sharp boundaries and chrysocolla and malachite in fractures within the quartz diorite.

The quartz diorite in hand specimen is medium grained, commonly equigranular but rarely porphyritic, with plagioclase phenocrysts. Quartz, white plagioclase, biotite, and chlorite are easily distinguished megascopically. The color of the quartz diorite is typically greenish gray. The quartz diorite is less typically found as a purplish-gray, biotite-poor, quartz-rich rock or may be pinkish-gray due to pink feldspars. Contacts are commonly float covered (Fig. 7), with color changes marking the boundaries between the andesite and quartz diorite. In thin
Figure 4. Andesite inclusions in quartz diorite matrix

Figure 5. Contact between andesite and quartz diorite breccia bearing andesite fragments
Figure 6. Andesite bearing xenoliths of quartz diorite

Figure 7. Float contact between andesite (right) and quartz diorite (left)

Small outcrop of quartz diorite visible at left edge of photograph.
section, the rock is holocrystalline, usually hypidiomorphic-granular, but less commonly autoclastic and porphyritic. Ten thin sections made from the quartz diorite samples were studied both for composition and alteration. Alteration will be discussed later in the chapter on economic geology. The composition of the thin sections is given in Table 2. Other accessory minerals present are hematite, zircon, limonite, rutile, apatite, and possibly xenotime. Averages of the data presented in Table 2 show the typical quartz diorite to have 34 percent quartz, 50 percent plagioclase, only slight orthoclase (less than 1 percent), less than 2 percent microcline, 3.5 percent biotite, 5.5 percent chlorite, 2 percent calcite, and less than 1 percent magnetite. Williams and others (1954) define a quartz diorite as a diorite containing over 10 percent quartz with alkali feldspars constituting less than a third of the total feldspars. They propose that many quartz diorites are intermediate, not felsic, rocks, with their lack of orthoclase placing them in the diorite classification.

Plagioclase is generally subhedral, and the more calcic cores are commonly altered to kaolinite or sericite, while the outside or sodic rim is unaltered. In thin section NW27 from a sample taken adjacent to a contact with the Pinal Schist where an autoclastic texture is noticeable, the plagioclase is sheared and strained. The plagioclase is shown by the Michel-Levy method of determining maximum extinction angles of albite twinning to have a composition ranging from oligoclase to andesine, a finding contrary to Iles’ (1967) report that the composition was approximately that of bytownite. The quartz is anhedral, commonly several millimeters in size, as is the plagioclase. Thin section NW21
Table 2. Composition of quartz diorite

<table>
<thead>
<tr>
<th>Mineral</th>
<th>NW23</th>
<th>NE3</th>
<th>2-15</th>
<th>NW27</th>
<th>NW36</th>
<th>NE2</th>
<th>NW2</th>
<th>NW38</th>
<th>NW43</th>
<th>NW21</th>
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<tbody>
<tr>
<td>Quartz</td>
<td>12</td>
<td>30</td>
<td>50</td>
<td>8</td>
<td>50</td>
<td>41</td>
<td>38</td>
<td>45</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>75</td>
<td>50</td>
<td>35</td>
<td>70</td>
<td>40</td>
<td>41</td>
<td>45</td>
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<tr>
<td>Orthoclase</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>3</td>
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<td>3</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td>Microcline</td>
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<td>2</td>
<td>2</td>
<td>3</td>
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</tr>
<tr>
<td>Biotite</td>
<td>--</td>
<td>10</td>
<td>--</td>
<td>--</td>
<td>3</td>
<td>10</td>
<td>3</td>
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</tr>
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<td>Chlorite</td>
<td>3</td>
<td>--</td>
<td>10</td>
<td>13</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Calcite</td>
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<td>2</td>
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<td>1</td>
<td>5</td>
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<td>3</td>
</tr>
<tr>
<td>Epidote</td>
<td>1</td>
<td>tr</td>
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<tr>
<td>Magnetite</td>
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<td>1</td>
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</table>
shows a porphyritic texture, with quartz grains forming a fine-grained groundmass. Typically, the strained quartz grains show undulating extinction and low 2V. Biotite is subhedral to anhedral and is commonly replaced by at least 50 percent chlorite as well as by calcite and by epidote in smaller amounts.

Iles proposed a Laramide age for the quartz diorite because of the copper mineralization present in it. He further stated that in six southeastern Arizona districts igneous rocks related to copper mineralization range in age from 72 to 56 m.y., the range which is used in this study to define Laramide time. I believe that the use of these reasons alone is an oversimplification, although reasonable due to lack of opposing evidence. Although most mineralized intrusive stocks in southeastern Arizona have been dated as Laramide, the Juniper Flat Granite at Bisbee has been dated as pre-Cretaceous and post-Paleozoic by stratigraphy (Bryant and Metz, 1966), and at 170 m.y. (Creasey and Kistler, 1962). While the Juniper Flat Granite is a good example of a non-Laramide, mineralization-related intrusion, there are other pre- and post-Laramide intrusive rocks occurring in southern Arizona. A biotite quartz diorite-granodiorite stock in the eastern and southern Tortolita Mountains has recently been dated by the Rb-Sr and $^{87}$Sr/$^{86}$Sr methods at 50 m.y. Several outcrops of this stock in the Tortolita Mountains were examined; these are similar in mineralogy and texture to the quartz diorite mapped further north. According to Phillip Anderson (oral commun., 1975), this rock is similar to the Cargadero diorite mapped by McCullough (1963) in the western Santa Catalina Mountains. This information suggests that
the quartz diorite may not be localized in the area north of the Tortolita Mountains.

I would like to narrow the tentative Laramide date for the quartz diorite to early Eocene based on several reasons.

1. Field relations show that the andesites were extruded upon the Pinal Schist.

2. The quartz diorite has intruded both the Pinal Schist and andesitic volcanics. Quartz diorite found within andesite outcrops shows evidence that the quartz diorite was also intruded by the andesite during succeeding volcanic events (Figs. 4 and 5). This evidence suggests that the andesites may be Laramide.

3. On no other reasons than dates of other mineralized intrusive stocks, one can conclude that it is more likely for an intrusion in southern Arizona to be both mineralized and Laramide than mineralized and non-Laramide.

4. The quartz diorite in outcrops mapped during this study does not appear to have undergone metamorphism, while the quartz monzonite appears to have undergone at least one period of weak regional metamorphism.

5. Volcanic units in the mapped area normally show no copper mineralization. However, at the andesite-quartz diorite intrusive contact, the quartz diorite and the adjacent intruded andesites are mineralized for several feet from the contact. Also, where xenoliths of quartz diorite were found within younger andesites, the fracture fillings of chrysocolla and malachite in the quartz diorite end abruptly at the contact.
6. The above evidence shows that the quartz diorite is younger than the oldest volcanic units within the Chief Butte volcanic pile but older than the younger volcanics. Until age dates are obtained for both units, an early Tertiary date for the quartz diorite seems most likely.

Occurring east of the mapped area, outcrops of a flesh-colored weathered monzonite were found in Parker Wash just east of Chief Butte. Iles (1967) described several outcrops of this rock type, one covered by a basal volcanic flow and another intruding the quartz diorite. This may be a phase of the quartz diorite, but it is probably a younger unit.

**Granoaplite**

A series of granitic dike-like intrusive rocks, varying from fine to coarse grained, crops out sparsely in most of the mapped area. These rocks have been described by Barter (1962) and Iles (1967) as aplites, a name fitting few of the rocks present in the area. The rocks are medium to coarse (1 to 5 mm) in grain size, while aplite is fine grained (less than 1 mm). The rocks are found within the mapped area, except in the northernmost parts adjacent to Red Rock Road, where deeper alluvium may obscure possible outcrops.

Composition varies from almost entirely milky quartz to that of a quartz-K-feldspar-muscovite rock. One key to differentiating this unit from nearby pegmatites or other local rock units is the presence of black tourmaline (schorl). The granoaplite is usually more resistant than the rocks it intrudes and is commonly found on ridges, which are capped by
this rock type. The granoaplite locally obscures adjacent rocks with broken fragments, making accurate mapping of contacts very difficult.

One thin section of the granoaplite was studied to determine the mineralogy for rock classification. The results determined using a 200-grain point count were: 43 percent quartz, 28 percent orthoclase, 12.5 percent microcline, 9.5 percent muscovite, and 6 percent plagioclase. The granoaplite is typically fresh, with only a slight kaolinitic dusting of some feldspar grains. Since no copper mineralization is associated with the granoaplite and field relationships show the granoaplite to intrude the quartz diorite, the rock is designated as younger than the quartz diorite, probably early Tertiary in age.

In several places, the granoaplite is sheared and limonite stained. A thin section made from a sample taken along the road in sec. 27, T. 9 S., R. 12 E. showed the rock to be a cataclastically deformed granite of the same approximate composition as the previous sample studied. This sample, from a location lying on a projected east-west fault, constitutes ample evidence for designation in this area of a probable rather than a possible fault. This will be further discussed in the chapter on structural geology.

Barter (1962) suggested that the granoaplite is a facies of the quartz monzonite, comparing it to the aplitic facies of the Oracle granite. Iles (1967) believed that the unit was intruded between the quartz monzonite and a large block of Pinal Schist. Both of these interpretations are inconsistent with field relationship. The granoaplite is found to intrude the quartz monzonite, quartz diorite, and Pinal Schist and is thus not a facies of any of these intrusive rocks. However, it could be
a late-stage derivative of the quartz diorite. Its age depends wholly on
the age of the quartz diorite which, along with the quartz monzonite, is
older than the granoaplite. The granoaplite is not found to intrude the
volcanics in the area.

A large mass of granoaplite is found in sec. 4, T. 9 S., R. 12
E., where it has intruded the quartz monzonite. The rocks typically form
dikes or lenses, as exemplified by west- to northwest-trending dikes
found in the western part of sec. 23, T. 9 S., R. 12 E., which intrude
the quartz diorite. In the center of sec. 8, T. 10 S., R. 12 E., near the
southwestern edge of the Owl Head Buttes, there are unmineralized frag-
ments of quartz and granoaplite enclosed in a volcanic matrix, giving
credence to the idea that the andesites postdate the granoaplites.

**Pegmatite Dikes**

Throughout the mapped area and in other nearby localities, peg-
matite dikes intrude the quartz monzonite, the volcanic rocks, and all
other units, indicating that the pegmatite is the youngest rock in the
area and is of late Tertiary age or younger.

The pegmatite dikes resemble the granoaplite except for their
lack of tourmaline. Also, the pegmatite is commonly present as dikes
or lenses of pure bull quartz. Near the Apache mines, just south of the
mapped area, weak galena mineralization has been observed in the
quartz. Four main directions of pegmatite intrusions are found: N. 20°
W., N. 70° E., north-south, and east-west.
**Diorite Dikes**

Diorite dikes have been identified at several locations within the mapped area. A large dike in the eastern part of sec. 5, T. 10 S., R. 12 E. is traceable for about 3,000 feet and trends approximately N. 20° W. The diorite is fine to medium grained, greenish black, locally sheared, and limonite stained. This dike intrudes the granoaplite along its direction of weakness. Diorite was also mapped in the northwest part of sec. 23, T. 9 S., R. 12 E., where it is not in visible contact with any other unit but lies within 100 feet of outcrops of both quartz diorite and the volcanic rocks of the Chief Butte area. Barter (1962) mentioned diorite and quartz diorite dikes that trend N. 20°-30° W. in the Durham Hills north of the mapped area. He described these dikes as silicified but unmineralized and unmetamorphosed. He attributed the silicification to mineralizing fluids whose migration was controlled by the N. 20°-30° W. fractures. He further suggested that because the dikes are unmetamorphosed and unmineralized and have been intruded along fractures that controlled mineralization the dikes are probably older than some of the volcanic rocks in the area and are therefore early Tertiary. This suggestion assumes that mineralization occurred after intrusion of the diorite dikes and that the N. 20°-30° fractures controlled the mineralizing fluids. Barter reported that diorite dikes found in the Durham Hills crosscut aplite dikes, a relationship which was also observed for the large dike in section 5.

I agree with Barter's interpreted age of early Tertiary for the diorite but suggest that the diorite is either a later stage or a hypabyssal equivalent of the Tertiary volcanic rocks and is not related
temporally or compositionally to the quartz diorite. Direct field relationships show that the diorite is younger than the granoaplite, which itself is the youngest pre-volcanic rock mapped in the area. The complete absence of any mafic mineral other than biotite in the quartz diorite and the presence of amphibole in the diorite may give credence to the belief that the diorite and quartz diorite units were not derived from the same magma.

**Basalt Dikes**

In several isolated areas, small outcrops of basalt were found. Most of these were too small to map, but one, which forms an east-west-trending dike, is located south of the San Juan Road in sec. 15, T. 9 S., R. 12 E., where it cuts across a wash. In hand specimen, this rock is blackish, fresh, and very fine grained. It may be a fine-grained equivalent of the diabase mapped in the area or it may be related to the Tertiary-Quaternary basalt dikes mapped by Barter (1962) to the east. I tentatively place the basalt in the Tertiary-Quaternary period solely on the basis of textural and compositional differences between it and the diabase, realizing that comparative thin-section study and isotope dating will be necessary to unravel the full geologic history of these rocks in this area. The basalt dike, although having no visible contact with the Pinal Schist, is surrounded, in part, by the schist and appears to have intruded it. Such an observation leaves a wide range for the possible age of the basalt.
Extrusive Rocks

Tertiary Volcanic Rocks

The most prominent rocks in the mapped area, both topographically and in color, are a series of volcanic rocks found in two large masses as well as many smaller ones. One large mass is the Owl Head Buttes are and the other the Chief Butte area. The former is on the western edge of the mapped area and the latter beyond its eastern boundary. Both have a maximum relief of about 500 feet (152.4 m) above the pediment surface.

The series of volcanic rocks, estimated by Barter (1962) to be 5,500 feet (1,676.8 m) thick in the Chief Butte area, appears to be more than 2,000 feet (609.8 m) thick in the Owl Head Buttes area, although that figure is merely an estimate because no section has been measured. A drill hole about 2 miles (3.2 km) northwest of the Owl Head Buttes went through over 2,200 feet (670.7 m) of andesitic rocks before reaching the Pinal Schist basement, showing the presence of downthrown blocks to the west of the Owl Head Buttes.

The rocks consist mainly of purple to purple-gray or, locally, brown to reddish-brown andesite flows, agglomerates, ignimbrites, coarse-grained tuffs, volcanic breccias, and a dacite. Flows are extremely massive and commonly nonporphyritic vesicular and contain concentrically banded quartz-filled amygdules and only local layering. Phenocrysts, where present, are plagioclase, averaging 2-3 mm. The andesites are unlike those of the Silver Bell formation to the west, which are found in the field to contain abundant lithic fragments. Volcanic
tuffs are rare in the study area, suggesting that the flows were locally derived. These flows are possibly related to other Laramide or early Tertiary flows of andesitic composition found in the Silver Bell and Tucson Mountains.

Fragments of all major rock units mapped in the area are locally present in the volcanic rocks. Barter (1962) stated that where contacts are found between the volcanic rocks and quartz monzonite and schist it appears that the volcanics flowed onto an eroded surface of the older rocks. In one place in the study area, a large xenolith of quartz monzonite occurs in an andesite flow (Fig. 6). The only other evidence of a flow contact in the Owl Head Buttes was north of the power line in the southeast corner of sec. 32, T. 9 S., R. 12 E., where a westward traverse went from west-dipping Pinal Schist into west-dipping conglomerates containing schist fragments and then into west-dipping andesite flows. About 2,000 feet (609.8 m) to the north, a weakly mineralized fault separates the volcanic rocks and Pinal Schist, which lie on the east side of the brecciated and slightly malachite-stained zone. A fault, striking N. 60°-70° E. and dipping steeply northwest, can be traced for almost a mile to the western extent of outcrop west of the Owl Head Buttes. In several locations along this fault, fragments of Pinal Schist are found in breccia of andesitic matrix. Although no surface evidence exists, study of aerial photographs suggests that this structure may be a normal fault with the west side downthrown. Near the Owl Head Buttes (Fig. 2), the andesite-schist contact is very irregular, float covered, and appears both on the ground and from study of aerial photographs to be a conformable contact. It appears that the volcanic rocks were
extruded onto the eroded surface of the schist. A similar problem of a float-covered contact was observed at the western edge of the Chief Butte volcanics, although only a cursory looks was given this area.

In sec. 34, T. 9 S., R. 12 E., a N. 20° W.-trending block of andesite flows, typically hematite stained, is present. It is probably bounded by a fault on the west side where the Pinal Schist is somewhat bleached and silicified near the contact. On the northern edge of this block, a small prospect shows the volcanic-schist contact to be slightly brecciated with chrysocolla along fractures and surrounding fragments. The east and south sides of the volcanic block appear linear from aerial photographs, but mapping revealed nothing about the contacts on these sides. It appears that this block may represent a downthrown portion of a once continuous cover of volcanic rock between the Chief Butte and Owl Head area. Barter classified this outcrop with the early Tertiary Chief Butte volcanics because of their lithologic similarities.

A drill hole in the western half of sec. 32, T. 9 S., R. 12 E. went through 545 feet (166.2 m) of andesite before reaching quartz monzonite, while drill holes located progressively westward over the next mile reached the andesite-intrusive contact successively at 220 and 20 feet (67.1 and 6.1 m). There is a westward drop in elevation of approximately 200 feet (91.5 m), thus showing that the contact, assuming no faults having vertical throw, dips eastward at over 200 feet (61 m) per mile (Fig. 8).

A number of small andesite outcrops in northeastern sec. 29 and northwest sec. 28, T. 9 S., R. 12 E. vary in color from purple to brown and locally have quartz amygdaloidal fillings. One outcrop shows
Figure 8. Structural fence diagrams compiled from Continental Oil Co. drill logs
an agglomeratic unit dipping southwest as do the rocks of the eastern part of the Owl Head Buttes some 1.5 to 2 miles (2.4 to 3.2 km) directly to the south. These outcrops are believed to be part of a downthrown block on the north side of an east-west fault easily traced on aerial photographs across secs. 27 and 28, T. 9 S., R. 12 E. Older rocks are present south of the fault, giving credence to the idea that the volcanics were originally continuous between the Owl Head Buttes and these isolated outcrops. Barter (1962) established an early Tertiary date for the Chief Butte volcanics from the interbedding of the upper volcanics and the Miocene Pantano Formation. Iles (1967) dated the volcanics, using relationships between the volcanics and Pantano Formation, as probably early Oligocene.

The agglomerates within the volcanic units contain angular to subrounded boulders in a light-gray tuffaceous matrix. Barter noted that the lithic fragments are of volcanic composition. I agree with the description of these intermediate flows in the volcanics, except that the basal agglomeratic flows include Pinal Schist lithic fragments (Fig. 2).

Iles stated that the rocks become more vesicular with increased mafic content, which agrees with the observation that only the most mafic andesites and basalts in the area are vesicular. A basalt flow found within the Pantano Formation northeast of the mapped area is highly vesicular and is quite similar to the outcrops in the northeast part of sec. 29, T. 9 S., R. 12 E. due to the fact that the vesicles have amygdaloidal fillings of chalcedony and crystalline quartz.
Sedimentary Rocks

Pantano Formation

Although the Pantano Formation does not crop out within the mapped area, some general facts help to shed light on the structural history of the area studied as well as the surrounding environs.

Brennan (1957) studied the Pantano Formation in detail in eastern Pima County. His section describes 13,762 feet (4,196 m) of continentally derived basin-fill clastic sediments varying from conglomerates to clay-rich limestones. Three volcanic episodes interrupted sedimentation with the deposition of andesitic flows. Barter (1962) described the Pantano Formation in the Owl Head mining district as having pebbles and cobbles derived from acid intermediate igneous intrusive rocks. He described the beds as dipping from 10° to 30° E. and NE. Iles (1967) concluded from his mapping east of the study area that the basal and lower beds of the Pantano were those present in his mapped area and that the beds of Pantano rocks were interbedded with the Tertiary volcanics forming a transitional zone between the Pantano proper and the underlying Tertiary volcanic unit. Iles' measurements of the attitude of the Pantano rocks showed strikes ranging from S. 43° E. to S. 57° E. and dips from 72° to 80° NE. Iles also concluded that the Pantano within his area of study was a transitional zone between two rock sequences having the same attitude. This evidence suggests that the entire Chief Butte area has been tilted eastward in post-Pantano time. The Pantano Formation has been assigned an early Oligocene to early Miocene age by Finnell (1970).
Sedimentary (?) Units

Barter (1962) proposed that several outcrops of quartzitic and carbonate rocks found near the border between secs. 14 and 15, T. 9 S., R. 12 E. are parts of the Dripping Spring Quartzite and Mescal Limestone, respectively (Fig. 2). Quartzose outcrops are found to grade into more schistose beds within 500 feet (152.4 m). After studying several other areas of quartzitic and carbonate outcrop, I take the position that the quartzites are beds within the Pinal Schist and the carbonate occurrences are calcite fracture fillings and veins. Several hundred feet south of Parker Wash in the east-central portion of sec. 21, T. 9 S., R. 12 E., outcrops of Pinal Schist are highly quartzose, although they display weak foliation. South of San Juan Road, a calcite vein, appearing to be marble, cuts through a quartz diorite terrain and contains fragments of quartz diorite within it.

On the east-central edge of sec. 14, T. 9 S., R. 12 E., also within an area of Pinal Schist, an outcrop of brown massive calcite is found within the area Barter mapped as Mescal Limestone. The outcrop does not match Barter's description of a "white, crystalline marble." The calcite breaks easily along cleavage forming rhombs and appears to be a vein, 3-6 feet (1-2 m) thick, within the schist. Several calcite veins cutting the quartz diorite commonly enclose fragments of the intrusive rock. The calcite has a fine-grained texture similar to that of limestone. The veins are 6 to 12 inches (15 to 20 cm) thick and trend northeast, except for one vein that trends northwest.
Several outcrops of carbonate rocks were mapped west of the Owl Head Buttes on the western edge of sec. 5 and in the NW1/4 sec. 8, T. 10 S., R. 12 E. The southernmost exposure appears at first glance to be a gray marbleized limestone, and if it were not in an area having so many "pseudo-marble" occurrences would definitely be mapped as an outcrop of limestone or marble. However, two facts appear to dispute this assumption. Further north, calcite veining and fault (?) breccias with calcite matrices are found, and even the most cursory examination of the topographic map or stereo aerial photographs shows that these carbonates occur along the fault bounding the west edge of the Owl Head Buttes. Such evidence should prove that sedimentary-appearing carbonates found flanking other rock types are fault or fracture controlled and suggests that no sedimentary carbonate rocks exist within the mapped area.

**Alluvium**

No bedded post-volcanic alluvium was found in the study area. Typically, the Quaternary alluvium is shallow and is undergoing erosion. It is composed primarily of quartz, feldspar, muscovite, and magnetite sands, as well as of partially decomposed rock fragments.

Locally, boulder conglomerates are found as walls along the sides of washes. The poorly sorted clasts are cemented by calcite (caliche). The fragments are composed mainly of quartz monzonite, andesite volcanics, and Pinal Schist, in that order of abundance. Where the alluvium is relatively thick, it forms a sandy soil populated mostly by tall stands of cholla.
Contact Relationships

This section presents evidence to explain the temporal relationships between the various mapped units.

Pinal Schist—Quartz Monzonite Contact

No in-place contact was mapped between the Pinal Schist and quartz monzonite, although a boulder of quartz monzonite containing a xenolith of Pinal Schist (Fig. 3) is offered as evidence that the quartz monzonite intruded the Pinal Schist.

Diabase Relationships

Direct field evidence shows that the diabase has intruded both the Pinal Schist and the quartz monzonite. In the NE1/4 sec. 8, T. 10 S., R. 12 E., a north-south-trending diabase dike is found intruding the Pinal Schist. In the NE1/4 sec. 3, T. 10 S., R. 12 E., two north-south-trending diabase dikes intruding the quartz monzonite show chill zones at the contact with the host rock. No direct relationships are found between the diabase and the other units that prove intrusive sequence between the diabase and the other units. In the east-central part of sec. 27, T. 9 S., R. 12 E., several north-south-trending outcrops of diabase are found within an area consisting of granoaplite outcrops. Some shearing in the granoaplite rocks adjacent to the diabase implies a fault and not an intrusive contact.

Quartz Diorite Relationships

The low rubbly outcrops of quartz diorite were rarely found in direct contact with other units due to the poor exposures and heavy
weathering associated with the rocks. No contacts were found between quartz monzonite and quartz diorite. This observation questions Barter's suggestion that the quartz diorite is a phase of the quartz monzonite. In Parker Wash, northeast of Chief Buttes, quartz diorite engulfs small outcrops of Pinal Schist and at one place a window of altered and mineralized quartz diorite has altered the surrounding Pinal Schist in the northeast corner of sec. 28, T. 9 S., R. 12 E. All of the quartz diorite outcrops occur north of the fault line trending N. 75° E. to east-west in the northern parts of secs. 27, 28, and 29, T. 9 S., R. 12 E. Thus, there is a possible structural boundary between the quartz diorite and the quartz monzonite, since quartz monzonite crops out only south of the fault. There is no textural change in the quartz diorite as the southern boundary is approached, suggesting that the boundary is structural.

Granoaplite Relationships

Islands of slightly metamorphosed and highly weathered quartz monzonite commonly appear within large areas of fresh granoaplite outcrop. These quartz monzonite outcrops are probably remnants of the original body of quartz monzonite, which was partially assimilated by the granoaplite. In several instances, the granoaplite is found intruding the quartz diorite and islands of both Pinal Schist and diabase are found within large masses of granoaplite.

Extrusive Rocks

Direct field evidence shows that the andesitic rocks are younger than the Pinal Schist and that andesitic rocks rest on or intrude the quartz diorite. In turn, the andesite is intruded by the quartz diorite.
Agglomeratic flows in the Owl Head Buttes have basal flows containing fragments of Pinal Schist stratigraphically above the underlying Pinal Schist.
STRUCTURAL GEOLOGY

Regional Structure

Both Barter and Iles refer to Mayo's (1958) oft-quoted study on the structural framework of the Southwest, which discussed belts and zones of projected lineations. The zones (Fig. 9) that have a bearing on the Tortolita-Owl Head area are: (1) the northwest-southeast-trending southwest and central Arizona belts which may be an extension of the Walker Lane fault zone extending from western Nevada; (2) the northeast-southwest Morenci belt—Jemez zone; (3) the north-south Utah—Arizona belt; and (4) the N. 75° W-trending Texas (lineament) zone, which Mayo suggested may exceed 150 miles (241.4 km) in width. Rehrig and Heidrick (1972) studied joint sets, veins, dikes, and faults in eight nonproductive and three copper-bearing Laramide porphyry stocks. Their results compare favorably with Mayo's findings in that a system of orthogonal N. 20° W ± 20° and N. 60° E. ± 20° Laramide fractures correspond with Mayo's southwest and central Arizona belts and the Morenci belt—Jemez zone and a minor west-northwest fracture direction corresponds with Mayo's Texas zone.

The northwest trends are evident in the range from N. 20° W. to N. 30° W on Wilson and Moore's (1959) geologic map of Pinal County. Structure in the Tortilla Mountains and Mammoth area show this trend, while structure in the Tortolita quadrangle (Barter, 1962, Plate 1) shows the more recent Tertiary volcanic and Pantano formations striking northwest and northwest faults in the Durham Hills, Suizo Mountains, and
Figure 9. Arizona structural belts—Adapted from Mayo (1958)
Owl Head mining district. Northeast trends are seen in gneissic foliations found in the Black Mountains.

Study of high-altitude NASA color photographs reveals structure not discernible from large-scale aerial photographs or ground reconnaissance. The most important structural direction is N. 20° W., which parallels Mayo's southwestern Arizona belt closely, lying less than 10 miles (16 km) southwest of the Tortolita range. I have classified these structures as Laramide and possibly middle to late Tertiary, part of the Basin and Range orogeny as well. Three reasons for my conclusions are:

1. N. 20° W. faults have locally played a major part in delimiting the major physiographic features, and aerial photographs suggest they have displaced older east-west faults.

2. A N. 20° W. left-lateral separation displaces all units from Pinal Schist through Tertiary granoaplite. This structure can be traced from the southwest tip of the Durham Hills in the N1/4 sec. 26, T. 8 S., R. 12 E. across the southwest tip of the Suizo Mountains in the E1/2 sec. 17, T. 9 S., R. 12 E. through gaps in secs. 29 and 33, T. 9 S., R. 12 E. into the northernmost Tortolita Mountains in sec. 10, T. 10 S., R. 12 E., a distance of approximately 10 miles (16 km).

3. No mineralized areas are associated with this structural direction.

The late Tertiary date disagrees with the Laramide date postulated by Rehrig and Heidrick for a N. 20° W. structure, although they suggest that this direction is derived from east-northeast Laramide compression resulting in elongate folds with north-northwest axes. The strike-slip
movement indicates either later movement on a preexisting structure or an older age for the rock units, such as the granoaplite, that the N. 20° W.-trending fault displaces.

Northeast fracture trends range from N. 25° E. in the Owl Head Buttes area to N. 60° E. in the Suizo Mountains (Iles, 1967, Plate 1) an and N. 65° E. in the Tortolita Mountains and the Black Mountain areas. These trends are shown on the geologic map of Pinal County (Wilson and Moore, 1959) as foliation directions along with similar trends shown to exist in the Picacho Mountains. On the NASA photographs, they are strong photolinears. N. 45° E. trends are strong within the Owl Head Buttes, Suizo Mountains, and Durham Hills. These structures may be part of the zone comprising the Morenci belt and Jemez zone.

The north-south direction of Mayo's Utah-Arizona belt is present in the Owl Head area and is also represented by the Pirate fault on the west side of the Santa Catalina Mountains. The Texas lineament direction is represented by a N. 65° W.-trending fault along the south-west edge of the Black Mountain block, by the Mogul fault on the north side of the Santa Catalina range, and by east-west normal faulting on the east side of the Owl Head Buttes.

Mayo (1958) divided structural intersections into four classes, ranging from the most important, first class, downward. To prove his point, he shows that seven of the eight first-class intersections studied have associated ore deposits, while only three of six second-class intersections are associated with deposits. Districts located near the first-class intersections were also more productive than the marginal districts associated with second-class intersections. A first-class
intersection was defined as one having either four intersecting directions plus a post-Nevadan intrusion or an intrusion, the Texas lineament, the Santa Rita-Morenci belt or the Jemez zone, and at least one other direction.

In the Owl Head Buttes region, the Utah-Arizona belt, Texas lineament, and the southwest Arizona belt intersect. The central Arizona, Morenci belts, and Jemez zone intersect within 50 miles (80.5 km) of the study area. If the quartz diorite intrusive unit is of Laramide age, the Owl Head mining district is either at or within 50 miles of a first-class structural intersection.

**Local Structural Geology**

Major structural features mapped in the field differ only modestly from those revealed by the NASA high-altitude photographs. Measurements of fractures in the quartz diorite were hampered by poor outcrop. Measurements were also made of joints and fractures in the other rock types and of fault, vein, and dike walls. The purpose of this work was to determine any dominant structural trends and specific relationships between structure and alteration and to use structure to aid in differentiating between units and to determine age relationships.

Structure was difficult to determine in weathered quartz monzonites exposures. A number of northeast fracture trends averaged N. 50° E. with 75° NW. dips, and several northwest fracture trends averaged N. 60° W. with 70° SW. dips. The northeast trends may be part of the Morenci belt and Jemez zone, and the northwest fractures may show the Oracle granite to be concordant with the Texas lineament zone.
Several dozen fracture trends were mapped in the quartz diorite (Fig. 10). Four prominent trends emerge: (1) N. 40°-50° W., corresponding with the central Arizona belt; (2) N. 20°-35° E., corresponding with the Morenci belt–Jemez zone; (3) east-west, almost vertical, coinciding with the strong east-west directions shown on the NASA photographs; and (4) less numerous trends, averaging N. 70° W., corresponding with the Texas lineament.

The N. 40°-50° W. and N. 20°-35° E. fractures were typically the most active hydrothermally, with abundant epidote and pink plagioclase alteration. East-west-trending fractures are completely fresh, showing neither alteration nor mineralization. Rehrig and Heidrick (1972) point out in their comparison between productive and barren stocks that productive stocks show both north-northeast and east-northeast mineralized directions, while barren stocks show only east-northeast directions. The ubiquitous network of microfractures and cracks found in productive stocks by Rehrig and Heidrick is absent in the quartz diorite.

The granoaplite shows two dominant trends, N. 15°-20° W. and east-west. Veins and dikes of granoaplite found in the quartz monzonite and quartz diorite have both east-west and N. 20° W. directions. Lack of alteration and the presence of these two directions in the younger granoaplite and volcanics show that these two directions are the younger, coinciding with the same outstanding trends shown on the NASA photographs. It is suggested that these structures were active from early Tertiary through the Basin and Range orogeny.

Figure 11 is a generalized structural map of the Tortolita–Owl Head–Suizo Mountains area based on the aerial photographs. East-west,
Figure 10. Structural trends in quartz diorite
Based on 34 measurements of fractures.
Figure 11. Generalized structure map of study area
N. 20° W., and N. 60° E. faults delimit the major structural blocks in the area. The east-west fault, which bounds the Owl Head Buttes to the northeast, is displaced approximately 1,500 feet (457.3 m) by a later left-lateral strike-slip fault. From the northern end of the Tortolita range north, three south-dipping fault blocks (Fig. 12) are bounded by north-south normal faults, each successive footwall on the south side being Pinal Schist. One of these was corroborated in the mapping by discovery of a sharp, silicified contact at a location where the aerial photographs indicate a fault. The repeated succession from north to south is older → younger → fault: (1) Pinal Schist → quartz diorite → volcanics → fault; (2) Pinal Schist → quartz monzonite → granoaplite → fault; (3) Pinal Schist → gneisses within the Tortolita range.

The N. 20° W. faults are left-lateral strike-slip faults (?) east of the Owl Head Buttes with 1,500 to 1,800 feet (475.5 to 549 m) of lateral displacement. This feature is evidenced by various rock units having differing structural attitudes over a span of several miles, all being translated in a left-lateral direction, as viewed from aerial photographs. These structures are parallel to the Owl Head and Chief Butte complexes, which strike in a northwesterly direction, with the Owl Head volcanics dipping generally southwest, while the Chief Butte volcanics dip northeast. In secs. 27 and 34, T. 9 S., R. 12 E. (Fig. 2), a N. 20° W. block of volcanics has been downthrown into a grabenlike structure into older rocks. The graben illustrates a textbook example of structural geology: an anticlinal structure with a graben formed within the tensional area along the axial plane. To the east, the Pantano Formation overlies the Chief Butte volcanics in an apparently conformable manner.
Figure 12. North-south cross section A-A'
Rehrig and Heidrick (1972) suggest the formation of a broad north-northwest warp in Laramide time composed of numerous elongate uplifts possibly including the Owl Head-Chief Butte area coaxial with Laramide fold axes and associated thrust sheets in Arizona. Their analysis demonstrates that the earliest and most prominent set of fractures trends east-northeast or transverse to the assumed north-northwest elongate uplifts containing the stocks (Fig. 10). Data from porphyry copper deposits show that both the east-northeast and north-northwest fracture directions were active during Laramide mineralization.

Iles (1967) described the Pinal Schist-Chief Butte sequence contact as a clean schist surface covered by extrusive flows. This observation agrees with similar relationships found in the Owl Head Buttes during this study. Continental Oil Corporation provided access to drilling logs which showed the Owl Head Buttes as a thick volcanic pile underlain by Pinal Schist and quartz monzonite and not as necks or plugs (Fig. 13). A fence diagram (Fig. 8) was constructed from the drill logs provided by Continental Oil. The logs and diagram show accumulations of over 2,000 feet (610 m) of andesite beneath the alluvium west of the Owl Head Buttes. The andesite is in turn underlain by a Pinal Schist basement. Large downthrown blocks show displacements of over 500 feet (152.5 m), and almost immediately north of the Owl Head Buttes the volcanics are present under the alluvium. Pinal Schist underlies the volcanics northward until a higher block forms the Suizo Mountains. The drill records totally refute any argument that the volcanics in the Owl Head or Chief Butte areas are isolated flows; they are instead
Figure 13. East-west cross section D-D'
lava-capped, tilted, fault blocks and a part of flows covering 30 or more square miles (77.7 km²).

Neither Barter nor Iles have uncovered any evidence that identifies the source of the volcanic rocks nor did the present investigation uncover any structural or compositional evidence that might point toward a vent or other local source structure. Three possibilities exist: (1) a local source is hidden within the Chief Butte or Owl Head complexes or in a minor area of volcanic outcrop; (2) a distant source, such as the Tucson Mountain volcanic pile, exists; or (3) since drill logs show thick accumulations of unexposed volcanics, almost wholly andesites, the true source may be within the study area beneath the recent alluvium and is concealed by downfaulting and erosion deposition. Field evidence in the vicinity of the Owl Head Buttes and drill information from the area north and west of the Owl Head Buttes show that wherever the andesitic volcanics were encountered and drilled through, the underlying formation is Pinal Schist. This as well as other evidence strongly suggests that the Owl Head Buttes are lava-capped buttes and not plug or vent structures.

Although most diabase outcrops were without direction and appear as shapeless masses only a few square feet in area, those having planar orientation trend from north–south to N. 20° E. in the same direction as fractures in the older rocks in the area.

Pegmatite and granoaplite dikes range in direction from typically N. 20° W. in the central and southwestern areas, while further north and east they seem to trend closer to N. 60° W. One dike cuts through a small outcrop of diabase in an irregular manner, showing the diabase to
be pre-volcanic and probably pre-Cenozoic in age. East of the Owl Head Buttes, a large N. 20° W. diorite dike cuts through the granoaplite almost conforming with the predominant structural weakness of the latter. North and west of the Owl Head Buttes, the same apparent diorite is found intruding two outcrops of the quartz monzonite in a north-east direction. The delimiting structural controls on the west side of the Owl Head Buttes are almost vertical N. 10°-20° W. normal faults, while on the east side the volcanic flows are found overlying the schists conformably.
ECONOMIC GEOLOGY

Mining History

The earliest recorded reference to the Owl Head mining district is from the July 29, 1882 Arizona Weekly Enterprise, published by Thomas F. Weedn. Weedn himself wrote of his trip to the Jesse Benton Consolidated mines and mill and of "other matters we fancied would be of interest to the fifty million readers of the Enterprise." He reported that the Indians had named the five small buttes Chew-Too-A-Maw (Owl Heads) for their resemblance to the "head of the lord of Wisdom."
Weedn described the Jesse Benton mine, located in sec. 1, T. 10 S., R. 12 E., and the Eagle and Desert mines located approximately in secs. 3 and 4, T. 10 S., R. 12 E. The Desert and Jesse Benton mines had walls of "porphyry" (probably quartz monzonite) and "granite" (probably Tertiary granite), with "pay streaks" of chloride ore ranging from 8 inches to 2.5 feet wide found along the footwalls. The Eagle mine was described as having a 12-inch "pay streak" of gold-silver-lead ore assaying $100 of gold per ton. The objective descriptions also included that of a new five-stamp mill probably located in the SE1/4 sec. 9, T. 10 S., R. 12 E., at the northwest tip of the Tortolita Mountains.

Pickard (1912) reported on the Apache mines. Along with history and geography of the area, he described some of the structure in the Apache mines. His descriptions implied that between 1882 and 1912 most of the ore above the water table had been removed by various organized and unorganized mining attempts. Random assays above and
below ground ranged from $1.75/ton to $18.20/ton, while hand-selected chalcocite specimens were as high as $192/ton, including the abundant secondary copper. Pickard closed his report by suggesting that primary copper ore could be found beneath the location of the Apache mines and recommended a drilling program to depths of about 600 feet.

In 1923, the Arizona Blade Tribune, Florence, Arizona, headlined: "Rich Gold Strike Made in Owl Heads---$2000 Ton." The article repeated much of the local history and made an interesting prediction of another Comstock lode. The Blade Tribune described Weedin, the writer of the 1882 article, as a man who did a great deal of developmental work on a group of claims in the area. While Weedin's article was written in a very detached and unemotional manner, describing no ore as higher than $300/ton, he may have later become involved in the property and the question does exist whether Weedin was trying to publicize an area in which he had an interest.

The area studied is dotted with shallow prospects and a number of vertical but minor shafts, showing that the region had been combed by prospectors. Today, much of the San Juan claims are held by the BBB Mining Company, although no work appears to have been done recently. The area to the south is largely under the control of W. R. Ewing of Arizona Western Mines, Inc., which has been prospecting in the area since 1971 (W. R. Ewing, oral commun., 1973).
Hydrothermal Alteration

Quartz Monzonite

As was discussed under rock descriptions, the Precambrian quartz monzonite is commonly weathered and locally argillized but rarely mineralized near faults and fractures. Typical background hand specimens show only slight alteration. The thin section studied showed about 5 percent of the biotite altered to chlorite with only a slight dusting of kaolinite in calcic cores of plagioclase crystals.

Quartz Diorite

Although alteration was of major interest to this study, the poor exposures and scarcity of outcrop hampered research and evaluation. A large number of outcrops flush with the ground or barely protruding above its surface were heavily weathered, allowing little or no possibility of hand-specimen or thin-section determination of alteration.

The prevailing form of alteration is propylitic. Alteration of biotite to chlorite is commonly moderate to complete. Epidote replacing biotite commonly composes less than one percent by volume of the rock away from fractures, but hand specimens taken near the fractures may show 10 percent by volume epidote. Veinlets of quartz and epidote less than 1 cm wide are occasionally found. Up to 5 percent calcite is present in most thin sections studied as veinlets and replacements. Traces of apatite, zircon, xenotime, and rutile are also present.

Plagioclase is commonly altered to sericite or kaolinite, the former as much as 45 percent and the latter as high as 65 percent. Plagioclase crystals vary from euhedral to subhedral, with crystalline
boundaries commonly intact and zoning pronounced. In thin section NW-43 sericite and kaolinite alteration obscures the crystal boundaries. The crystalline cores are commonly altered to kaolinite, with rims fresh and sericite dusting the grains or in veinlets. In thin section NW-27 formerly euhedral plagioclase is now sheared, with strained quartz showing small 2V.

Secondary quartz is apparent in numerous prospects and fractures but is apparent in only one of the thin sections (NW-43) taken away from fractures. Quartz here replaced approximately 5 percent of the plagioclase in the form of veinlets, and sericitic alteration is predominant over argillic characterized by kaolinite with minor montmorillonite.

Another type of alteration worthy of discussion is the "pink feldspar" alteration. Volumes paralleling fractures (Fig. 14) as haloes averaging 3 cm but as wide as 0.7 m are typically bright pink like dolomite, not fleshy colored like orthoclase. The pink bands are commonly laced with veinlets of epidote. At first glance, this might be judged to be secondary potassic feldspar alteration because of the symmetrical bands of pink feldspar surrounding the fractures. In thin section, the pink feldspars proved to be plagioclase with typical albite twinning visible. No secondary biotite is present, which is significant, since Creasey (1966) states that new biotite and K-feldspar are essential ingredients of potassic alteration. Creasey also states that the secondary K-feldspar is formed as rims around original K-feldspar and albite. Negative results of several sodium cobaltinitrite tests and lack of strong zoning would tend to refute the argument that the pink feldspar is
Figure 14. Pink feldspar and epidote alteration adjacent to a fracture in quartz diorite

Photograph taken in the wash just south of San Juan Road in center of sec. 15, T. 9 S., R. 12 E.
secondary K-feldspar. Epidote is typically a member of the propylitic alteration assemblage of minerals. Iles (1967, p. 72) concluded that the pink feldspar "is a hydrothermal alteration product characterized by almost complete sericite and clay alteration of plagioclase, almost complete alteration of biotite to chlorite, the presence of muscovite, and possible secondary biotite." The definition is confusing because there is no explanation of the pink color in the rock or why mica alteration and its amount should affect the color of the rock. To answer these questions, thin sections of specimens taken away from prospect pits and fracture and fault zones such that localized alteration could not bias the conclusions. Thin sections of rocks that contain pink feldspar in hand specimen showed a pinkish masking in plane-polarized light, but the same crystals that megascopically show the pink color showed sharp, clear albite twinning when examined with crossed nicols. The amount of sericitic, kaolinitic, or montmorillonitic alteration has no apparent bearing on the intensity or hue of the pinkish color. Apparently, a pink color has been developed in normally grayish white plagioclase in what is compositionally the same rock on both sides of the color change. This would imply that no wholesale replacement has occurred. Since the structure of the plagioclase crystals is intact, solutions traveling along the fractured zones have probably added small quantities of exotic ions to the mineral. Deer, Howie, and Zussman (1966) report Ti, Fe²⁺, Fe³⁺, Mn, Mg, Br, and Sr in very limited amounts within plagioclase. Most of the iron reported in the feldspar analyses is shown to be Fe³⁺, which replaces Al in the structure. The characteristic appearance of aventurine feldspars in the albite to labradorite range appears to be due to reflecting
lamellae of hematite parallel to certain crystallographic planes. Deer et al. also mention that coloration other than white in plagioclase is commonly due to inclusions within the plagioclase crystals. Dana (1906), Hurlbut (1949), Vanders and Kerr (1967), and Deer et al. (1966) all state that plagioclase is rarely pink red, flesh red, pink, or reddish white. "Sunstone" is described by Vanders and Kerr as oligoclase with gleaming reddish hematite inclusions. The pink present in megascopic specimens is more of a red-white pink mixture than the flesh color of orthoclase in rocks that have been potassically altered as well as well as from rocks primarily rich in K-feldspars.

Table 3 gives the percentage alteration present in ten thin sections of quartz diorite. These percentages are not to be confused with total volume percentages. Figure 2 shows sample sites.

Table 3. Percentage alteration of primary minerals in quartz diorite

<table>
<thead>
<tr>
<th>Thin Section No.</th>
<th>Plag. to kaol.</th>
<th>Plag. to mont.</th>
<th>Plag. to ser.</th>
<th>Biot. to chl.</th>
<th>Percent by Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW-23</td>
<td>15</td>
<td>--</td>
<td>40-45</td>
<td>100</td>
<td>1 tr</td>
</tr>
<tr>
<td>NW-36</td>
<td>30-35</td>
<td>--</td>
<td>20-25</td>
<td>50</td>
<td>-- tr</td>
</tr>
<tr>
<td>NW-27</td>
<td>--</td>
<td>10</td>
<td>15</td>
<td>90</td>
<td>a 2 1</td>
</tr>
<tr>
<td>2-15</td>
<td>60-65</td>
<td>--</td>
<td>2</td>
<td>90</td>
<td>2 2-4</td>
</tr>
<tr>
<td>NW-21</td>
<td>40</td>
<td>--</td>
<td>25</td>
<td>100</td>
<td>3 tr</td>
</tr>
<tr>
<td>NE-2</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1 tr</td>
</tr>
<tr>
<td>NW-12</td>
<td>30</td>
<td>--</td>
<td>15</td>
<td>50</td>
<td>b 5 --</td>
</tr>
<tr>
<td>NW-38</td>
<td>40</td>
<td>--</td>
<td>5</td>
<td>20</td>
<td>-- 1</td>
</tr>
<tr>
<td>NW-43</td>
<td>20</td>
<td>--</td>
<td>40</td>
<td>75</td>
<td>5 tr</td>
</tr>
<tr>
<td>NE-3</td>
<td>45</td>
<td>--</td>
<td>5</td>
<td>5</td>
<td>-- tr</td>
</tr>
</tbody>
</table>

a. Ten percent of biotite altered to calcite.
b. Twenty-five percent of biotite replaced by calcite.
About 50 percent of the biotite in NW-36 is altered to a brownish opaque mica, possibly vermiculite. Iles (1967) discussed alteration petrography of six specimens from the northeast part of the quartz diorite. He noted more sericite alteration than the thin sections reported in Table 3 suggest, although more of Iles' samples were from prospects than are those considered here. Iles also reported the presence of secondary biotite in one sample as well as stringers of secondary quartz associated with chrysocolla and trace azurite. My study attempted to get a broad understanding of the background alteration picture rather than going to the areas where the strongest alteration might be expected.

**Zoning.** There is no discernible radial increase in intensity or type of alteration within the quartz diorite intrusion. The western two-thirds is predominantly propylitic in alteration type, while the eastern third is mainly argillic (Fig. 15). The overlap of these two types is probably the zone of most pervasive alteration within the exposed quartz diorite. Several outcrops in this area showed sericite and argillic alteration in hand specimen and two thin sections taken away from both faults and prospects (NW-23 and NW-43) showed 40 to 45 percent of the plagioclase altered to sericite and 15 to 20 percent of the plagioclase altered to kaolinite as well as 75 to 100 percent of the biotite altered to chlorite and 1 to 5 percent total volume calcite, respectively, showing evidence of more than simply propylitic alteration. An area about a quarter of a mile southwest of the center of sec. 22, T. 9 S., R. 12 E. might be mapped more closely in order to study the area that seems most altered more accurately, but here it is also difficult to locate outcrops. A study of its nature is beyond the scope of this study, which was undertaken to
Figure 15. Alteration zoning within the quartz diorite
map a large area accurately with no prior knowledge of either the size or alteration of the quartz diorite intrusion.

**Pinal Schist**

The Pinal Schist in this area is not normally hydrothermally altered. Along fractures, foliation planes, and weathered edges are sparse to common limonite stains. These stains appear to be the weathering products of from 2 to 3 percent magnetite, as revealed in thin sections. No sulfides were observed in normal unmineralized schist, and only rarely were pyrite or pyrite casts found in mineralized prospects. Much of the magnetite in sample 2-30 has weathered to hematite, giving the schist a spotted appearance.

Sample NW-27 is by far the most interesting of the Pinal Schist specimens. A contact aureole around a small window of quartz diorite has been altered in the same manner as was the quartz diorite. Approximately 84 percent of the muscovite is altered to chlorite, while in the quartz diorite, approximately 90 percent of the biotite is altered to chlorite. The rock has the same pink and green color as the quartz diorite, with the plagioclase giving the rock the same pink color in the Pinal Schist as it does in the quartz diorite. Within several feet, the schist loses the pink color and resumes its normal gray color. Thin section study has shown the quartz diorite in this locality to be richer in plagioclase and poorer in quartz than the Pinal Schist. Thin sections NW-27 and NW-27A (Tables 1 and 2) show the composition more accurately. The fluids that altered the quartz diorite had the same effect locally on the adjacent schist.
Volcanics

Although the volcanic units were not studied specifically for alteration, several observations have been noted. Secondary quartz is abundant in the volcanic units in the form of amygdaloidal fillings, concentric agate bandings, vugs up to 3 inches in diameter filled with radiating quartz crystals, and quartz veinlets and lenses sometimes several feet across. I concur with Iles that the secondary quartz is not associated with copper mineralization but may be evidence of the same hydrothermal epoch which brought minor copper into the quartz diorite and Pinal Schist. Many of the quartz amygdaloidal fillings are stained with a greenish tint, which appears to be chlorite stain. In some locations, chlorite alteration along fractures and in vesicles has been identified. W. R. Ewing (oral commun., 1973) has told me that celadonite, an Fe$^{2+}$-rich form of glauconite found as a secondary mineral filling vesicles and replacing olivine in basalts, has been identified in the volcanic units. None was identified in the course of this study. The secondary quartz fillings may be evidence that at least the lower volcanic units are older than the quartz diorite.

Mineralization

Two areas of mineralization were found in the mapped area, the Owl Head Buttes and the San Juan claims area. The Owl Head Buttes area involves mineralization in the volcanic rocks and Pinal Schist and, in one case, the quartz monzonite. Mineralization in the volcanic rocks is on the western edge of the Owl Head Buttes where the Pinal Schist underlies the volcanics, probably at shallow depth. Iles mentions Pinal
Schist on the Big Mine dump east of the mapped area where andesite flows are the host rock. Several breccia zones in the schist and the volcanics contain disseminated chrysocolla and hematite along fractures. Chrysocolla was formed along N. 70° W., 75° SW. fractures, and malachite, chrysocolla, and limonite casts after pyrite were found on a dump near a shaft in the north-central part of sec. 5, T. 10 S., R. 12 E. Unmineralized fractures that trend N. 25° E. and dip 75° NW. were measured at the shaft. They are probably postmineralization; those that were the source of mineralization are not evident at the surface. Many other prospects show malachite, chrysocolla, tenorite, chalcopyrite, and minor chalcopyrite, although the mineralized samples were found on the dumps and not in the pits.

Continental Oil Company drilled approximately 16 rotary drill holes, some deeper than 2,000, along a possible fault trending north-south along the western boundary of the Owl Head Buttes and Suizo Mountains. The project was then abandoned and the claims allowed to lapse. Continental concluded that there was no economic potential present in the north-south structure or associated with it, which high-altitude photographs as well as drill logs suggest is a north-south normal fault (Fig. 13) related to the Basin and Range orogeny.

In the Pinal Schist on the east side of the southernmost Owl Head butte, several workings, including an adit and shaft, show abundant chrysocolla and malachite. Gold traces have been found here (W. R. Ewing, oral commun., 1973). Copper was also found in a brecciated, silicified, and calcified volcanic matrix at or near contacts between the Pinal Schist and volcanic units.
Approximately 1,000 feet (305 m) west of the southernmost Owl Head butte, a sheared and argillized area of quartz monzonite contained common hematite, malachite, and chrysocolla and minor limonite pseudomorphic after pyrite.

The scope of present-day activity in the area is a gold-silver undertaking by Arizona Western Mines. The mine is several miles southeast of the Owl Head Buttes in sec. 2, T. 10 S., R. 12 E. (Fig. 2). The operation consists of drilling, blasting, and mucking from an elongate trench along a fault zone. A mill facility, near completion, is a gravity concentration unit designed to recover precious metals. It is estimated by Arizona Western Mines, Inc. that more than 3,000 tons of high-grade material exists on dumps in the immediate area. No ore has been shipped but the following assays suggest some potential:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Gold oz/ton</th>
<th>Silver oz/ton</th>
<th>Lead %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.030</td>
<td>381.17</td>
<td>5.05</td>
</tr>
<tr>
<td>2</td>
<td>0.020</td>
<td>73.58</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>0.030</td>
<td>155.17</td>
<td>2.00</td>
</tr>
<tr>
<td>4</td>
<td>1.60</td>
<td>4.20</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>2.06</td>
<td>10.00</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>15.84</td>
<td>104.56</td>
<td>--</td>
</tr>
</tbody>
</table>

The geology is extremely complex with quartz monzonite, andesite dikes, massive quartz veining, and heavy silicification present. Galena is present on many of the dumps in the area.
The San Juan claims area has several dozen shallow prospects and one deep shaft, now filled in, showing widespread but sparse copper oxide mineralization, and rarely copper sulfides. As many as ten drill sites were discovered, but neither deep nor professional drilling has been undertaken in the area.

Mineralization occurs in the Pinal Schist, quartz diorite, and more rarely in the volcanic rocks. In most instances, the mineralization is found at or near contacts between the Pinal Schist and the quartz diorite. In one instance, just south of Parker Wash at the boundary between secs. 22 and 23, T. 9 S., R. 12 E., several prospects are found, one along a N. 80° E., 60° SE. fracture set, with moderate chrysocolla, malachite, and black copper oxides in fracture fillings less than half an inch wide. No sulfides were present. Chrysocolla was found in other prospects along N. 45°-65° W. fractures. Pinal Schist did not crop out within 500 feet (152.5 m), where a steep intrusive contact with the quartz diorite was present.

All along the San Juan Road and in the wash south of the road, many prospects show weak chrysocolla, malachite, chalcocite, black copper oxides, and rarely limonite after pyrite. Many prospects are now barren, the mineralized rock all being on the dumps. Iles (1967, plate 1) shows numerous discoveries of chalcopyrite, bornite, and chalcocite in these prospects. It should be noted that these areas, especially since Iles' work, have been overrun by "four-wheel enthusiasts," weekend scavengers, hunters, and rock collectors, and many prospects have been picked clean. One thing is amply evident: the quartz diorite is very poor in sulfide mineralization, and only rare limonite pseudomorphic
after pyrite is encountered. The quartz diorite is also poorer in magnetite than the quartz monzonite, a fact that might place the quartz diorite in the lower magnetic susceptibility Laramide porphyry-type intrusive class as opposed to the more magnetic Pinal Schist (Brant, 1966). It might be expected that ground and aeromagnetic surveys might be used to probe for further extensions of the quartz diorite intrusion, depending on the susceptibility of the other units in the area.

A dump off San Juan Road in the south of sec. 14, T. 9 S., R. 12 E. showed chrysocolla, malachite, and black oxides of copper (Fig. 16) associated with fractures, quartz veinlets, weak limonite, and hematite. The rocks are well fractured, with the general structure N. 50° E., 70° NW. Alteration is generally sparse, except for local epidote-quartz veining, random in direction, and some potassic feldspar alteration along fractures less than an inch wide. An estimate of the copper content might be 0.1% Cu. Iles quoted Glynn Burkhardt, owner of numerous claims in the area, as reporting that samples at this dump gave 0.17% Cu, 0.36% Cu, and 0.16% Cu. Other samples ranged from 0.13% to 2.0% Cu.

A prospect located near the center of sec. 14, T. 9 S., R. 12 E. showed malachite, chrysocolla, chalcocite, strong copper oxides, and traces of bornite, limonite, and hematite in an intrusive contact where the quartz diorite had intruded the andesites and small displacement had occurred. Iles (1967, plate 1) mapped the contact as a fault, but the andesite is vesicular and thus probably extrusive, and several fragments of andesite were observed within the quartz diorite (Fig. 4), showing that the quartz diorite has intruded the andesite. Veins of black
Figure 16. Mineralized prospect off San Juan Road in southern part of sec. 14, T. 9 S., R. 12 E.
copper oxides up to 1.3 cm thick were present, and the volcanics adjacent to the contact contain copper as well as iron oxides. The contact (fault) trends N. 65° W. and dips 80° SW., with the quartz diorite becoming finer grained toward the contact.

In one place, just north of Suizo Wash and also with it, the andesites show weak malachite, chrysocolla, and hematite staining. It appears that the quartz diorite brought the copper mineralization into the area, because it alone is the only rock type present or is very close to every occurrence of copper mineralization within the mapped area. Large areas of fresh unmineralized Pinal Schist and volcanic rocks were mapped. Geochemical sampling showed that the quartz monzonite and Pinal Schist are well below the common background for copper and the quartz diorite is closer to it (Hawkes and Webb, 1962). Pinal Schist is commonly a receptive host rock for mineralization, as at Ray, Arizona (Metz and Rose, 1966).

Mineralization is too weak to produce zoning patterns, although gold and silver have been mined in the Owl Head Buttes are and east of it. No reports were discovered of these metals elsewhere in the district.

Alluvial magnetite is being looked into more and more as a possible ore mineral. Several operations have tested the feasibility of mining placer magnetite in washes north and east of the mapped area and the Krupp Arms Company of Germany has recently undertaken work in this area. The apparent source for the magnetite is the Oracle granite northeast of the Owl Head mining district, which has contributed large quantities of residual accessory magnetite to the washes throughout the area.
GEOLOGIC HISTORY

The Pinal Schist, of older Precambrian age, is the oldest rock unit present in the Owl Head mining district. The schist, composed mainly of argillaceous and sandy sediments with few volcanic units, accumulated in a northwest-trending trough extending across Arizona (Schmidt, 1967). During the Mazatzal Revolution, the sediments were metamorphosed and compressed into open to isoclinal folds trending generally northeast (Erickson, 1962), although Barter (1962), Iles (1967), and I have found both northeast and northwest trends to predominate in the Owl Head mining district. Following this event, still in older Precambrian time, a large mass of porphyritic quartz monzonite intruded the Pinal Schist. In younger Precambrian time, probably during the Grand Canyon Disturbance, north-south dikes and small irregular masses of diabase intruded the local rocks.

Although Paleozoic sedimentary rocks exist within a few miles of the area in several directions, no direct evidence of their existence in the mapped area was found. They were probably once present but have since been eroded. No deposition is recorded in the mapped area between younger Precambrian and early Tertiary time, when andesitic lavas covered the area. Six to 8 miles (9.7 to 12.9 km) southeast of the Owl Head Buttes in the Tortolita Mountains, the Catalina granite, dated at 100 m.y. by the Rb/Sr method is intruded by a biotite-quartz diorite-granodiorite dated at 50 m.y. (S. B. Keith, oral commun., 1975), using the Rb/Sr and $^{87}$Sr/$^{86}$Sr methods. A similar quartz diorite body intruded
the area north of the Tortolita Mountains. A granitic unit consisting of dikes and larger masses was followed by the intrusion and extrusion of more andesitic lavas and hypabyssal rocks. A granodiorite gneiss in the Tortolita Mountains has been dated at 26 m.y., using the K-Ar method (Damon, 1968), which suggests strong thermal metamorphism preceding that time. Damon statistically shows in a histogram of Late Cretaceous-Cenozoic K-Ar age dates that two magmatic pulses affecting this area are grouped around 63-70 m.y. and 25-30 m.y. dates. The former dates are primarily plutonic, commonly associated with copper-bearing plutonism and possibly represented in the Owl Head district by the quartz diorite, while the latter are represented more by volcanic than plutonic rocks. The Paleogene-Neogene period of magmatic activity is represented in the area by the upper volcanic flows. The granoaplite is younger than the quartz diorite and older, at least, than upper volcanic units. It may be a part of later Laramide intrusive activity or, like the Catalina granite dated at 24 m.y. (Damon, 1968), it may be part of the igneous activity at the Paleogene-Neogene boundary. Interbedding of the andesites (Iles, 1967) with the Pantano Formation shows that volcanic activity continued into the Miocene. Contemporaneous with early Tertiary igneous activity, east-northeast horizontal compression formed elongate north-northwest uplifts and a network of north-northwest and east-northeast fractures (Rehrig and Heidrick, 1972). Whether the suggested uplift between the Owl Head and Chief Butte areas existed at this time is uncertain. The basal andesite-schist contact now dips 65° SW., suggesting that this may be the case. If uplift commenced in Laramide time, the basal volcanic flows are either pre-Laramide or early
Laramide, for example, latest Cretaceous when a period of magmatic ac-
tivity began (Damon, 1968).

Contemporaneous with or following the volcanism, relaxation
of the east-northeast compression and differential expansion (Rehrig and
Heidrick, 1972) resulted in normal faulting and north-northwest unmin-
eralized release joints striking perpendicular to the axis of compression
and in north-northwest fracturing of the volcanic and granoaplite units in
the Owl Head Buttes and the western half of the granoaplite unit. Local
units acquired their present attitudes through tilting; these include the
Owl Head and Chief Buttes areas as well as the Pantano Formation to
the east, which dips to the east. In the Pliocene epoch, local basalt
flows covered parts of the area and were followed by extensive erosion
and development of a pediment surface and the present topography.

Two periods of mineralization were identified in this study.
One, early Tertiary in age, is represented by hydrothermal alteration
of the quartz diorite and mineralization of the Pinal Schist and quartz
diorite. The other is a late early or middle Tertiary, post-volcanic epi-
isode of mineralization, in which north-northwest structures appear to
control the mineralization (Iles, 1967). Iles described local propylitic
alteration of the volcanics which would indicate a post-volcanic period
of hydrothermal activity.
GEOCHEMICAL INTERPRETATIONS

Stream Sediment Sampling

Twenty-four samples, taken according to a random method developed by AMAX Exploration, were analyzed for molybdenum by the AMAX laboratory in Denver, Colorado, using colorimetric determination, and for Cu, Pb, Zn, Fe, Mn, Ni, Co, and Ag, using atomic absorption. In order to determine which samples were anomalous, the log of parts per million copper versus cumulative frequency percent were plotted (Fig. 17). All samples above the threshold of 26 ppm were considered anomalous, while those above 35 ppm were considered highly anomalous. Location of samples and differentiation of anomalous from background samples are plotted on a drainage map at the same scale as that of the Tortolita quadrangle (Fig. 18).

The area southeast of the mapped area showed four anomalous copper samples, one of which was anomalous for both copper and molybdenum. No explanation is offered for these values, since the washes from which these samples were obtained drain the northern Tortolita Mountains outside the special area of interest. Rocks found in the anomalous washes as float include quartz monzonite, Pinal Schist, granoplastic, andesite, and in a wash in sec. 5, T. 10 S., R. 13 E., a cobble of rhyolite, probably derived further upstream in the Tortolita Mountains. Only one sample of those taken from the area draining the Chief Butte area was anomalous, probably due to high-level dilution of sediments derived from the Chief Butte andesites by alluvium. Only one sample
Figure 17. Plot of ppm copper in 24 stream sediment and 18 rock chip samples vs. cumulative frequency percent of occurrence.
Figure 18. Anomalous stream sediment samples plotted on 1:62,500 scale map
taken in the SE1/4 sec. 20, T. 9 S., R. 12 E., showed an anomalous amount of copper derived from the quartz diorite intrusive stock. The sediments obtained from the washes draining the San Juan claims area were below threshold, possibly because outcrop is subordinate to alluvium in this area. Stream sediment sampling points to the northern Tortolita Mountains as a site for further study.

Twenty stream sediment samples analyzed for iron concentration averaged 2.3% Fe, with three above 4.4% Fe. Many of the washes showed strings of magnetite-rich sands, but tonnages would be difficult to estimate because concentration is heterogeneous and magnetite strings follow local braiding patterns throughout the cross section of each drainage. Hawkes and Webb (1962) list 2.7% Fe as the average concentration in felsic igneous rocks, with 8.5% Fe as the average for mafic rocks.

**Rock Chip Sampling**

The threshold value for copper in quartz diorite, which was determined using atomic absorption, was 35 ppm. Of 14 samples in the quartz diorite, 5 were above threshold, the 2 highest being 61 and 590 ppm. Both were from outcrops where copper staining was noted. Although sampling intentionally avoided such areas. Due to the small number of samples, no pattern or trends can be seen. Five samples of Pinal Schist averaged 18 ppm copper, one sample representing typical diabase analyzed at 65 ppm, and two samples of quartz monzonite yielded results of 4 and 8 ppm copper. Hawkes and Webb cite 30 ppm as being the average concentration of copper in felsic igneous rocks and 140 ppm as the average in mafic igneous rocks. Anomalous rock
chip samples have been plotted (Fig. 18) on the map with stream sediment results.
CONCLUSIONS AND POTENTIAL OF AREA

There are several arguments in favor of further study in the Owl Head mining district, as well as others either questioning or opposing further inquiry. The lack of either porphyritic or associated porphyry intrusive units contemporaneous with the quartz diorite could be an extremely negative factor in assessing the area for future base-metal potential. In 24 porphyry copper districts studied by Stringham (1966), all except Pima and Mission have large porphyry bodies, and Stringham states correctly that further work might bring these intrusive bodies to light; they are indeed reported by Richard and Courtright (1966). Although the quartz diorite outcrops are locally porphyritic, in only one locality in the NE1/4 sec. 28, T. 9 S., R. 12 E. was the rock fresh enough to see that it was definitely dissimilar to the quartz monzonite and quartz diorite, with plagioclase phenocrysts about 4 mm long in a matrix of crystals 2-3 mm in size.

The widespread lack of pyrite and other sulfides indicates either a lack of hydrothermal activity in the quartz diorite or that if any more mineralized areas are present, they are laterally or vertically removed from the areas of outcrop mapped. The only areas within the area studied, which might have more altered rocks beneath the surface, would be the area north of Parker Wash and south of San Juan Road where outcrop is sparse. Many of the holes left on Barter's (1962) smaller scale map have been filled in with small quartz diorite outcrops, and only the
bedrock underneath the alluvium north of the San Juan claims area remains unknown.

The weak alteration zoning found in the area seems to lead toward the San Juan claims area, or just south and west, as the most altered area mapped. The San Juan area certainly contains the largest share of sulfide mineralization, although it is weak, spotty in nature, fracture controlled, and not disseminated throughout the rocks. Lowell and Guilbert (1970) state that propylitic alteration has its proper place on the fringes of the alteration zone and may continue several thousand feet beyond ore bodies. Jerome (1966) also states that colorful areas of leached capping do not necessarily lie above the ore body. Whether the quartz diorite and alteration continue to the north and east under the volcanic rocks is a subject for further research.

A study of Barter's (1962, Plate 1) map shows a definite N. 30° W. trend in areas of mineralization. The Apache mines, which appear to have precious metal potential, the Big Mine area, the San Juan claims, and the Blue Star mine in the northern Suiyo Mountains lie along this lineation (Fig. 11), and bent slightly to the north, the Durham Hills deposit could be added. However, unmineralized N. 20° W. faults and fractures are post-Laramide and probably Miocene. Rehrig and Hildrick (1972) state that north-northwest and east-northeast fracture directions were active during Laramide mineralization. The lineation of mineralized areas fits into the proposed north-northwest-trending anticline. A 4-mile-wide arch extending between the lithologically similar Owl Head and Chief Butte complexes is also suggested by the fact that both areas have parallel strikes but opposing dips (Barter, 1962; Iles, 1967).
The mineralization in the quartz diorite is related to fracture zones near contacts with Pinal Schist or volcanic units. The quartz diorite is believed to be the rock responsible for bringing the mineralization into the area because the mineralization is younger than the Oracle-type quartz monzonite and Pinal Schist and is present in many areas away from all local units except quartz diorite. Mineralization in both the Owl Head and Chief Butte areas is derived from a source other than the volcanics themselves, such as the quartz diorite dikes now covered by later andesite flows.

Regional petrologic studies (Scholz, Barazangi, and Sbar, 1971) have indicated that the southern Arizona region was the site of calc-alkaline andesitic volcanism during the middle to late Cenozoic, which changed abruptly to fundamentally basaltic in the late Cenozoic, accompanied by the beginning of major Basin and Range crustal extension. This shift is interpreted as a change from island-arc type of volcanism to active ensialic interarc spreading. Sillitoe (1972) states that calc-alkaline volcanism and underthrusting of the East Pacific ocean floor under the American plate in the western United States ceased in the Miocene. He suggests that the disperse pattern of porphyry copper deposits may be explained by partial fusion with consequent magma and metal generation from downdip extensions of the underlying East Pacific subduction zone rather than being related to structural intersections as proposed by Billingsley and Locke (1941), Mayo (1958), among others.

The Owl Head mining district and adjacent areas have not been sufficiently explored for mineralization, and the existence of a weakly mineralized Laramide or post-Laramide intermediate intrusive body
should be enough impetus for further in-depth alteration mapping, geo-
chemical and geophysical exploration work, and at least several drill
holes into the more promising parts of the quartz diorite intrusion.
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