GEOLOGY AND ORE DEPOSITS OF THE
SOUTHERN SECTION OF THE AMOLE
MINING DISTRICT, TUCSON MOUNTAINS,
PIMA COUNTY, ARIZONA

By

John E. Kinnison

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

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ABSTRACT

The southern section of the Amole Mining District was once covered by the Paleozoic strata common to southern Arizona. The Mesozoic strata consist of the dominantly clastic Amole group which, beginning with a basal conglomerate, is subdivided into four formations. The lower two are of Lower Cretaceous age, and the upper two are Upper Cretaceous or early Tertiary. These formations were intensely folded into a synclinorium with local thrust faulting during the Laramide revolution, and subsequently planed to a gentle erosion surface. The Tertiary formations are assigned by inference to the middle or late Tertiary, and begin with the Tucson Mountain chaos. This is a tabular unit about 200 feet thick composed of fragments of pre-Laramide rocks ranging in size up to 350 feet, and is postulated to be a sedimentary deposit resulting from combined fault action and landslide. Conformably above this formation is a layered sequence of volcanic and sedimentary rocks, which is divisible into a number of formations. These rocks were tilted northeasterly and broken by numerous high-angle faults, and mineralized by ore solutions with a high silica content. The youngest rocks are conglomerates, local (?) lake beds, basalt flows, and recent alluvium.
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INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The thesis presented herein, in conjunction with study for the degree of Master of Science from the University of Arizona, results from field mapping, petrographic study, and library research. Its purpose is to describe and interpret the principal geological features within the southern section of the Amole mining district.

LOCATION AND ACCESSIBILITY

The southern section of the Amole mining district, here defined to include that portion of the Tucson Mountains south of Anklam Road, lies approximately ten miles to the west and southwest of Tucson, Arizona (Pl. 1). Within the southern section, an area located south of the Ajo Road and extending roughly six miles in a westerly and four miles in a southerly direction was mapped in detail, but elsewhere reconnaissance observations supplement data obtained in the area of detailed mapping.

Nearly all of the detailed area is accessible by state and county roads and by numerous desert automobile trails. The more rugged areas to the north can be traversed in part by jeep, and in party by pick-up truck or by older model passenger cars. Since the completion of field work in 1955, numerous graded dirt roads leading to individual and
SOUTHERN SECTION OF THE AMOLE MINING DISTRICT.

Plate 1.
subdivision homesites have been built in the area south of the Ajo Road.

The state and county roads are accessible all year, but the desert auto trails, which commonly cross or follow washes, are frequently impassible for short periods during the summer rainy season.

CLIMATE AND VEGETATION

The climate is typical of the desert regions of southern Arizona, and is nearly identical to that of Tucson and the surrounding Santa Cruz valley. Data presented by Smith (1930) indicates that the Tucson Mountains occupy a rainfall transition belt; the southern portion receives ten to thirteen inches of rainfall annually and the northern portion receives somewhat less than ten inches annually. The temperature ranges from a minimum in the low twenties to a maximum of about 110 degrees.

Vegetation consists primarily of cactus, small trees, and bushes. As the largest trees present are mesquite and palo verde, no timber is available for mining or construction purposes.

TOPOGRAPHY

The Tucson Mountain range may be divided into two topographic units. On the western margin a well developed pediment, carved on Cretaceous and Paleozoic rocks, dips westerly with elevations ranging between 2500 and 2800 feet.
The main mass of the range consists of an easterly dipping volcanic sequence, with an escarpment on the west and dip slope to the east. The dip slopes, deeply incised by canyons, form fairly rugged peaks and slopes, and are bounded by the cliff faces of the western escarpment. The highest elevation, on Amole Peak in the northern part of the range, is slightly more than 4500 feet.

In the southern part of the range, north of the Ajo Road, the highest point is on Golden Gate Mountain where the elevation is 4288 feet. South of the Ajo Road the line of escarpment is nearly obliterated by erosion, and is represented by a line of low hills with elevations no greater than 2900 feet. The dip slope in this area is broken by somewhat higher, jagged peaks, due to the differential erosion of a volcanic intrusive.

FIELD WORK

Field work was conducted intermittently during 1953, 1954, and 1955. The area south of the Ajo Road was mapped on a scale of one inch to one thousand feet. Mapping was done, for the most part, on aerial photographs, using an acetate overlay. The photographs used were flown in February of 1949 (Photograph Nos. DHQ 5F: 62, 63, 64) by the U. S. Dept. of Agriculture, and extend westerly from the Santa Cruz River to the east margin of Saginaw Hill. The 15 minute San Xavier Mission Quadrangle, as mapped by the U. S. Geol. Survey in 1943, was enlarged by projector to a scale of one
thousand feet to the inch and used for the topographic base map. The bearing and lengths of section lines, furnished by the Pima County Engineering Dept., were used for control of the projection-enlargement. Transfer of geology from the aerial photographs to this base map was done with the aid of a vertical sketchmaster, thus allowing correction for tilt, and for the small deviation of the photograph scale. In that area not covered by aerial photographs, mapping was done directly on the enlarged topographic base map.

Reconnaissance mapping outside the detailed area was done directly on the 15 minute quadrangle map.

ACKNOWLEDGMENTS

Many people have contributed aid and suggestions during the preparation of this thesis, and I wish gratefully to acknowledge their help. Many of the faculty members of the University of Arizona have kindly spent time with me in the field and the office and have offered many constructive suggestions and criticisms. In particular I wish to mention Dr. J. F. Lance, thesis director, and Dr. D. L. Bryant (formerly at the University of Arizona, and thesis committee member), both of whom were actively interested during the course of field work; Dr. B. S. Butler (University of Arizona, retired, former thesis committee member); and Dr. R. L. DuBois and Dr. E. B. Mayo, who are members of the thesis committee at the present time.
I also wish to thank L. A. Heindl (U. S. Geol. Survey) and Messrs. Kenyon Richard and J. H. Courtright (American Smelting and Refining Company) in whose company I have had numerous field trips and general discussions, which in turn helped to formulate the ideas presented concerning problems of Cretaceous and Tertiary stratigraphy and volcanism.

I am pleased also to acknowledge the help given by my wife Elisabeth, who assisted in all phases of thesis preparation.
GEOLOGY

GENERAL STATEMENT

Previous Work

In the early part of this century, Guild (1905) briefly described some of the rock types and Tolman (1909) presented a short paper on the geology of Tumamoc Hill, a basalt flow just west of Tucson.

The first significant contribution to the general geologic knowledge of the range was presented by Wilson and Jenkins (1920) in the Arizona Bureau of Mines bulletin 106. In this same bulletin M. A. Allen described the mining industry of the southern section of the Amole mining district, restricting the use of the term "southern section" to the area south of the Ajo Road. In 1939 W. H. Brown presented a report covering nearly all phases of the geology of the Tucson Mountains. This work, with its description of rock formations and structure, together with the geologic map, served as a most useful base for this thesis study.

A resume of stratigraphy was given by Bryant (1952). Feth (1948) and Bryant (1955) discussed the Permian rocks at Snyder Hill. Bennett (1957) completed thesis work on the geology of the Sedimentary Hills area north of the Ajo Road, and Whitney (1957) made a detailed thesis study of a small area in the east-central part of the range.
Geologic Summary

The principal rock types in the Tucson Mountains are upper Paleozoic limestone, Cretaceous shale, arkose, conglomerate, and limestone, Tertiary and Quaternary volcanics, and post-Cretaceous intrusives. The pre-Cambrian basement of granite and schist is exposed only in the northern part of the range. The lower Paleozoic rocks are exposed in a normal sequence only in the northern part of the range. A generalized geologic column is shown in Plate 2.

The Cretaceous and older rocks were folded during the Laramide revolution, and form a synclinorium in which local overturning and thrust faulting may have played an important part. Overlying these folded rocks and separated from them in most places by a breccia composed of giant fragments of the pre-Laramide rocks, is a volcanic sequence consisting of several distinct units. The breccia and volcanics, of Tertiary age, dip gently to the east and have been complexly faulted by high angle faults. Flat-lying basalt flows crop out locally on the east and south margin of the range. The entire range, presumably bounded by basin-range type block faults, has been eroded with the development of a wide-spread pediment.

The ore deposits of the southern section of the Amole mining district include veins, replacements, and porphyry deposits, characterized by high silica content, and are interpreted to be of late(?) Tertiary age.
**Generalized Stratigraphic Column**

Southern Section of the Amole Mining District.

*Not to Scale.*

Plate 2
Alternate correlation above Echo Valley fm. eroded in So. Tucson Mtgs.

5000' +

Erosion surface Southern Tucson Mountains.

Tertiary (?)

Upper Cretaceous

1150' +

Eroded in pre-Tucson Mountain chaos time.

Amole Group – Lower Cretaceous (McKee, 1951)
(Central Tucson Mts.) - 2275' +

- Upper Cretaceous Moctera (Brown, 1939)

Recreation Red Beds 1250' +
(Red siltstone – arkose andesite pebble congl.)

Andesite pebble conglomerate. Pliomontite Flows. 300' +

Andesite flows, conglomerates, conglomerates, tuff. 2000' to 5000' +

By inference possibly correlates to Old Yuma Mine andesites.

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Andesite flows, conglomerates, conglomerates, tuff. 2000' to 5000' +

By inference possibly correlates to Old Yuma Mine andesites.

Modified from Brown's column (1939).

STRATIGRAPHIC COLUMN
OF CRETACEOUS - TERTIARY (?) ROCKS

Tucson Mountains

Plate 2-A
Summary of Rock Types

The rocks of the Tucson Mountains record a long, varied, and repeatedly interrupted sequence of geologic events. While only those rocks of the southern Amole mining district will be discussed in detail, I will attempt to correlate these rocks to their place in the regional environment.

In the following rock descriptions, subdivision will be made into two broad classifications: (1) all those rocks of layered aspect which may be grouped in a geologic column, and which consist of Paleozoic and Cretaceous sediments and Tertiary volcanic flows, tuffs, and sediments; and (2) intrusive igneous rocks.

The distribution of rock formations is shown by the geologic maps (Pls. 3 and 4.)

In so far as is practical, previously established formational names are used, but where warranted I propose certain changes and additions.

SEDIMENTARY AND EFFUSIVE ROCKS

Introductory Comments

The Paleozoic rocks are subdivided in the manner defined by Stoyanow (1936). The terminology proposed by Brown (1939) for the Cretaceous and Tertiary rocks has been slightly modified to the form here presented.

At this point I wish to define certain terms used in the text which relate to classification of clastic rocks. The Cretaceous series presents a thick and variable sequence of
arkose, quartzite, conglomerate, limestone, siltstone, and mudstone. For purposes of field mapping, the following loosely defined types have been noted. The terms arkose, quartzite, and limestone need no particular elaboration. The term conglomerate has been restricted to those rocks containing abundant pebbles of readily observable size (on the order of one-quarter inch or greater). The term shale is used in a purely structural sense, and thus includes not only thin-bedded siltstone and mudstone, but also thin-bedded, "shaly-structured", fine-grained arkose and quartzite.

Lower Paleozoic Rocks

Lower Paleozoic formations of Cambrian and Devonian age crop out in the Picacho de Calera Hills, two small peaks in the extreme north end of the Tucson Mountains. These formations (Stoyanow, 1936) consist of the Bolsa quartzite of Middle Cambrian age, which unconformably overlies the pre-Cambrian basement; the Middle Cambrian Cochise formation; the Upper Cambrian Abrigo formation and Rincon limestone; and the Upper Devonian Picacho de Calera formation and Martin limestone. The Cochise formation and Rincon limestone were separated from the Abrigo formation by Stoyanow (1936), as was the Picacho de Calera formation separated from the Martin limestone. Immediately below and above the Cochise formation are thin sandstone beds named by Stoyanow as the Pima sandstone and an unnamed quartzite respectively. The total thickness of the lower Paleozoic formations in the Picacho de
Calera Hills is 1700 feet.

The lower Paleozoic formations have not been recognized with certainty in any other part of the range, but some of the yellowish brown limestone blocks of the mega-breccia may be Martin limestone.

Upper Paleozoic Rocks

Mississippian Escabrosa Limestone

The Escabrosa limestone of lower Mississippian age is present in a recognizable stratigraphic section only in the Picacho de Calera Hills, where it overlies the Martin limestone with a gradational contact (Bryant, 1952). The Escabrosa limestone is dominantly a medium to light gray pure limestone with abundant crinoid stems and horn corals, and it is readily converted to a coarsely crystalline, pure white marble. At the Picacho de Calera Hills it is approximately six hundred feet thick.

The Escabrosa limestone has not been recognized elsewhere in the Tucson Mountains in a normal stratigraphic position, but has been identified as a common type of fragment in the mega-breccia zone; particularly in the central east side of the Tucson Mountains.

Pennsylvanian-Permian Rocks

The Pennsylvanian-Permian rocks of southern Arizona as defined by Stoyanow (1936) consist of the Pennsylvanian Naco formation, overlain in some areas by gypsiferous Permian beds which locally are termed Andrada formation, or "beds with a Manzano fauna", which are in turn overlain by the
Permian Snyder Hill formation. The Naco formation is generally a fossiliferous, thick and thin bedded, gray limestone with interbedded siltstone. At the Picacho de Calera Hills, where the top is removed by erosion, it is approximately one thousand feet thick. It has also been mapped by Brown (1939) in a small hill north of the Picacho de Calera Hills, and as a thin fault remnant at the northwestern part of the range. Many of the fragments of the mega-breccia zone are questionably identified as Naco formation.

The gypsiferous Andrada formation has not been recognized in the Tucson Mountains, but in the ranges to the northwest and southeast it attains a thickness of several hundred feet or more.

The uppermost Permian unit of Stoyanow (1936) is the Snyder Hill formation, which consists of dark gray to black limestone and dolomite. The type locality is Snyder Hill, in the southern end of the Tucson Mountains, but at this locality neither the base nor top is exposed. Recent work by Bryant (1955) has called attention to the presence of quartzite units within the upper Paleozoic rocks, some of which are more than 100 feet thick. These units, which vary from pure white quartzite to silty quartzite, occur in the Andrada formation and the lower part of Stoyanow's Snyder Hill formation, and to a lesser extent higher in the Snyder Hill formation. The total thickness of the Snyder Hill formation is probably in excess of 800 feet.
Except for the limited exposure at Snyder Hill, this formation is not exposed in a recognizable stratigraphic sequence in the Tucson Mountains, but I have questionably identified the Snyder Hill formation as the principal type of limestone block in the mega-breccia zone. Some of the blocks of quartzite within the mega-breccia may also derive from the Snyder Hill or Andrada formations.

At Snyder Hill, Bryant (1955) assigns the lower limestone to the upper Concha limestone and the upper dolomite to the upper Rain Valley formation.

Cretaceous Rocks

Basal Conglomerate

In most places in Southern Arizona the separation between Paleozoic and Cretaceous rocks is marked by a surface of erosion cut on the Paleozoic rocks and a conglomerate consisting of fragments of Paleozoic and locally of pre-Cambrian rocks. The best known locality is at Bisbee, where this unit, termed the Glance conglomerate, separates Lower Cretaceous marine limestones from a pre-Cretaceous erosion surface which cuts through all rocks of the Paleozoic and pre-Cambrian. At Bisbee the Glance conglomerate varies in thickness from zero to 650 feet (McKee, 1951). Conglomerates which may be correlated with the Glance occur as far north as Johnson Camp, a mining town about 50 miles east of Tucson.

A limestone conglomerate separates the Paleozoic and Cretaceous non-marine (?) rocks in the Tucson, Santa Rita,
Empire, and Sierrita mountain ranges and has been noted (McKee, 1951) at the south end of the Rincon mountains. The rocks overlying the conglomerate at these localities are shale, arkose, and conglomerate of probable near-shore continental or marine origin.

The limestone conglomerate crops out in the Empire Mountains along Total Wreck ridge. Where examined near the Total Wreck Mine it is about 30 feet thick and consists almost entirely of very angular limestone cobbles.

In the Tucson Mountains, the Paleozoic-Cretaceous contact with its characteristic conglomerate is well exposed on the southwest limb of an overturned anticline near the Braun shaft. At this location the conglomerate is thinner than noted in the Empire Mountains but contains similarly sharp-edged limestone cobbles. The conglomerate zone varies from two to ten feet in thickness and appears to grade upward into the overlying arkosic beds. The fragments of the conglomerate, which consist of angular to sub-rounded pebbles and angular cobbles of three inch maximum size, are dominately limestone of black (Snyder Hill ?) and brown (formation unknown) colors. The remainder of the fragments are quartzite of possible Paleozoic origin and of varve-like siltstone of a type common to the overlying Amole formation.

The conglomerate overlies dark gray to black Snyder Hill limestone on an apparently smooth surface. The contact is offset by small cross faults, and it is therefore difficult to identify erosional depressions, even though the
existence of depressions is suggested by the varying thickness of the conglomerate. It is fairly evident, however, that a highly irregular jagged surface, or karst topography, does not exist on this surface in the Braun Mine exposure.

Overlying the conglomerate with conformity (?) are thin to medium-bedded brown shale and fine-grained arkose of the Amole group. The Amole group conglomerate contact is modified by bedding faults near the Braun shaft but farther east along the same outcrop it appears to be a transition zone which varies in thickness from 2 to 25 feet, and consists of silty pebble conglomerate which grades abruptly into brown siltstone.

Based on the evidence of transition between the conglomerate and the overlying Amole group, this limestone conglomerate may be considered to be a basal conglomerate for the Cretaceous series. This interpretation is open to question, however, because the apparent transition could be due to reworking of the conglomerate at some time after its deposition. The siltstone of Amole type in the conglomerate also suggests some form of contemporaneity, but it is possible that these siltstones belong to the Naco formation or Abrigo formation. The problems of age and correlation will be discussed in another section.

Amole Group.

The Amole group was first named and described by Brown (1939). Brown's name for this unit was "Amole arkose", but is modified in this thesis to Amole group because:
(1) it contains a variety of rock types other than arkose;
(2) it is divisible into several formations, and (3) it may prove desirable in the future to extend the coverage of this name to include similar series of rocks in other areas.

Within the area of detailed mapping, four broad subdivisions are recognized. Because their continuity and importance beyond this small geographical area are unknown, I propose no formal names for these members, but for purposes of reference they are here designated by the following field names. Beginning at the base of the series I name them:
(1) Braun formation (named for the Braun Mine); (2) Dead Cow formation (local name of a low, but conspicuous, elongate ridge); (3) Mouse House formation (local name of a dry wash); (4) Echo Valley formation (local name for a homesite area north of Saginaw Hill).

Braun formation.— This formation overlies the basal (?) conglomerate of the Cretaceous series, and its lower contact has been previously discussed in conjunction with the conglomerate. The rocks of this unit are shale and thin- to medium-bedded arkose and siltstone, in approximately equal amounts. The color tones range from light tan through yellowish brown to light gray. A very small percentage of thin-bedded silty limestone is also present, usually occurring as gray to black varve-like units not more than two feet thick, and as single one half to two feet thick brown to black colored beds.
The most continuous exposure of this formation is on the pediment southwest of the Braun Mine. Due to the complex folding and reverse faulting it was impossible to measure accurately the thickness, but it must be well over 1500 feet. The Braun formation also occurs to the northeast of the Braun shaft but is almost completely obscured by a thin film of caliche cemented limestone boulders derived from the outcrop of Snyder Hill formation near the Braun Mine.

Dead Cow formation.— The Dead Cow formation consists principally of fine-to coarse-grained pure (not silty) arkose and quartzite, with a characteristic clear white or light gray color. It is predominantly medium-bedded with well developed stratification in thin bands. The most complete section of this unit is exposed in the fault block east of the Ivy May Mine on Dead Cow ridge. At this locality I estimate the Dead Cow formation to be approximately 2000 feet thick. An exact measurement is difficult because there, as in nearly every other exposure, the unit is shattered by numerous cross faults. These faults, which appear to be of both small to large displacements, cannot be adequately delineated due to the lack of internal stratigraphic marker beds.

At the type locality east of the Ivy May, about twenty per cent of the Dead Cow formation consists of tan, gray, and olive siltstone, and the remaining 80 per cent consists of the characteristic white or light gray arkose
and quartzite. Some of the arkose beds contain feldspar fragments, with fresh cleavage or remnant euhedralism, up to one half inch in length. Pebble conglomerates containing gray to tan fine-grained arkose and siltstone fragments occur throughout the Dead Cow formation, and are commonly associated with the beds of very coarse-grained arkose. At the type locality desert varnish colors much of the otherwise gray-white beds a light to dark brown.

The Dead Cow formation is particularly significant for two reasons. First, because of its distinctive pureness, gray-white color, coarse grain size and pebbly areas, and prominent stratification, it affords a readily recognizable stratigraphic unit; and second, a thin but persistent limestone within this unit contains abundant tiny ostracods which have been identified by Peck (letter to D. L. Bryant, April 9, 1954) as of an age no younger than Early Cretaceous. This limestone bed is about four feet thick, with a rather distinctive blue gray to slightly purplish color and a sandy appearance. Part of the sandy appearance is due to the presence of small sand grains, but the great majority of "sand grains" are recognizable under the hand lens as small (1/2 to 3/4 mm) silicified bivalves which are the ostracods mentioned above. Also present in most exposures are shiny black to gray flat fragments which may be remnants of shark teeth or scales.

In the type locality east of the Ivy May, the ostracod bed crops out about 1200 feet above the base and is traceable.
for approximately 1000 feet, its most continuous exposure. The fossils examined by Peck were collected from a flat area south of a desert road between hill 5 and hill 10. At this locality the bed is traceable for about 25 feet, and is cut off at both ends by faults.

It is noteworthy that the ostracod bed has been found in nearly every structural block containing the Dead Cow formation, although it is rarely traceable for a distance greater than 200 feet. The discontinuity of the ostracod bed gives an indication of the degree of large scale brecciation within the Dead Cow formation. This brecciation is particularly noticeable in the small block west of the Braun shaft. That the unit as a whole is very competent is evident by its composition and bedding structure, and this is further shown by the fact that it deformed by large scale shattering and brecciation.

In the type locality the extreme eastern outcrops are characterized by an increasing proportion of silty beds, some of which contain unidentified gastropods. I have presumed that the base of the Dead Cow formation is approximately at this location and that this is a gradational contact with the underlying Braun formation.

In the type locality approximately 300 feet stratigraphically below the top of the Dead Cow formation is an angular discordance in strike which may represent an unconformity. The beds below this line vary approximately 20 degrees from the strike of those above and appear to be
truncated by a continuous ledge-forming, medium-grained white quartzite. Below the quartzite, and resting apparently on the truncated edges of the beds below, is a lensoidal limonite-stained conglomerate containing well-rounded to sub-angular quartzite pebbles in a coarse-grained arkosic matrix, and containing locally plentiful rusty brown silicified wood fragments. An alternate hypothesis is that the discordance of strike is due to faulting, but the presence of the conglomerate and associated fossil wood beneath a continuous quartzite bed favor the possibility of an angular unconformity.

The beds above the unconformity (?) are indistinguishable from those below and were derived either from the same source, or from erosion of the beds below at another locality. The possible significance of this unconformity (?) will be discussed in connection with the overlying Mouse House formation.

Mouse House formation.— The Mouse House formation is distinguished as a unit because it contains a far greater percentage of limestone beds than do other parts of the Amole group. Its stratigraphic position is defined between the underlying Dead Cow formation and the overlying Echo Valley formation, but its upper and lower limits are not well established and its true thickness is unknown.

This unit consists of thin- and medium-bedded brown siltstone and brown and black shale, and thin beds of massive
and of laminated varve-like limestone. The limestones are dark gray to black and commonly give off a carbonaceous odor when the fresh surface is struck with a hammer. Individual beds are rarely over one and one-half feet thick, but several beds may be grouped within a short stratigraphic interval.

The whole formation, characterized by thin bedding, is highly incompetent and deforms readily into intricate folded patterns. Because of this structural plasticity, the Mouse House formation has been both thickened and thinned, probably to a very appreciable extent, and it is doubtful if any of the outcrops present the original stratigraphic section.

This formation is important as a mapable unit, and can be recognized with some degree of certainty due to the high content of limestone. Although recognition is impaired by metamorphism near the Saginaw porphyry, it is probably the Mouse House formation which crops out in the western part of the Saginaw area and which has furnished the limestone host rocks for the replacement ore deposits.

Although the Mouse House formation contains an appreciable quantity of limestone, it has yielded few fossils. In one locality a two foot brown sandy limestone bed is replete with small unidentified pelecypods. The black shales and limestones might, however, yield identifiable pollen. A sample from the type locality east of the Ivy May Mine was
analyzed by Rodger Y. Anderson (letter dated March 21, 1955),
who isolated several grains of "Betula (birch)" type and
tentatively assigned them as being no older than Upper
Cretaceous. This matter will be discussed in more detail
under "age and correlation". It will be noted that the
Upper Cretaceous pollen occurs above a zone interpreted as
an angular unconformity within the Dead Cow formation, which
unconformity in turn overlies the bed with Lower Cretaceous
ostracods.

Echo Valley formation.— The Echo Valley formation
overlies the Mouse House formation, and is the uppermost
member of the Amole group which has been differentiated dur­
ing mapping. Its thickness is unknown but is probably at
least 1000 feet. In general appearance it is identical to
the Braun member and is distinguishable only by its strati­
graphic position.

Age and Correlation

As in other parts of Southern Arizona, there is no
definite record of Triassic or Jurassic sedimentation in
the Tucson Mountains. Although there is no direct paleon­
tological evidence that the Glance and similar conglomerates
at the base of Cretaceous strata are not older than Cretaceous,
McKee (1951) considers an older age unlikely and suggests
that the conglomerates are all accountable to one general
period of uplift in the Early Cretaceous, or approximately
the time of the Nevadian revolution. The evidence cited on
previous pages of this thesis indicates that the conglomerate
at the base of the Cretaceous (exposed near the Braun shaft) correlates to conglomerates in ranges to the south and east, and furthermore that it grades into overlying strata and is probably a basal conglomerate shortly pre-dating deposition of the Braun formation. I will begin this discussion, then, by assuming that the basal conglomerate and overlying Amole group are post-Jurassic.

South of the Ajo Road there are numerous fossil localities containing small pelecypods and gastropods, usually well preserved by silicification. These fossils are unidentifiable except for a few which were recognized as unionids (D. L. Bryant, personal communication). In all of these fossil localities, the fossil-bearing beds are thin, single beds of limey siltstone or sandy limestone. I observed no fossils in the black varve-like limestones.

Samples collected from the ostracod-bearing limestone bed in the central portion of the Dead Cow formation were submitted to Raymond E. Peck of the University of Missouri, who writes as follows:

"The ostracods you sent all belong to the genus Metacypris. I turned the sample over to Mr. Richard Hoare who did his M. A. thesis last year on the genus Metacypris in North America. His report, showing the identification of about 60 specimens, is enclosed. The range of these species is chiefly Morrison but they do go as high as the Draney limestone of the Gannet group (Aptian) of southeast Idaho. They have never been recorded from strata younger than the Draney. We have a large Bear River fauna and they are not present in it."
Mr. Hoare's identification of the 60 specimens is summarized below:

<table>
<thead>
<tr>
<th>Number of Specimens</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>M. pahasapensis (Roth)</td>
</tr>
<tr>
<td>11</td>
<td>Metacypris (whitei Jones)</td>
</tr>
<tr>
<td>9</td>
<td>Metacypris (young molt)</td>
</tr>
<tr>
<td>8</td>
<td>Metacypris (molt)</td>
</tr>
<tr>
<td>2</td>
<td>Metacypris n. sp.</td>
</tr>
</tbody>
</table>

A sample of the Mouse House formation, taken from a poorly indurated gray shale, was analyzed by Rodger Y. Anderson, who reports:

"Regarding the sample from the Amole section in your thesis area...The sample is a dense black shaley limestone and about a dozen pollen grains have been isolated by maceration techniques. All of these grains are of the dicotyledonous type. So far I have been able to identify one of the grains as belonging to either the family Myricaceae or Betulaceae. Generic identification in this group of plants must be made with some degree of uncertainty because many of the grains are similar and more than one grain is helpful in identification. The germ pores are circular and the grain is of the 'Betula' type but it has four pores. Betula (birch) generally has three but sometimes it has four pores. The grain is probably Carpinus or Comptonia which more commonly have four pores.

As to the age of the limestone, the following seems pertinent: Dicotyledonous plants and pollen have been found in Lower Cretaceous rocks but they are rare and no fossil record is known of the above two families before the Upper Cretaceous. The plants of early Cretaceous were mainly ferns, Cycads, and Conifers, an association which was cosmopolitan and recorded in many different parts of the world. Upper Cretaceous forests were dominated by hardwood dicotyledons and Conifers and the Betulaceae and Myricaceae were common, at least in the more temperate regions. According to Naumova, pollen of the Betulaceae were among those predominant during the Upper Cretaceous of eastern Asia. A similar situation probably existed in the interior of North America and the Betulaceae and Myricaceae were recorded in the Upper Cretaceous of the Rocky Mountain
area. Although there are no previous pollen studies in North America to rely on, the evidence from other areas and Paleobotanical evidence indicate that the pollen grains are probably no older than Upper Cretaceous. Grains of these two families were common throughout the Cenozoic and representatives are living today. Many more grains will have to be identified before a minimum age can be established.

I'm sorry for the preliminary nature of these conclusions but it will probably be some time before more data is available and perhaps this will help in your field problems."

In addition to the pollen described above, Anderson (personal communication) also found a single squashed pollen grain which he believed to be a grass seed. Mr. Anderson felt that this determination was open to argument and that more grains must be examined before a positive identification could be made (and also eliminate the possibility that this single grain was introduced by contamination), but if grass seeds are present, these strata almost certainly belong to the Tertiary period.

Brown (1939) submitted fossiliferous samples, collected 300 feet above the base (sic) of the Amole group, to Stoyanow who identified them as mactroid lamellibranchs of Upper Cretaceous age. Subsequently Reeside (McKee, 1951) identified a collection of fossils from the Amole group as of probable Lower Cretaceous age.

In other parts of southern Arizona Upper Cretaceous sediments attain an appreciable thickness, and probably formed in a deep basin of sedimentation (McKee, 1951). In the Empire Mountains Paleozoic limestone is overlain by a
thick sequence of rocks similar to those of the Amole group. Farther south, near Patagonia, Stoyanow (1949) described 5800 feet of strata containing red and brown shales, conglomerates, and volcanic rocks. These strata he termed the Patagonia group. The upper part of the group, named the Molly Gibson formation (Stoyanow, 1949), contains fossils which correlate to the upper part of the Lower Cretaceous. From another locality near by, Stoyanow (1949) described the Sonoita group, which he subdivided into the Fort Buchanan and the Fort Crittenden formations. The Sonoita group consists of conglomerates, shales, sandstone, and redbeds, and overlies unnamed andesite flows with apparent conformity (Stoyanow, 1949). These beds, which have certain fossiliferous limestones containing Unio sp., Viviparous sp., and Physa sp. were believed by Schrader (1915) to be Tertiary, but Stoyanow (1949) although agreeing to the Tertiary aspect of this fossil assemblage, dated these rocks as pre-Eocene on the basis of dinosaurian teeth and bones, and correlated the entire Sonoita group to the Upper Cretaceous. Ross (1925) has described a series of shales and arkoses in the Stanley mining district of central Arizona which are dated as Upper Cretaceous from fossils found near the base.

Based on the ostracod and pollen determinations from the area south of the Ajo Road, certain correlations seem logical. I have noted on previous pages that there appears to be an angular unconformity within the upper portion of
Dead Cow formation. This unconformity is a logical line of separation between the Lower Cretaceous (dated by the ostracods) and the Upper Cretaceous or Tertiary (dated by pollen). I would relate the Braun formation and that part of the Dead Cow formation which lies below the unconformity to the Lower Cretaceous, and the Mouse House and Echo Valley formations to the Upper Cretaceous or Early Tertiary.

Brown (1939) believed that the Cretaceous system consisted of a thick series of volcanics, overlain by the Recreation redbeds, in turn overlain by the Amole group. The contact between the Recreation redbeds and the Amole group is a fault in those exposures which I have seen, but Brown (1939) notes a transition zone 75 feet thick, consisting of red and brown arkose, which suggests that the Amole group in this area does overlie the Recreation redbeds. Brown's (1939) evidence that the volcanics in the Piedmontite Hills underlies the Recreation redbeds is subject to argument but nevertheless offers the best working hypothesis presently available. Note should be taken of the fact that Brown (1939) placed the volcanic rocks at the base of the Cretaceous series only by supposition, for he did not actually see the Paleozoic-Cretaceous contact.

I would like now to call attention to the variable lithology within the Amole group as it was defined by Brown (1939), as it is used in this thesis, and which is in common use at the present time. Nearly any sequence of brown or
grayish nondescript arkose, quartzite, conglomerate, or thin-bedded limestone, fine or coarse grained, fits the classification of "amole-type" rocks. It is therefore quite conceivable that the conditions required to produce "Amole-type" strata may have prevailed more than one time.

From the above discussion it is evident there are two possible correlations between the Cretaceous rocks of the southern and the central portions of the Tucson Mountains (Pl. 2-A). Under the principal hypothesis shown it would seem that the same source area prevailed to produce a sequence of typical arkoses and quartzites of the Dead Cow formation above the unconformity within that unit, and that the angular discordance is the result only of a gentle upwarp and possibly brief interval of non-deposition. With this interpretation of stratigraphy, however, there is a definite conflict between Reeside's (McKee, 1951) Lower Cretaceous fossils and Anderson's (letter, 1955) Upper Cretaceous (or perhaps Tertiary) pollen. Shown in dotted lines on Pl. 2-A is an alternate correlation, somewhat more in agreement with the recorded fossil determinations. But there is also difficulty in this way of thinking, because an exact duplication of conditions required to produce "Dead Cow-type" beds must have been reproduced after deposition, tilting and partial erosion of volcanics, Recreation redbeds, and Amole group.

The Braun formation and that part of the Dead Cow
formation below the unconformity are probably the near-shore equivalent of the Lower Cretaceous marine Bisbee group. It is not feasible at this time to suggest any correlations of the Upper Cretaceous (or Tertiary) strata to areas beyond the Tucson Mountains.

I can see no basis at the present time on which to restrict the term Amole group. Future studies should recognize, however, that the rocks of the Amole group may be separated by volcanics and redbeds and may represent a span of time beginning in the Lower Cretaceous and ending possibly as late as Early Tertiary, and at such time as definite stratigraphic relations can be determined it may be well to restrict the term Amole group as here used to those strata above the Recreation redbeds which constituted the type section measured by Brown (1939).

Tucson Mountain Chaos

General Statement

The formational unit of uncertain origin which separates the highly deformed Cretaceous-Tertiary (?) and older rocks (pre-Laramide) from the gently dipping Tertiary volcanic sequence consists of very large fragments of all the pre-Laramide rocks in a disoriented, or chaotic, arrangement. Noble (1941), who first described a formation of this type, states: "The Amargosa chaos or features resembling it are widespread in the southern Death Valley region, and if they occur in other regions the term chaos, as a common noun, may
prove to be a useful geological term". Thus this forma-
tion, which occurs throughout the Tucson Mountains, de-
rives its name from its location and from the word chaos
as used by Noble.

Distribution

The Tucson Mountain chaos is exposed on the pediment
and escarpment line south of the Ajo Road. To the north
are excellent exposures in steep gullies on the south
slope of Cat Mountain. Although generally covered by
talus, it is exposed at scattered points at the base of
the western escarpment in the area between Cat Mountain
and Gates Pass and possibly extends northwesterly to Amole
Peak. It is also exposed on the eastern dip slope through-
out the south and central portions of the range. A few
miles south of the Old Yuma Mine, the chaos is terminated
in an unknown manner and in its place below the Tertiary
volcanics are dark colored andesitic rocks.

Other megabreccias occur elsewhere in southern
Arizona but their correlation with the Tucson Mountain
chaos is undetermined. The conglomerates mentioned by
Richard and Courtright (1954) occupy the same stratigraphic
and time (?) interval, and so may be in some way related
to the Tucson Mountain chaos.

Description

Although the individual blocks are too small to map
separately, the total of this heterogeneous mass presents a
tabular unit easily recognized as a distinct formation. Its thickness varies from a few feet in the very southernmost exposures to a maximum in excess of 300 feet on the central east side of the range. Its long dimension in the Tucson Mountains is approximately 14 miles, and its short dimension, exposed to erosion on both sides, varies from two to three miles.

Its stratigraphic position is always the same; i.e., above the steeply dipping rocks of pre-Laramide age, and below the Tertiary Cat Mountain rhyolite. The upper and lower contacts are rarely visible, but they have been traced closely enough to indicate that although fairly even, they may nevertheless contain some irregularities.

The best exposures in the southern section of the Amole Mining district are on the flats between Hills 2 and 5 (Pl. 3), in the steep gullies cut in the south slope of Cat Mountain, and on the western escarpment south of Gates Pass. In these areas the fragments of the Tucson Mountain chaos consist mainly of arkose of the Amole group, with numerous blocks of Paleozoic limestone and Recreation redbeds. A few blocks of andesite porphyry are present. At widely scattered places are blocks of a gray sericite-quartz schist which resembles the pre-Cambrian Pinal schist. On Cat Mountain I observed one fragment of granite. No members of the Tertiary volcanic sequence have been recognized.

Because I made no attempt to analyze statistically
fragment composition or size, the following observations are based on impressions gained in the field, and as such are subject to error. The size of the fragments varies greatly. Fragments of the Amole group, including specifically blocks of the Braun and/or Echo Valley formations, the Dead Cow formation, and the Mouse House formation (?) constitute about 60 per cent of the total, and range in size from fragments of about 1 foot to large blocks with a maximum observed long dimension of about 350 feet. Many of the blocks are on the order of 100 feet in the long dimension. The blocks of thin-bedded Amole group or redbeds tend toward a tabular shape, and the more uniform Paleozoic limestones and other directionless rocks tend toward a more equidimensional shape. The majority of blocks range in size between 20 and 40 feet, with a second abundant size ranging from 1 to 10 feet. These smaller blocks fill the interstices between the larger blocks. As seen in the exposure on Cat Mountain the blocks are separated by a small amount of gouge or earthy material. The blocks of Paleozoic limestone, although prominent due to differential weathering, rarely exceed 100 feet where exposed south of Cat Mountain. Redbed blocks do not generally exceed 30 or 40 feet, and the fragments of schist are all in the smaller size range (less than 20 feet).

The bedding attitudes are unoriented. It is worth note that the bedding within the blocks is not distorted,
even in the thin-bedded shales of the Amole group. I have no definite knowledge as to whether the tabular blocks have a preferred orientation, but if so, it is not an obvious feature.

As exposed near Gates Pass and on Cat Mountain the thickness of the Tucson Mountain chaos is about 200 feet, but south of the Ajo Road it thins rapidly and is only about 20 feet thick where exposed on Hill 10, and may pinch out entirely farther south. I suspect this is due chiefly to original variation in thickness, but it could be due in part to pre-Cat Mountain rhyolite erosion.

Angular limestone conglomerate lenses (?) are erratically distributed throughout the Tucson Mountain chaos, but are not traceable and have no well defined boundaries. That they are conglomerates and not fault breccias is indicated by the rounded shape of some pebbles and of sorted stratification observed on the sawed surface of one typical sample. The conglomerates are most prevalent near limestone blocks, and are frequently quite conspicuous due to weathering of pebbles which are surrounded by siliceous cases, which stand out to produce angular closed ribs.

A few conglomerates consisting of pebbles and cobbles of dark colored andesite porphyry are present, and are distributed in the same erratic manner as the limestone conglomerates mentioned above. Some of these may actually be fragments of conglomerate but others may derive from nearby
Typical Cat Mountain rhyolite
Basal member Cat Mt. rhyolite. Inclusions up to 10 feet.

Typical "chaos" max. size 40 ft. 145' thick.

Ton-colored andesite agglomerate or flow breccia. Possibly a block in "chaos". 40' thick.

2' of red arkose.
Conglomerate, similar to below. Pebble zone, no silt beds, 50' thick.

Conglomerate, boulders well rounded, fairly spherical, 6" to 12" mostly volcanic. Interbeds of red silt and pebble layers. 40' thick.

Conglomerate, Angular to well rounded boulders 3" to 1', a few 2 1/2', mostly Amole formation, 50' thick.

Cross Section Through Part Of Cat Mountain.
(Looking West)
Figure 1.

Diagramatic Longitudinal Section Showing Inferred Relations at Cat Mountain.
(Looking North)
Figure 2.

TUCSON MOUNTAIN CHAOS AT CAT MOUNTAIN.
Plate 5
blocks of andesite in the Tucson Mountain chaos. One lens of conglomerate has been traced for a short distance, and is shown on the geologic map (south slope of Hill 2). In one place I measured a dip of 60 degrees, but I believe the average attitude is much flatter. It is significant that it occurs at the base of the Tucson Mountain chaos proper, and above a dark andesite which I believe to be older than the Tucson Mountain chaos, but possibly of post-Cretaceous age.

Type Locations

Certain locations present typical examples and are worth individual discussion.

1. South of Hill 2. This area affords an excellent view of the Tucson Mountain chaos in the horizontal dimension. The topography there is gentle and rolling, and the differential erosional effect of the various blocks is well shown. This weathering effect produces blocks rising slightly above the terrain, and separated by flat areas covered with loose debris. It is readily evident that the blocks are of different rock types, different sizes, and different orientations.

2. Pediment east of Hill 8. Mapping here was done only on a reconnaissance basis, but it is evident that the Tucson Mountain chaos consists of blocks generally less than 20 feet in size, and that the proportion of limestone blocks is much greater than in other parts of the Tucson Mountain chaos. Limestone conglomerates are widespread in this location. The underlying Amole group appears to be exposed in
Diagramatic Cross Section
One-half Mile South of Gates Pass.
(Looking North)

TUCSON MOUNTAIN CHAOS NEAR GATES PASS.
places, suggesting that the Tucson Mountain chaos is thin, and may not exceed 50 feet.

3. Cat Mountain. The base of the Cat Mountain rhyolite has been elevated in a fault block along the southern slope of Cat Mountain. There several steep canyons afford excellent vertical exposures of the Tucson Mountain chaos. One of these canyons exposes the entire section without alluvial cover (Pl. 5). At the base is a well-rounded cobble conglomerate with a reddish brown color. The cobbles consist of arkose and siltstone of the Amole group, Recreation redbeds, and dark andesite porphyry. Above the conglomerate is a thin bed of arkose and a layer (or block) of andesite. The Tucson Mountain chaos is about 150 feet thick and is capped by the basal member of the Cat Mountain rhyolite, which contains numerous blocks of the Amole group, some of which are as large as 10 feet in size. There is no evidence of erosion at the top of the Tucson Mountain chaos. The base and top is not exposed in adjacent canyons, but it appears that the conglomerate at the base is thinner. Schist fragments are fairly numerous, and I observed one block of coarse-grained granite.

4. Gates Pass. A vertical section of the Tucson Mountain chaos is fairly well exposed on the steep western slope of the peak south of Gates Pass and east of Golden Gate Mountain (Pl. 6). The particularly interesting feature at this locality is the presence, in the basal part of the
East wall, looking east.
Fig. 1.

West wall, looking west.
Fig. 2.

EXPLANATION
Is = Massive grey limestone, Naco fm (?)
Rb = Cretaceous (?) red beds.
V = Brown volcanics (andesite) Cretaceous (?)

SKETCH OF "CHAOS" IN THE ENTRANCE TO A QUARRY NEAR SWEETWATER DRIVE.
Tucson Mountain chaos, of a crudely stratified conglomeratic unit consisting of rounded cobbles of arkose and volcanics with a small amount of sandy (?) matrix. The fragments within this unit are boulders up to 10 feet in diameter, generally surrounded by a thin concentric layer of gouge. The overall appearance of this material suggests that it is a mud flow, and it is significant that the easterly dip of the stratification closely parallels the dip of the overlying Cat Mountain rhyolite. The chaos, including the basal mudflow (?) is approximately 200 feet thick.

5. Sweetwater Drive. On the eastern dip slope in the central Tucson Mountains, near Sweetwater Drive, a large area of rolling hills is composed of the Tucson Mountain chaos. In this area dark brown and purple andesites, andesite agglomerates, and andesite-pebble conglomerates comprise a principal number of the blocks in the Tucson Mountain chaos. As in other localities, arkose, shales, red-beds, and limestones are also present. Near the Thunder Bird Mine, about 2-1/2 miles northwest of Sweetwater Drive, a remnant of Cat Mountain rhyolite is present to mark the upper contact and it is evident that unless unknown structural complications of considerable magnitude are present, the thickness of the Tucson Mountain chaos must be at least 400 feet, and may be greater, as the base is not exposed.

In the Sweetwater area two divisions are recognizable.
The first, which constitutes the majority of aerial exposure, may be considered as typical chaos, similar to that exposed at the localities described on preceding pages. The only principal difference is that the blocks appear generally to be larger, especially near the Thunder Bird Mine, and there are fewer interstitial small blocks. The only measurement I have made is of one Paleozoic limestone block, which is approximately 225 feet long. The second division comprises a group of separated blocks of Paleozoic limestone which I believe may be correlated as a single unit. These are located in the area immediately south of Sweetwater Drive in sections 34 and 35. These blocks cap several small knobs which project above the terrain at about the same elevation, and which range in size from two hundred to about 1000 feet. Although the contacts with the underlying chaos are not exposed, nevertheless they can be located closely enough to determine that the limestone blocks contact the underlying chaos with an approximately horizontal, flat contact. To casual observation the strikes appear to be generally east-west. Whitney (1947), who has mapped this area in detail, has shown that the blocks do strike essentially parallel in an easterly direction and with one exception dip northerly. As identified by Whitney (1947) the blocks consist of Paleozoic rocks ranging from Devonian through Permian age. Although Whitney (1947) did not interpret the underlying
SKETCH MAP OF OLD YUMA AREA

Diagramatic Cross Section
(Looking Northwest)

"Chaos" and Volcanics.

OLD YUMA MINE AREA
unit as "chaos", his excellently detailed map (scale: one inch equals 300 feet) clearly shows the great diversity of rock types which comprise the blocks of the Tucson Mountain chaos. Within the zone of chaos, Whitney (1947) has identified Cretaceous arkose, siltstone, shale, redbeds; Cretaceous (?) volcanics; and Paleozoic rocks ranging in age from Devonian through Permian.

That the upper division, consisting of the limestone blocks of easterly strike, was once one continuous sheet is suggested by their similarity of strike and dip, and similar elevation. Although not in a perfect stratigraphic sequence, the rocks are roughly arranged from older to younger toward the north (Whitney, 1947). This sheet, then, once covered the typical "chaos" with a fairly flat contact.

In the entrance to a quarry cut in the north side of the largest block is an exposure of chaos material against a steep contact with the Snyder Hill formation (Pl. 7). The debris contains some stratified silt and gypsum which dip northerly. This particular exposure is important because it may represent material deposited in front of an advancing thrust-fault scarp or a huge land slide block. This will be more fully discussed under "Origin".

6. Mile Wide Mine. Judging from Brown's (1939) map and by projection from the eastern side of the range, the Tucson Mountain chaos is present in a considerable thick-
ness in the vicinity of the Gould Mine, Mile Wide Mine, and southeasterly along the rim of the western escarpment to its exposure at Gates Pass, but I have not checked this area in the field and so can say nothing further about it. The Tucson Mountain chaos, if present, is undoubtedly obscured by the metamorphism which pervades the area around Amole Peak and the Mile Wide Mine.

7. Old Yuma Mine. The northernmost outcrop of the Tucson Mountain chaos is on the south side of an easterly trending ridge capped by Cat Mountain rhyolite, located about 1 mile south of the Old Yuma Mine. In the area between this ridge and the north end of the range, the Tertiary volcanic rocks are underlain by dark colored andesites, classified by Brown (1939) as Cretaceous (Pl. 8). These andesites, however, are somewhat different from the volcanic series of the Piedmontite Hills, which is more definitely related to the Amole group and Recreation red-beds. The Tertiary volcanics rest unconformably on the andesites of the Old Yuma Mine area and north of Contzen Pass are separated from them by a thin bed of conglomerate, but the base of the andesites is not exposed. Brown (1939) noted steep northerly dips on tuffaceous or arkosic beds, all with a generally easterly strike. Brown (1939) maps 3 such dips, and I have noted 2 others, also of easterly strike but of southerly dip.

This area contains three principal varieties of andesite, which are: (1) dark brown fine-grained andesite with
a few tiny feldspar phenocrysts; (2) dark gray to purple-black andesite with abundant lath shaped plagioclase phenocrysts, which resembles the Ivy May andesite of the Tertiary volcanic sequence; and (3) flow-breccias or angular conglomerates composed of andesite porphyry pebbles. These rocks resemble the andesites which occur as boulders in the Tucson Mountain chaos, and also resemble the volcanics which I interpret to be possibly post-Laramide but pre-Tucson Mountain chaos in the southern part of the range. The beds with steep dips and easterly strike which occur at scattered points throughout the northern part of the range suggest that these volcanics belong to one thick stratigraphic series. Brown (1939) interpreted them in this manner and correlated them with the volcanics of the Piedmontite Hills. By a well near the middle of section 7, two and a half miles west of the Old Yuma Mine, an outcrop consisting of blocks of the fine-grained andesite presents definite "chaos" aspects.

Interpretation of the history of these andesites is critical to a complete analysis of the Tucson Mountain chaos. It is problematical whether these andesites occupy a position above the pre-Tucson Mountain chaos erosion surface or whether they constitute part of the strata underlying the Tucson Mountain chaos. The field sketches shown in Pl. 8 illustrate the problem. Any future study of the Tucson Mountain chaos should include a study of the relationships
between it and the andesites of the Old Yuma Mine area.

Associated Volcanics

Southeast of Hill 2 dark porphyritic andesites appear to lie below the Tucson Mountain chaos, and are shown as undifferentiated andesite porphyry on the geologic map. There are two dominant varieties, both of which are dark purple to black. One type contains abundant large plagioclase phenocrysts, lath-shaped to slightly elongate and rounded, and the other contains a small percentage of small needle-like plagioclase phenocrysts. In some localities, these volcanics appear to be composed of large blocks as in the overlying chaos, but it is difficult to prove this beyond doubt due to the uniform characteristics of the andesite. Irregular patches of angular conglomerate or flow-breccia occur locally.

Similar volcanics underlie two small knolls capped by Cat Mountain rhyolite, located east of the Old Bat Mine on Mission Road. Another large area of outcrop is about one mile west of Mission Road and about one mile north of Ajo Road.

The area of andesite extending southeast from Hill 2 is on strike with the folded Amole group west of Hill 2, suggesting that these andesites, as well as the Tucson Mountain chaos which overlies them, rest in depth on the truncated edges of the Cretaceous strata.

Origin

Any theory of formation of the chaos must explain
the following facts which are well established by field evidence.

1. The blocks include all of the pre-Laramide formations. The gray sericite schist and granite may be pre-Cambrian.

2. The blocks range in size from less than one foot to a maximum of about 350 feet. The smaller blocks appear to act as interstitial filling between the larger blocks.

3. The thickness varies from zero to greater than 400 feet, but 200 feet is probably the most common. In aerial distribution it is 14 miles long and a minimum of 3 miles wide.

4. The size of the blocks appears to vary directly with the thickness of the chaos; i.e., the thicker sections have generally larger blocks.

5. The chaos rests on an erosion surface. This is demonstrated conclusively by the conglomerate at Cat Mountain. It also may overlie an erosion surface on top of the undifferentiated andesites southeast of Hill 2.

6. Limestone conglomerates occur throughout the chaos. They are not continuous, as would be expected in a developed stream, but rather are suggestive of essentially residual erosion and deposition along small irregular rills. But
CONDITIONS PRECEDING "CHAOS"
Horizontal scale: 1" = 1 mile
Figure 1.

REACTIVATION OF OVERTHRUST,
FORMATION INITIAL TALUS.
Figure 2.

CONTINUED MOVEMENT,
CHAOS SPREAD LATERALLY BY
MUDFLOW AND LANDSLIDE;
ROCKS SATURATED WITH WATER.
Figure 3.

THEORETICAL DIAGRAM SHOWING
POSSIBLE ORIGIN OF
TUCSON MOUNTAIN CHAOS
(Looking North)
Plate 9
under any interpretation, these conglomerates show that the chaos was subjected to sedimentary action during its formation.

7. The unit dip of the tabular-shaped chaos is essentially parallel to that of the overlying Cat Mountain rhyolite.

8. The stratified material exposed on Cat Mountain and at Gates Pass dips in the same direction as that of the overlying Cat Mountain rhyolite, although at Cat Mountain the beds dip at a steeper angle.

9. The chaos locally overlies andesite and chaos(?) of andesite blocks.

10. In the Sweetwater Drive area a large sheet of Paleozoic limestone overlies the chaos with a flat contact, and chaos and stratified gypsumiferous debris is deposited against the northern edge of this sheet.

11. The appearance of the chaos at Cat Mountain and Gates Pass suggests analogy to modern talus slopes. Also, the basal part of the chaos at Gates Pass is suggestive of a mud flow.

Of the above statements, numbers 2, 5, 6 and 11 collectively prove the dominantly sedimentary nature of the Tucson Mountain chaos. Numbers 5 and 6 are probably conclusive in themselves.
Since there is no evidence to indicate that ice-rafting was a factor in the formation of the chaos, it must be explained by some orderly sedimentary process. The large blocks of the chaos must have derived from a mountainous area or steep scarp. It seems to me that such an area of high relief is a primary requirement for the accumulation of such large blocks, and furthermore I believe that the most reasonable assumption is that it resulted from the scarp of either a low-angle thrust fault, or a high-angle reverse or normal fault. The basic assumption in the following discussion, then, is that the chaos resulted from a combination of tectonics and sedimentation.

The pre-chaos orogeny (Laramide) of Early Tertiary (?) caused intense deformation of the pre-Laramide rocks, and produced both folds and thrust faults. This fact is demonstrated in the area south of the Ajo road, and has been noted in numerous areas in southern Arizona by other writers. After this deformation, a period of erosion planed these deformed rocks to a surface of moderate or gentle relief for which I propose the name "Tucson surface". A post-erosion fault scarp could be expected to expose rocks of diverse ages, because such rocks were brought together by the preceding complex structural deformation. Such a scarp, if it continued to move during the formation of the chaos, would continue to expose a variety of rocks as the original scarp was eroded.
In the following discussion, although I have chosen to relate the chaos to thrust faulting, with certain modifications the same method of formation may be applied to any type of active fault scarp.

Figure 1, Pl. 9 illustrates my conception of the conditions immediately prior to the time in which the Tucson Mountain chaos was formed. The deformed pre-Laramide rocks had been eroded to a surface of moderate relief which I have named the Tucson surface. This surface was covered locally with conglomerate and the deeper gullies were filled with conglomerate as shown at Cat Mountain.

The relation between the andesites in the southeastern and northern portions of the Tucson Mountains and the Tucson Mountain chaos is not known. They may be earlier or possibly contemporaneous with the Tucson surface, being in part flow material of Tucson surface time and in part remnants of a Laramide overthrust, or they may represent huge landslide blocks related to the process which formed the Tucson Mountain chaos.

Re-activation of a Laramide thrust-fault might have exposed an overthrust block of extreme complexity, in which rocks ranging from pre-Cambrian to Cretaceous age had been brought together by folding and imbricate thrust-faulting. In front of the scarp produced by this action a thick talus pile would accumulate (Fig. 2, Pl. 9), the thickness of the pile and size of blocks within it depending in part on the height of the scarp. Activation within
the overthrust block would also influence the size of fragments. This activation, resulting from the couple produced by the thrusting force on the overthrust block and frictional force in the opposite direction along the thrust fault plane, might be expected to loosen and help dislodge large blocks along the exposed scarp. The talus pile, as it was pushed and activated by the advancing overthrust, would be especially susceptible to the action of landslide and mudflow. Even in an arid climate, large mud flows have resulted when semi-stable talus piles have been sufficiently lubricated during torrential cloud bursts. But it need not be assumed that the climate during the time the chaos was formed was like that which exists today, and it may well be that the chaos was formed during a much wetter period than now exists, and the rocks may have been in a semi-saturated condition. Further, it may be that the fault scarp and initial talus pile acted as a dam behind which lakes were formed. I realize that these statements are extremely speculative, but I suggest these actions as ones which may have aided in producing the Tucson Mountain chaos.

As each landslide or mud flow occurred, carrying with it the very large fragments accumulated near the scarp, the talus pile would be locally thinned, but expanded laterally. The muddy matrix of the mud flow or landslide mass would produce a gouge-like zone around the blocks of the chaos, and might even produce slickensided surfaces.
Diagrammatic Cross Section
East End of Cat Mountain
(looking West)

Figure 1.

Pictorial View
West End of Cat Mountain.
(looking Easterly)

Figure 2.

CAT MOUNTAIN RHYOLITE
AT CAT MOUNTAIN

Plate 10
Under proper conditions of lubrication, extremely large blocks can slide for considerable distances, impelled by gravity, down a gradient of only a few degrees. This type of movement may account for some of the blocks of 200 feet and greater size. It is further logical that if a single block can move by gravity along a gentle slope, so also can large masses of many rock fragments. With landslide and mud flow masses as well as large single blocks set in motion by the active movement of the fault scarp and being caused by gravity to slide down gentle slopes, the chaos could be spread in a thin layer for a distance of several miles from its source (Fig. 3, Pl. 9). Mud flow stratification in this thin layer would more or less parallel the Tucson surface.

In this manner, large blocks of diverse ages would be set in a matrix of talus, rockslide, and mud flow, and distributed in a thin layer over a large area. While this mass was being deposited and spread out, it was subject to erosion, and deposition of conglomerate took place along intermittent rills. The direction and location of these small water courses was constantly changed with each new earth movement, probably disrupting and fragmenting the conglomerates previously deposited.

The remnants of a large limestone block with chaos piled along its edge has been described on page 37 and in Pl. 7. For this occurrence there are two possible origins.
It may represent a single large block which slid down the surface of the chaos, impelled by gravity. The second possibility is that it represents the remnant of the overthrust scarp, with the chaos spread out in front, in an area in which the scarp had been thrust over previously deposited chaos. Of course, if a high-angle normal fault rather than a thrust fault were responsible for the formation of the Tucson Mountain chaos, the first, or landslide, possibility is required.

Referring again to the eleven basic characteristics of the chaos (pp. 41 - 42); number 1 is satisfied by the assumption of an originally complex area which was elevated along a fault scarp; number 2 by the nature of talus and earth movement under the wet conditions assumed, as well as internal stress within the fault block; numbers 3, 5, 6, 7, 8, 9, and 11 by the suggested mechanism of formation; number 4 by the probability that the thicker areas of chaos would be nearer the source; and number 10 by either of the two methods discussed above. The origin of pre-chaos andesites (number 9) has been discussed previously, and is admittedly not understood. The chaos (?) of andesite blocks must derive, however, from these pre-chaos andesites.

Late (?) Tertiary Volcanic Sequence

Cat Mountain rhyolite

The lowest member of the Tertiary layered volcanic sequence is the Cat Mountain rhyolite, which rests in apparent conformity on the Tucson Mountain chaos. There is
nothing to suggest that appreciable erosion took place after the formation of the Tucson Mountain chaos and before eruption of the Cat Mountain rhyolite. Considered as a unit, the Cat Mountain rhyolite is a homogenous formation with certain distinctive characteristics readily recognized in the field, but in detail it may be divided into several units. Unfortunately these are not always distinguishable and may not retain a consistent stratigraphic position. The details of subdivision of the Cat Mountain rhyolite could probably be resolved if the intricate fault system of the southern Amole mining district were fully understood, but the fault details require for their solution a stratigraphic knowledge of the Cat Mountain rhyolite. This situation is probably unsolvable in the area south of the Ajo Road, but might be deciphered in the area to the north.

The thickness of the Cat Mountain rhyolite is variable, even over short distances. It is in excess of 800 feet at Cat Mountain (Brown, 1939), but thins to little more than 100 feet in the southernmost outcrop.

At Cat Mountain, the type locality used by Brown (1939) in his original definition of the Cat Mountain rhyolite, at least four major divisions are possible (Fig. 1, Pl. 10) and in a general way, these divisions may be extended to the north and to the south, although their thicknesses and details cannot be so projected.

The basal member is white to light tan, streaked, and laminated rhyolite packed with inclusions of Amole group,
which vary in size from barely visible to as much as 3 feet in diameter. The flow structure swirls in an air-flow pattern about the larger inclusions. A particular feature of this unit is the presence of a green platy mineral tentatively identified as Nontronite which occurs generally parallel to the flow structure in thin wisps not more than 3/8-inch in length. The pale tan color, green Nontronite (?), and the large inclusions combine to render the basal unit recognizable in most outcrops. In its other features it resembles the rest of the Cat Mountain rhyolite. In small isolated exposures which are highly weathered, the basal member closely resembles the spherulitic rhyolite. On the southeast slope of Cat Mountain, the basal unit is 20 feet thick, and although its exact thickness has not been measured elsewhere, I have never observed it to attain a greater thickness.

Lying above the basal member is a brown colored banded rhyolite (member No. 2, Fig. 1, Pl. 10) which shows the typical texture of the Cat Mountain rhyolite, characterized by lamination and banding. Vesicles are abundant and are rounded but drawn out along the flow structure into thin elongate forms. The streaked flow lines, distinguishable by slight color differences, swirl around the phenocrysts, inclusions, and vesicles, giving the rock a texture similar to that of an augen gneiss. Phenocrysts of clear quartz and white feldspar are irregularly distributed in minor quantity. Weathering causes disintegration along wavy and irregular planes causing the rock to break off by weathering, or under a hammer, to
jagged tabular pieces. These features of the Cat Mountain rhyolite occur throughout the entire unit and are so characteristic that it is easily recognized even in isolated outcrops. At Cat Mountain member No. 2 attains a maximum thickness of 200 feet.

Member No. 3 (Fig. 1; Pl. 10) is a banded rhyolite with certain additional distinctions. Like member No. 2 below, it has the typical Cat Mountain texture, but in addition contains abundant inclusions of Amole group and redbeds, generally well rounded and varying in size to a maximum of 4 inches. The fragments of Amole group are larger and more numerous near the base, and at the top is a zone about 50 feet thick with many large Amole group fragments. Even on the steep-sided Cat Mountain, member No. 3 tends to form a talus covered slope with interspaced ledges, and this susceptibility to weathering is common in other areas. As exposed on the vertical ledges and steep gullies on Cat Mountain, member No. 3 weathers to a whitish color with purple staining along joints and cracks, but the talus fragments and limited exposures in the talus slope weather a light to deep purple. The two characteristics which distinguish member No. 3 are the presence of numerous fragments and the variable color produced on weathering. South of the Ajo Road, most of the exposures show the characteristic purple color on the slopes, and in some instances a purplish undertone is noted to a light brown overall color when exposed on cliff faces. The whitish
color is very conspicuous on the top of small hills. This was first noted during an attempt to map the contact between "white rhyolite" on the top of a small knoll and "purple rhyolite" below.

Unfortunately, member No. 2 and member No. 3 are so similar in texture that separation is quite difficult. Four factors must be considered: (1) Member No. 3 does not always show the purple or white weathering color and sometimes has the same brown color as does member No. 2; (2) on the other hand, I suspect that member No. 2, under favorable conditions, weathers purple and also white; (3) the percentage difference and size difference of inclusions as noted at Cat Mountain may not hold true elsewhere, although I have observed that what would appear to be member No. 3 does normally have more and larger fragments than member No. 2; (4) as seen on Cat Mountain, the thickness of these two members is variable. It may be possible by careful work to differentiate these two members in the complicated fault-block area south of the Ajo Road, but inasmuch as the details presented above were not understood until field mapping was nearly completed, I have shown no distinction on the geologic map (Pl. 3).

At Cat Mountain, it appears that not only does member No. 2 vary radically in thickness due to original deposition and/or contemporaneous faulting, but that member No. 3 varies in thickness due to faulting prior to deposition of member No. 4. Along the central south slope of Cat Mountain, the
Tucson Mountain chaos has been elevated by a horst-like structure, and is capped by a normal thickness of member No. 2 over which lies a very thin layer of member No. 3. This relation, viewed from the west, is illustrated diagramatically in Fig. 2, Pl. 10. Member No. 4 caps member No. 3 with no indication of displacement on its bottom contact. The most logical explanation is that this horst was formed contemporaneously with volcanism, shortly after extrusion of member No. 2 but before extrusion of member No. 3.

The fourth member of the Cat Mountain rhyolite, as exposed on Cat Mountain, is characterized by typical Cat Mountain structure, but contains fewer inclusions than does member No. 3 below. It weathers to a brownish color and forms cliffs with long and closely spaced vertical joints, somewhat resembling columnar structure, and probably originating from cooling stresses. Member No. 4 has a harder, more uniform ground mass, and the inclusions do not loosen and stand out on weathering as they do in the units below. It is member No. 4 that forms the cap of Cat Mountain and of the ridges to the north and is perhaps the more dominantly exposed unit of the Cat Mountain rhyolite in that area.

There are two possible modes of origin for the Cat Mountain rhyolite. One of these is by extrusion of a molten lava flow, and the other is that of origin by some form of explosive action, i.e., the Nues Ardents gaseous emination possibly combined with mud flow, to form a welded tuff. Brown (1939) originally suggested origin by mud flow for the unit here
termed member No. 3. Of this unit, Brown (1939) stated, "Near the middle of the cliffs on Cat Mountain there is a poorly defined bench, ... formed by a bed similar to the material at the base. This horizon is porous and crowded with foreign material. It resembles a tuff, but microscopic examination suggests that it is probably a mud flow." Further, he states, "In some sections the matrix appears to be the typical glassy ground mass of the flows but elsewhere in the same sections it may appear to consist of altered shards. It is apparently best described as a flow breccia, or mud flow." From these descriptions, it is not quite clear just what microscopic evidence suggests mud flow, but from the great abundance of inclusions it could be argued that mud flow is one possible explanation. The few thin sections I have examined have been cut from what is probably member No. 2 from localities south of the Ajo Road, and they all show euhedral, slightly kaolinized, and somewhat resorbed orthoclase, and highly resorbed quartz phenocrysts set in a banded and swirled matrix which now consists of sericite, carbonate, and clay (?). In most sections certain areas can be found, which, when examined under dim light, exhibit poorly defined curving elongate structures suggestive of very flattened and deformed shards. The evidence of shards, coupled with the wide distribution of the Cat Mountain rhyolite, suggests the possibility that some or perhaps even all of its members may be welded tuffs. Another very critical factor here is the
relation of Cat Mountain rhyolite to a small outcrop of gray fragmental agglomerate and tuff exposed west of the intersection of Mission and Ajo Roads. This tuff is light gray and porous and contains fragments of pumice. This outcrop is situated just south of an exposure correlated with the Safford formation and it was assumed by Brown (1939) that it also belonged to the Safford formation. A fault trending easterly from Cat Mountain was postulated by Brown to separate this exposure of tuff from the hill to the south composed of Cat Mountain rhyolite. I have examined these outcrops several times, and can find no indication of faulting between the exposure of agglomerate and tuff, and the Cat Mountain rhyolite. Instead, there appears to be a gradation between the two over a distance of not more than 100 feet. The fault must pass between the tuff and the Safford formation exposed to the north, and has coincidently brought close together the Safford formation (known to be tuffaceous) and the gray tuff and agglomerate. I interpret the gray tuff and agglomerate to be an island of unwelded material which grades into what apparently is the No. 1 member of the Cat Mountain rhyolite, but I offer no explanation concerning the mechanics which would allow such a small area of tuff to remain unwelded. This area is certainly critical to a study of the genesis of the Cat Mountain rhyolite, and needs further investigation.

The uppermost unit of the Cat Mountain rhyolite is a purple flaggy tuff (?) which is not more than a few feet
thick. It has been noted in several places south of the Ajo Road, immediately below the Safford formation and may in some instances have been included in the Safford formation during mapping. Brown (1939) states that this unit caps the rhyolite nearly everywhere.

Safford Formation

The term Safford formation is here used for the unit above the Cat Mountain rhyolite, originally defined by Brown (1939) as the Safford tuff. The type locality is at Safford Peak in the extreme north end of the range. The choice of names was most unfortunate in this case, because Safford Peak is a little known landmark whereas the town of Safford in south central Arizona is quite well known, and furthermore a series of late Tertiary (?) or Pleistocene lake beds from that locality is commonly referred to as the "Safford beds". It may be well in the future to rename the Safford formation and to designate another type locality, particularly as most of the Safford formation does not resemble the beds at the type locality and are correlated to it by stratigraphic position. Because all of the Safford formation is not readily identified as being tuffaceous, I have substituted the word formation for the word tuff.

With the exception of the type locality, which contains abundant boulders and coarse material, the typical Safford formation consists of thin-bedded, fine to medium-grained poorly indurated siltstone and arkose. Brown (1939) states that the
thin-bedded variety contains abundant shards and angular quartz grains. The colors range from red and purple to light gray, including various shades of orange. The two best exposures are north of the Ajo Road; one being at a small quarry just north of Ajo Road and west of Mission Road, from which locality Brown collected fossil plant remains, and the other along steep-walled gullies on the north side of the Twin Hills, just south of Anklam Road. The Safford formation is exposed between the Cat Mountain rhyolite and the Ivy May andesite west of Saginaw Hill, but outcrops are very poor. Its exact thickness is not known, but at Twin Hills probably exceeds 500 feet.

As exposed west of Saginaw Hill, the Safford formation contains many cobbles and boulders, up to three feet in size, of the Amole group, some of which contain pelecypod fragments. On the slope west of the Ivy May Mine, considerable gypsum-ferous material crops out in isolated patches. A sample of chalky-white material, taken from a small knoll immediately north of Hill 12, shows in thin section abundant grains of quartz and feldspar. Some of these are rounded but others are extremely sharp-edged and elongate, and are set in a matrix of sericite and very abundant carbonate. I interpret this as a lake bed into which volcanic ash was deposited.

No fragments of Cat Mountain rhyolite have been observed in the Safford formation, although cobbles and boulders of the Amole group are quite prevalent. This suggests that there
Photograph of Quarry.
Looking West.
Fig. 1.

Sketch from photograph
Looking West
Fig. 2

RELATIONS OF IVY MAY (?) ANDESITE, SAFFORD FM., AND SHORTS RANCH ANDESITE AT QUARRY HILL.

Plate 11
was little erosion of the Cat Mountain rhyolite before the beginning of Safford formation deposition, and that a nearby source of Cretaceous rocks was present as a high area. East of Saginaw Hill, the Cat Mountain rhyolite may be little more than 100 feet thick, and might wedge out entirely within a short distance.

The Safford formation appears to thin very rapidly between Hills 12 and 13, and is not seen south of this point. In the following section, I will present evidence which suggests that this is due to removal by intrusion of the Ivy May andesite and subsequent erosion.

Of all the formations of the late (?) Tertiary effusive series, the Safford formation offers the one possibility of furnishing evidence of age. Brown (1939) collected fossil plant remains from two localities in the Safford formation, of which Edward W. Berry (Brown, 1939) reported, "...I am inclined to think that it is more apt to belong in the later than in the earlier half of the Tertiary". A series of large fragments up to four feet have been observed to crop out on the west side of Hill 12 in a manner suggestive of a continuous ledge. These fragments consist of a limey sandstone which contains numerous pelecypods. These shells are replaced by coarse dark-brown calcite and leave no trace of any marking. They have been examined by Dr. D. L. Bryant who states (personal communication) that he was unable to identify them. It is possible that these shells were reworked from Cretaceous rocks or that the large bounders observed in the talus slope
I  rails
to
600
Ivy May Andesite
(Based on field observation and comparison to methods
of intrusion of diabase north of
Globe, Arizona.)

Figure 1.

Diagramatic Cross Section
Twin Hills to Ajo Road
Showing Unconformity at Base of
Shorts Ranch Andesite.
(Looking Northeast)

Figure 2.

SOME RELATIONS BETWEEN THE
IVY MAY ANDESITE, SAFFORD FORMATION, AND
SHORTS RANCH ANDESITE.

Plate 12
are actually fragments of Cretaceous strata, but neither of these alternatives seems probable.

Ivy May Andesite

The Ivy May andesite is the unit which Brown (1939) designated as the diopside andesite. The type locality of this unit is the hill (No. 12) west of the Ivy May Mine, for which it is named. It is probably contemporary in age with the Safford formation, but because it is both intrusive and extrusive, it occupies no consistent stratigraphic position.

The typical Ivy May andesite is a dark gray, highly porphyritic andesite which weathers to a dark brown, pitted surface. It is generally entirely massive and without any indication of flow structure, although some of the dike-like bodies which crop out between Hills 12 and 13 show a distinct parallelism of the tabular feldspars which coincides with the strike of the dike. In thin section, the Ivy May andesite of the type locality consists of elongate plagioclase phenocrysts of random orientation, set in a ground mass consisting of a felted mat of plagioclase. Large elongate but highly ragged phenocrysts of siderite (?) occur as pseudomorphs after accessory pyroxene, sphene (?) and olivene. Diopside was not specifically identified. Brown (1939) describes the rock as containing diopside phenocrysts, partly altered to chlorite.

I propose the change in name of this unit because it
appears to be widespread, to be both intrusive and extrusive, and to vary somewhat in texture and composition. It is probable that diopside is not present in all these areas and types.

At Hill 12, the Ivy May andesite rests on the Safford formation with apparent conformity between its bottom contact and the Safford formation bedding. The south slope of Hill 12 and the saddle with small knobs between Hills 12 and 13 occupy a zone of complex relation between the Safford formation and the Ivy May andesite, which I believe due to complex intrusion. The andesite appears to change position vertically along high angle contacts. This might be the result of faulting but no faults are traceable through the underlying contact between the Safford formation and the Cat Mountain rhyolite. As previously mentioned, there are dike-like bodies in this area which contain high-angle flow structure parallel to the dike walls. The Safford formation, in part, appears to be tilted and split by intrusion. South of this saddle, the Safford formation is much thinner than on Hill 12 and wedges out entirely near the center of Hill 13. The lower contact of the andesite and the Safford formation is clearly exposed in a small open cut at the head of a large gully near Hill 13 (at location of 15 degree dip, Pl. 3). The contact is conformable with the bedding in the Safford formation and the base of the andesite shows no brecciation or irregularities. No indication of erosion of the Safford formation is evident. No
chilling or decrease in grain size is evident in the andesite. This contact is no different from many which I have seen between thick diabase sills and the Apache group in the area north of Globe, Arizona. The abrupt cross-cutting habits as seen in the saddle between Hills 12 and 13 is also similar to the intrusive habits of the diabase sills mentioned above. For these reasons, I regard the Ivy May andesite in this area as an intrusive sill and not a flow. In the area south of the Ivy May Mine the sill appears to intrude at the base of the Safford formation, but some of the high angle faults shown bounding the andesite and the Cat Mountain rhyolite may be steep cross-cutting intrusive contacts.

Correlation of Ivy May andesite beyond the main mass is somewhat tenuous, but I believe this unit to occur in three other localities, one of which is located in the northern end of the Tucson Mountains, indicating that it may be a significant and widespread unit.

A dark brown to black andesite is exposed in the wall of a quarry on the east side of a small knoll just north of the Ajo Road and slightly west of Mission Road. This is the same locality from which Brown collected plant remains in the Safford formation. The andesite cuts across tilted beds of the Safford formation with a very irregular contact (Pl.11). The andesite is highly fractured and brecciated and the contact is marked by a white gouge zone. The beds near the contact are reddish colored, and fade into gray and brown
beds at some distance. The andesite is slightly vesicular towards its top contact. It may be noted that if the beds are rotated to their original horizontal position, the contact line could well be the walls of a small stream. I interpret this exposure to represent a flow breccia along the bottom of a small channel in the Safford formation, the time of extrusion being before tilting of the beds. Both the andesite and the Safford formation are truncated by the Shorts Ranch andesite which caps the hill (Fig. 2, Pl. 12). Although there is no lithologic similarity between this andesite and the Ivy May andesite (other than color), the textures are not incompatible with what might be expected in an extrusive equivalent of the Ivy May andesite. Because of the time occurrence (post- or contemporary-Safford formation and pre-Shorts Ranch andesite), I suggest that this andesite is equivalent to the Ivy May andesite.

At Twin Hills, just south of Anklam Road (Fig. 2, Pl. 12), a thick sequence of Safford formation and of a brown to black porphyritic andesite crop out in the steep gullies on the north slope. This andesite is very similar both megascopically and microscopically to the Ivy May andesite. The andesite seems to split the Safford formation, and both are truncated by the overlying Shorts Ranch andesite. Near the top of the andesite are vertical zones of oxidation with a generally east trend. The nose of the andesite body is exposed in the wall of a canyon near the eastern side of the north slope.
From this point westward the andesite thickens until it is considerably greater than 100 feet thick. The first foot or so of this nose (Fig. 1, Pl. 13) is fine-grained and slightly vesicular. The beds above and below the contact do not seem disrupted. There is no suggestion of erosion of the andesite, and no boulders of andesite were noted in the Safford formation. I interpret this area to represent a flow contemporaneous with deposition of Safford formation, with no great erosion interval. An alternate possibility is that the andesite intrudes the Safford formation. The Safford formation and the andesite appear to have been tilted before deposition of the Shorts Ranch andesite, although some exposures on the northeastern slope give the impression of a gradation between the Shorts Ranch andesite and the lower andesite. On the basis of lithology (megascopic and microscopic) I correlate this andesite to the Ivy May andesite.

The third area which may contain exposures of the Ivy May andesite is located north and east of the Old Yuma Mine in the northern end of the range (Pl. 8). In this area, Brown (1939) has mapped the uppermost andesite of that area as lying directly on a dark andesite porphyry which he assigns to the Cretaceous system. Actually, there is a thin bed, perhaps only 10 feet in thickness, of white, soft, tuffaceous (?) siltstone, which is undoubtedly equivalent to the Safford formation, and which separates the overlying Tertiary andesite from the underlying andesite porphyry. Exposed in a
Figure I.
Sketch of Outcrop on Side of Gully, Central North Slope of Twin Hills.
(Looking West)

Figure 2.
POSSIBLE ORIGIN OF THE BIOTITE RHYOLITE.
Diagramatic Cross Sections.
Not to scale.
Plate 13
cliff face north of the Old Yuma Mine and in a wash to the east is a thin layer of dark gray porphyritic andesite which resembles the Ivy May andesite, and which overlies the Safford formation. The association of this andesite with the Safford formation, coupled with its lithology, suggests that this unit is equivalent to the Ivy May andesite.

In Fig. 1, Pl. 12 I have diagramatically shown the different methods of intrusion and extrusion discussed on the preceding pages.

I have made no study that would lead to sound conclusions of the igneous history of the Ivy May andesite, but if the interpretations concerning the finer-grained extrusive facies is correct, it is then clear that the prophyritic texture was developed after emplacement of the igneous mass, and that the phenocrysts did not develop in a magma chamber prior to emplacement to its present position.

Biotite Rhyolite

The Biotite rhyolite crops out over a large area in the vicinity of Beehive Peak. It was described and named by Brown (1939). Although its composition, determined by thin-section, is that of a quartz latite I propose no change in the name because it is a logical field classification and is already established in the literature. Although I believe the Biotite rhyolite to be dominantly intrusive, it is discussed with the effusive rocks because it also shows extrusive aspects, and may in part be truly an extrusive flow rock.
In hand specimen the rock is nearly always the same and presents few variations. On the fresh surface it is light gray to pinkish in color and consists of rounded clear quartz crystals and euhedral books of black biotite, set in a matrix of tabular feldspar. Weathered exposures are tan to red. The quartz grains break conchoidally and exhibit rounded, pseudo-rhombic, and hexagonal outlines. Packed throughout the rock are inclusions which range in size from a millimeter to four or five inches. The most common size, however, is on the order of one quarter to two inches. For the most part, the inclusions consist of fragments of the Amole group, but some are of the pre-Cat mountain volcanics. Fragments of Cat Mountain rhyolite have not been identified with any certainty, but a few fragments of the Ivy May andesite are present. A small but undetermined percentage of the inclusions are Biotite rhyolite; the percentage being smaller than would appear from casual observation. Because most of the inclusions have a thin (1/32 inch) tightly adhering film of Biotite rhyolite around them, which remains attached when the fragments weather from the matrix, the inclusions appear at first glance to be of Biotite rhyolite unless a fractured surface is exposed.

In thin-section (Appendix I) it consists of euhedral and highly resorbed quartz and andesine phenocrysts, or fragments of phenocrysts, set in a matrix of smaller crystals and angular and elongate fragments and devitrified glass.
The phenocrysts are packed closely together but each crystal or fragment is an individual. Biotite laths are commonly bent and broken, particularly where crowded between phenocrysts or inclusions. The texture resembles that of a crystal tuff but not a single glass shard is present in the thin-sections examined.

The characteristics of the Biotite rhyolite in both hand specimen and thin-section are highly distinctive. South of Helmet Peak, a prominent landmark in the Pima Mining district about 15 miles south of Beehive Peak, are isolated small outcrops of a rock identical to the Biotite rhyolite. In thin-section this rock shows a texture and composition almost identical to those described above from the Beehive Peak area. This suggests that the Biotite rhyolite, as a rock type, has a wide distribution. It is not known to occur north of the Ajo Road, however, unless a thin quartz-bearing unit between the Safford formation and the Shorts Ranch andesite at Twin Hills is its equivalent.

In the Beehive Peak area are several dikes of approximately the same mineral composition as that of the Biotite rhyolite. The most prominent of these are a set of two dikes which intersect at right angles at Beehive Peak. These two dikes have well defined vertical flow structure and sharp vertical contacts. In hand specimen they consist of an aphanitic reddish ground mass (70 per cent) with euhedral phenocrysts of feldspar (10 per cent), euhedral black biotite (10 per cent), and clear rounded quartz phenocrysts.
(10 per cent). Other dike-like bodies, some of which are shown on the geologic map (Pl. 3), more closely resemble the Biotite rhyolite except that they lack inclusions. For the most part these other dikes have poorly defined or gradational boundaries but do possess well-defined flow structure which exhibits various directions of dip and strike. Some of the west-trending hills east of Beehive Peak contain thin, very irregular, dike-like bodies.

The contacts of the main mass near Beehive Peak with other rocks are nowhere exposed, but can be located within a few feet over considerable distances. This contact (Pl. 3) is irregular in detail, and in overall view is somewhat circular. The outcrop pattern in the field suggests that the contact must be steeper than about 40 degrees, and that it dips always toward the central area of Biotite rhyolite. This outcrop pattern cannot be explained by faulting and would appear to represent a circular, funnel shaped igneous contact. To the south of Beehive Peak the Biotite rhyolite is exposed in several isolated fault blocks, suggesting that there it is an extrusive rock of specific thickness, and thus is capable of being preserved or removed by faulting.

The Biotite rhyolite has two outstanding features which bear on its origin. First, it contains abundant inclusions disseminated throughout the entire mass, and second the igneous matrix consists of individual crystals, crystal fragments, and bent and broken biotite laths. Also significant are the
irregular dikes with gradational boundaries. The funnel-shape of the main mass suggests that it is directly intrusive or that it has filled a volcanic crater. Another possibility is that the Biotite rhyolite was deposited against moderately well eroded fault scarps. The existence of the Safford formation in a prospect shaft about 2000 feet northwest of Beehive Peak, but east of the area of Cat Mountain rhyolite, suggests that there was pre-Biotite rhyolite faulting along this contact, with the downthrown side on the east. Because only silicified material was present on the dump, however, I could not establish definitely that the rock was Safford formation. Also indicative of an eroded surface is the east-trending lens of conglomerate at the contact west of Beehive Peak (Pl. 3). Again, there is considerable uncertainty in this interpretation because this conglomerate may correlate to the Tucson surface of pre-Tucson Mountain chaos age (as it has been questionably shown on the geologic map, Pl. 3). The characteristic texture of the biotite rhyolite indicates that crystallization was nearly complete prior to movement to its present position. The magma must have consisted of a mesh of well developed phenocrysts with a minimum amount of interstitial molten material. The inclusions may have been derived from an exploded magma roof, and incorporated by a coalescing system of dikes, similar to the irregular dikes described above. Under this theory, the Biotite rhyolite is essentially a breccia pipe, although with
considerably more igneous matrix than the normal breccia pipe. The Beehive Peak and Hill 8 areas are the locus of intrusion, or possibly an intrusion flaring into a crater at the surface. Such a crater, if it existed, may have been partly formed by faulting as suggested above. The main dikes at Beehive Peak, although undoubtedly of related origins, clearly cross-cut the main mass, and represent a later stage of igneous activity. Fig. 2 of Pl. 13 diagrammatically illustrates the concept of origin present above.

The relative age of the biotite rhyolite is established by inference. It intruded and/or is deposited against Cat Mountain rhyolite and Ivy May andesite. South of Beehive Peak, it also appears to be extrusive. It is not definitely known to underlie the Shorts Ranch andesite, but a possible equivalent of the biotite rhyolite occurs at the base of the Shorts Ranch andesite on the west side of Twin Hills. It is, then, certain to be younger than the Safford formation and the Ivy May andesite, but whether there is a significant time interval is completely unknown. I have tentatively placed the biotite rhyolite as older than the Shorts Ranch andesite (Pl. 2), but this relation is open to further investigation.

Shorts Ranch Andesite

The Shorts Ranch andesite, named and described by Brown (1939), is the uppermost unit of the Tertiary volcanic sequence. It is exposed extensively on the eastern side of
the range north of the Ajo Road. South of the Ajo Road, its only outcrop is on the large hill at the south end of the range, but there its vertical flow structure indicates it to be intrusive rather than extrusive. As exposed at Twin Hills and at Quarry Hill, it overlies the Safford formation and Ivy May andesite with angular discordance, which I interpret (see previous discussion under Ivy May andesite) to be an angular unconformity (Fig. 2, Pl. 12). Elsewhere, however, the Shorts Ranch andesite may conformably overlie the Safford formation. Brown (1939) estimated that the Shorts Ranch andesite was at least 400 feet thick.

The Shorts Ranch andesite is the most uniform member of the Tertiary sequence, and it is nearly the same in every exposure. In hand specimen it is a light gray to nearly white even-textured rock exhibiting white feldspar phenocrysts in a white aphanitic matrix. Where exposed north of the Ajo Road, it contains black hornblend phenocrysts, but in the intrusive area south of the Ajo Road, the mafic mineral is euhedral biotite. Petrographic work shows very little variation from one locality to another.

Flow structure is exhibited by orientation of the tabular minerals, as well as by faint color banding. North of the Ajo Road, where the rock is extrusive, flow structure appears to be relatively uncommon. One small area east of Twin Hills shows moderately well developed flow structure, which forms a funnel-like shape several hundred feet in diameter, suggesting that this is an intrusive neck. South of
the Ajo Road, in the intrusive outcrop by hill No. 14, flow structure is quite well developed. Here the rock in part weathers to produce reddish discoloration parallel to the oriented feldspar. One puzzling feature in this area is the tendency to develop a second planar structure, defined only by oriented feldspar phenocrysts, which intersects the flow structure at 90 degrees.

The small dike-like body on the flats north of hill No. 14 contains flow structure which tends to parallel its immediate contacts. Elsewhere in the vicinity of hill No. 14 the trend of the flow structure is east to northeast. Somewhat east of hill No. 14 the flow structure bends sharply into a northwesterly trending direction (Pl. 3). The explanation for this structure is not immediately apparent, but it could be a reflection of horizontal movement along the contact while the mass was still molten. It can be noted on Pl. 3 that two faults parallel this contact and are located but a short distance north of it.

Age and Correlation

To date there are no further data which would allow a more precise dating of the Tertiary volcanic sequence than that assigned by Brown (1939) who placed them questionably in the latter half of the Tertiary. The fossiliferous strata in the Safford formation have been discussed under that unit. It seems unlikely that, unless some of the shales of the Safford formation eventually yield identifiable pollen, the age
will be more closely resolved.

Schrader's work (1915) in the Empire Mountains suggests a correlation of the Tertiary rocks between the Tucson and Santa Rita Mountains. The sequence there records essentially the same history; i.e., rhyolite flows followed by erosion and deposition of tuffaceous lake beds in turn followed by andesite eruptions. I have seen specimens of the lower rhyolite from the Santa Rita Mountains as float fragments in Madera Canyon, and its general appearance suggests a correlation with the Cat Mountain rhyolite.

The Esmeralda formation, which ranges from upper Miocene to lower Pliocene (Gilbert, 1941), crops out over a considerable portion of southwestern Nevada, and separates two periods of volcanic flows. The meager information available on the volcanics of central-western Arizona suggests that a similar division might be possible in that area. It is interesting to speculate whether such a three-fold division might be useful as a possible method of regional correlation for the Tertiary volcanic series.

Post-Shorts Ranch Andesite Rocks

Tertiary Lake Beds

In the extreme southeast corner of the range is a single outcrop of thin-bedded limestone, siltstone, and gypsiferous marl, to which Brown (1939) referred as Tertiary (?) lake beds. Since the top of this series has been eroded, its thickness is not known, but exceeds 30 feet.
Some of the limestones contain algal structures and on the dump of a shaft or well in the center of the outcrop are shale fragments containing abundant ostracods. Brown (1939) submitted several ostracod samples to John B. Reeside, Jr., who replied, "No one will admit ability to determine the simple cyprid ostracods present".

On the west the lake beds appear to overlie the Shorts Ranch andesite, but the contact is covered by talus. On the dump of the shaft in the center of the outcrop are fragments of Shorts Ranch andesite. These fragments are, in part, freshly broken, probably by digging; but also they show weathered and poorly rounded edges, suggesting that the lake beds rest on a weathered soil surface of Shorts Ranch andesite. An alternative possibility, suggested by Brown (1939), is that the lake beds are thrust over the Shorts Ranch andesite.

The lake beds would most nearly correspond in general character to the Safford formation, but this correlation would require that they be older than the Shorts Ranch andesite. On the east side of "A" Mountain, in angular unconformity below the Quaternary (?) basalt flows, are thin-bedded marls and limestones nearly identical to Brown's Tertiary lake beds. These beds are exposed only in three steep gullies, near the "A" Mountain Dairy, and the relation to rocks other than the basalts is not known.

Water Tank Conglomerate

On the pediment east of Beehive Peak are numerous isolated exposures of poorly consolidated arkose and boulder
conglomerate. They have been studied only in a cursory manner, and only the principal outcrops are shown on the district map (Pl. 4). The arkose beds are inconspicuous on the pediment, and probably there are numerous smaller outcrops which are not shown. One of the most continuous exposures is along a ditch dug for a water line, extending northwest from a water supply tank which serves the surrounding subdivision.

The arkose consists of coarse-grained quartz and feldspar, and rock fragments, cemented by a calcareous silt. These beds range from tan to greenish in color. For the most part, they exhibit gentle dips, but along the water line ditch they dip easterly twenty to thirty degrees.

Interbedded with the arkose are conglomerates with a very distinctive nature. These beds of conglomerate, which range in thickness from a few feet to well over ten feet, are composed dominantly of well-rounded but slightly elliptical and tabular cobbles and boulders of light tan coarse-grained arkose. The fragments generally resemble the arkoses of the Dead Cow formation of the Amole group, but are somewhat less consolidated and may represent some horizon higher in the Cretaceous series than any of the formations exposed south of the Ajo Road. The size range of the boulders and cobbles is two inches to one foot, but a few are as large as three and one-half feet. These larger boulders are also well rounded. Scattered throughout the conglomerates are pebbles and cobbles of angular to slightly rounded fine-grained, laminated black
hornfels, such as are common in the areas of metamorphosed shale near Amole Peak. A few fragments of unidentified volcanic rock (rhyolite?) are present. The boulders of arkose are cut by closely spaced parallel fractures which trend across the long axis of the boulder. The fractured boulders, black hornfels, and the well rounded shape of the fragments identify this unit. I observed one fragment of pelecypod-bearing arkose identical to the fossiliferous bed in the Safford formation on hill No. 12, and described under that section.

The correlation of the Water Tank conglomerate is questionable. Its thickness is not known (but probably exceeds 50 feet) and its top and bottom contacts are not exposed. The similarity in elevation between the Water Tank conglomerate and the Tucson Mountain chaos, exposed less than a quarter mile to the north, suggests a correlation between the two. The contact between the two, however, is not exposed and may be a fault. Another possibility is that the Water Tank conglomerate correlates to the San Xavier formation of L. A. Heindl (unpublished name given by personal communication) which crops out at Black Mountain. Other possibilities are: (1) It might represent sedimentary deposits along the rim of a crater or erosion surface which may have existed during eruption of the Biotite rhyolite (see discussion under that section); (2) it might correlate to Brown's Tertiary lake beds; or (3) it may represent a formation not recognized elsewhere.
Alluvium

Alluvium consists of recent stream gravel, talus, and older caliche-cemented stream conglomerate. These types have not been differentiated on the geologic maps (Pl. 3, Pl. 4). Although the caliche-cemented conglomerate definitely pre-dates the surface stream wash and talus, field evidence suggests that it is a young deposit, and I consider all three alluvial types to be recent Quaternary. Brown (1939) has described the alluvial deposits in more detail.

Because the pediment areas and talus slopes represent a considerable areal portion of the area mapped, and because on these surfaces bedrock is nearly always covered in intermittent patches, interpretation of bedrock was made in the field, and only larger areas of deeper alluvium were mapped separately.

TERTIARY INTRUSIVE ROCKS

Andesite

Intrusive andesite crops out in the eastern half of the detailed area (Pl. 3). It occurs as narrow, steeply dipping dikes of considerable strike length, and also in shorter but wider dike-like bodies and small plugs. In composition, two types are represented; viz., a light tan to reddish colored fine-grained andesite (?) with small feldspar phenocrysts, and a dark gray andesite porphyry. The dark variety more commonly occurs as narrow dikes, but this is by no means always true, and conversely the wider dikes more often are
composed of the lighter colored variety. In part, the lighter color of some of the dikes may be due to bleaching associated with alteration, but in other cases appears to represent the true color of the rock and may reflect a composition more acidic than that of andesite.

Flow structure is shown by aligned phenocrysts and by layers of varying hardness which weather to produce narrow irregular bands. In the narrower, dark colored dikes, there are prominent close-spaced en echelon joints which parallel their contacts. Elongated vesicles occur in some of the dikes.

These andesites are seen to intrude the Cat Mountain rhyolite, Safford formation, and the Biotite rhyolite. Short narrow dikes of dark andesite porphyry (not mapped) cut the undifferentiated andesite of pre-Cat Mountain rhyolite age. Because the intrusive andesites are younger than the Biotite rhyolite, I classify them as late (?) Tertiary, but there is nothing to indicate whether they are post-Shorts Ranch andesite.

Spherulitic Rhyolite

The Spherulitic rhyolite was named by Brown (1939) for a light tan to yellowish white, hard dense rhyolite which locally shows a prominent development of spherulites. This unit crops out, in association with the Tucson Mountain chaos, on the pediment south of the Ajo Road and below the Western escarpment to the north.

The Spherulitic rhyolite is characterized by a well
developed flow structure, and being harder than the rocks it intrudes, often stands out as erosional remnants. The flow structures commonly have gentle dips, and in some exposures are seen to bend abruptly into steep dips. Spherulites are most common along the flow lines with the flatter dips. The composition and microscopic character have been discussed by Brown (1939), who regards it as a sodic rhyolite.

The Spherulitic rhyolite seems particularly to favor the Tucson Mountain chaos as a host for intrusion, and many small bodies occur in irregular shapes within the chaos zone. Some of the intrusions contain fairly large inclusions of the Amole group and of Paleozoic limestone; e.g., as at hill No. 6. North of the Ajo Road a few of the intrusions cut the lower parts of the Cat Mountain rhyolite. It appears likely that the intrusions of Spherulitic rhyolite stoped their way into the relatively unconsolidated Tucson Mountain chaos, and formed domical structures against the bottom contact of the more resistant Cat Mountain rhyolite.

As noted above, the Spherulitic rhyolite is known to be post-Cat Mountain rhyolite and therefore Tertiary, but a more definite age has not been established.

Saginaw porphyry

The term Saginaw porphyry is here used for the acid porphyry stock and smaller intrusives in the immediate vicinity of Saginaw Hill. The main body forms Saginaw Hill, and
THRUST FAULTS NEAR BRAUN MINE.

Plate 14.
smaller masses intrude to the north (Pl. 3). On its east side the main mass tapers to a root-like shape, and then narrows to a dike about five feet wide, which is traceable about one mile easterly to a point northeast of hill No. 10 where it terminates against a fault. Around the margins of the Saginaw porphyry are small replacement ore deposits in the Amole group, and Saginaw Hill is the site of siliceous veins and disseminated copper mineralization in the porphyry. The unit is quite variable in texture. Near the margins the texture is finer grained, with quartz and feldspar phenocrysts set in an aphanitic ground mass, but in the central portion of the stock the ground mass is medium-grained with large phenocrysts of feldspar. A few areas in Saginaw Hill contain feldspar crystals an inch length, and the texture approaches that of a pegmatite.

The coarser grained variety is classified megascopically as a quartz monzonite, and the finer grained type as a quartz latite. The composition is variable, however, and in part contains very little quartz.

The porphyry dike extending easterly from Saginaw Hill is essentially the same as the finer grained facies, and retains this appearance nearly to the crest of hill No. 10. As seen in thin-section from that location, although too altered to be specifically identified, it is probably a latite porphyry. It is covered for a short distance on the northeast slope of hill No. 10, and in its next outcrop
consists of a brown ground mass with about 20 per cent feldspar phenocrysts. Near the merger of the dike and the stock, silicified joints flare outward from the dike parallel to the edges of the stock (Pl. 3).

In the Palo Verde Mine a highly altered phase of the finer grained facies forms the south wall of the Palo Verde fault. In thin-section it consists of large phenocrysts of quartz, some of which show rounded and highly embayed outlines of resorption type, set in sericite matrix. The quartz phenocrysts are commonly fractured and some occur as angular fragments. Remnants of feldspar phenocrysts are smaller than the quartz, and are altered to sericite and muscovite to the extent that they are not specifically identifiable. This rock is best classified as a quartz porphyry.

East of the Saginaw Mine the Amole group sediments and the Saginaw porphyry have been feldspathized to the extent that their contacts are blurred and difficult to establish (Pl. 3). In part, the porphyry appears to contain feldspathized inclusions of sediments, but other areas of mixed rock (igneous-appearing with inclusions) may be entirely due to granitization of the sediments. In thin-section, a quartz-feldspar recrystallized mosaic is seen to be developed in both the porphyry and in arkose and siltstone. Also, in both the porphyry and sediments, feldspar porphyroblasts are formed with very ragged outlines and abundant included material. The larger grains of the arkose have retained in part their clastic outlines.
There is no direct evidence to aid in predicting the shape of the main stock in depth. The lack of metamorphic effects along the western and southern margin, however, suggest that the contacts there are steep, and conversely the more pronounced metamorphism on the east margin suggests that the stock dips under the sediments. The metamorphism of the small hill at the Saginaw Mine suggests that at depth there is a larger intrusive than is presently exposed.

The mechanism of intrusion is open to speculation. On the northeast side of Saginaw Hill the Amole group sediments appear to bend, for a short distance, in conformity with the margin of the stock, but elsewhere they have northwesterly strikes which seem to be truncated by it. Such folds as have been recognized are related to the district structure. It appears that Brown's suggestion (1939) that the stock was intruded by magmatic stoping is the most likely. Assimilation seems improbable in view of the generally sharp contacts.

The Saginaw porphyry dike discussed above is interesting for two reasons. It presents a classic example of a stock and connected dike, an occurrence rarely seen outside of textbooks. Because it intrudes the Cat Mountain rhyolite, it shows that the Saginaw porphyry and related ore deposits are of post-Cat Mountain rhyolite age. Evidence will be presented later concerning the age of mineralization which suggests that the Saginaw porphyry and related ore deposits are post-Shorts Ranch andesite.
Sedimentary Hills Quartz Monzonite

North of the Ajo Road, a small stock of quartz monzonite crops out in the Sedimentary Hills. This rock has been studied in detail by Bennett (1957), who divides the stock into two types, which he believes were intruded separately, but possibly from the same magma.

The two intrusives are approximately equal in size. The northern one is a medium-grained quartz monzonite with a minimum amount of quartz (not seen in hand specimen), and the southern one, classified as a granite porphyry, contains fairly abundant large quartz phenocrysts. (Bennett, 1957).

The two intrusives are separated by a thin segment of hornfels. A quartz-pegmatite plug about 25 feet in diameter intrudes the quartz monzonite. The plug shows a banded circular structure formed by stringers of quartz and orthoclase. Bennett (1957) suggests that it was formed by some combination of replacement and direct magmatic intrusion.

The Sedimentary Hills stock shows little resemblance to the Saginaw prophyry, and it is essentially unaltered in contrast to the hydrothermal alteration at Saginaw Hill. Chalcopryite is found on the outcrop in the granite porphyry, but Bennett (1957) believes it to be a late magmatic product. There is no apparent association with the stock and the surrounding ore deposits.

Lacking any lithologic similarity to the Saginaw porphyry, there is no direct evidence as to the age of the
Sedimentary Hills quartz monzonite. Its lack of alteration or association with mineralization suggests that it might be of a different age than the Saginaw porphyry, and might belong to the Laramide period rather than to the later part of the Tertiary.

STRUCTURE SOUTH OF THE AJO ROAD

Laramide

Folds and Associated Faults

General statement. --The dominant elements of Laramide structure are folds, and associated thrust and tear faults. These structures pre-date the Tucson surface and were presumably formed during the late Cretaceous or early Tertiary. A complete understanding of these structures is retarded by the uncertainties of the Amole group stratigraphy, but enhanced by the generally well developed bedding of that group.

There are four orders of folds, three of which are observable in the field. The first order is established by interpretation; i.e., I interpret the major structure to be a synclinorium on which are superposed folds of the other orders. Folds of the second order have wave lengths which range from 200 to over 1000 feet, and the asymmetry is controlled by the inferred synclinorium. On the limbs of these second order folds are smaller drag folds, of a third order, not mapped precisely but shown diagramatically, approximately to scale, on Pl. 3. The asymmetry of each third order fold is controlled by a second order fold. Finally, fourth order
drag folds, generally only a few feet in amplitude, are superposed upon and owe their asymmetry to third order folds. These relations should be considered in future studies because, for example, the direction of asymmetry or overturning of third order folds is meaningless with respect to the first order synclinorium.

Associated with the formation of the synclinorium are thrust and tear faults, whose existence is largely a matter of interpretation.

Synclinorium.— The existence of a large synclinorium is inferred by the direction of asymmetry and overturning of second order folds. Its axis is indefinitely located, but probably is between the Five fault and the Burger fault. East of the Five fault the second order folds are asymmetrically inclined and overturned to the east, and west of the Five fault they are overturned and asymmetrically inclined toward the west (Pl. 3-A). West of the Five fault all of the folds plunge southeast, whereas east of it the plunge is northwest. The reason for this is not clear but it could be that the Five fault separated the active forces sufficiently to allow folds on either side of that fault to form separate patterns.

Under the above interpretation, the Snyder Hill formation exposed at the Braun Mine is on the east limb of the synclinorium and at Snyder Hill is on the west limb. The steeper dip of the beds on the west limb, compared to the gentler dipping and more open folds on the east limb, suggests that the
synclinorium is asymmetrically inclined toward the north-east (Pl. 3-A).

Braun overturn.— The outcrop pattern near the Braun Mine is puzzling and requires explanation. As shown in Pl. 14, I interpret this area to represent an overturned isoclinal fold modified by two thrust faults. The dip of the dashed contacts in Fig. 1, Pl. 14 cannot be determined in the field, and it is not certain that they are all faults, but the interpretations presented in Figs. 2-5, Pl. 14 seem compatible with the surrounding structure. The fault against which these structures terminate might be inferred to be a tear contemporaneous with folding.

The Five fault.— The Five fault is inferred to explain the structural relations seen at the surface (Pl. 3). As interpreted in Pl. 3-A, the relative movement appears to be down on the hanging wall side, but its association with the folds suggests that it may be a thrust fault.

Burger fault.— The Burger fault is inferred to explain the structural relations seen at the surface. Its association with overturned beds, and the formations in contact, indicate that it is a thrust fault. The extension of the Burger fault and the overturned section of the Dead Cow formation southeast beyond the middle of section 1 is based on speculation rather than on direct evidence.

Tear fault on east line of section 36.— This fault is located just south of a plowed field (Pl. 3). It strikes
northwest and can be located on-the ground within a few feet but the fault surface is not exposed. The topography in this area is too gentle to yield any suggestion of the direction or of the amount of dip. The fault seems to terminate along a curving northeasterly contact which I infer to be a thrust fault. It may be seen (Pl. 3) that the Dead Cow formation in this fault block forms a poorly defined, steeply plunging anticline. It would appear that the competent arkoses of the Dead Cow formation refused to yield to the extreme deformation within the thin-bedded Braun formation, and were thrust over the nose of a northwesterly dipping anticline. At the same time, the Braun formation on the southwest side of the tear fault was complexly folded. On the section in Pl. 3-A this fault is shown to flatten in height and to be truncated by the Five fault, but this is a matter of speculation.

Jig fault.—The Jig fault cuts slightly across the bedding of the Amole group, and pinches out the Mouse House formation. Its importance or magnitude is not evident even in the vicinity of Wyoming Street, where it can be mapped. Its southeast extension is a matter of interpretation, but in the area east of Saginaw Hill the Mouse House formation seems to be absent, and so the Jig fault may extend into that area.

Normal Faults

It can probably be assumed that at least some high-
angle normal faults were formed shortly after the Laramide folding, but I identified none in the field. The fault extending northeast from Saginaw Hill, occupied by the Saginaw porphyry dike, has definitely undergone displacement because the beds on either side do not match, but the magnitude is unknown. The displacement of Cat Mountain rhyolite along this fault is slight, if any. This may be, then, a pre-Tucson surface fault which was reactivated in the Tertiary with very slight displacement. Many of the other faults which cut the Tertiary rocks may have originated during Laramide time, but field mapping neither supports nor disproves this possibility.

Tertiary

High-Angle Faults

High-angle faults dominate the Tertiary structure, and although it was impossible to measure dips (few of the faults are exposed) I assume that at least most of them are normal faults. These faults are shown to displace the Tertiary rocks in Pl. 3 and Pl. 3-A, and need no explanation.

The fault pattern is highly complex and it is not clear which faults formed first, or whether movement was contemporaneous on all of them. Such fault surfaces as are exposed show gently dipping slickensides, suggesting that horizontal movement may have been important.

It has been previously mentioned that some faulting took place during Cat Mountain rhyolite time, and that some
structural deformation in the form of local tilting occurred in the interval between deposition of the Safford formation and extrusion of the Shorts Ranch andesite. I believe, however, that most of the faulting took place in post-Shorts Ranch andesite time, but a minimum age cannot be established. Faults displace the flat-lying basalts of Tertiary-Quaternary age at "A" Mountain, (Brown, 1939) but enough time must have elapsed since the last period of faulting to permit erosion to form the extensive pediment on the western side of the range. It is noteworthy in this connection that nearly all the faults are obsequent fault line scarps with the downthrown sides topographically high.

Tilted Blocks and Folds

The Tertiary rocks generally dip at gentle angles. The measurement of tilt in the volcanic rocks is subject to error because part of the dip of the flow structure might have been due to original dip of the flow. I have observed, however, that the volcanic flow structure in the Tucson Mountains, as well as surrounding ranges, commonly dips gently (five to 30 degrees) in a northeast to east direction, which suggests that most of the dip is due to a regional tilting. Also, the sedimentary rocks, such as the Safford formation, show this same direction of dip. I believe that in consideration of those facts, the dip of flow structure may be assumed to have been essentially horizontal when formed.

In the complexly faulted area south of the Ajo Road
the Tertiary rocks exhibit folded structures; an apparently rare occurrence in the other parts of the Tucson Mountains and in surrounding ranges. For the most part, however, these folds can be postulated to be the result of fault drag. Plate 3 shows several folds, all of which are in the Cat Mountain rhyolite, although the dips of the higher formations suggest that they were also involved.

Some of the fault blocks show no relation to the adjacent folded structures, and exhibit independent homoclinal dips.

Thrust Faults

The possibility of renewed activity along a Laramide thrust fault during deposition of the Tucson Mountain chaos has been previously discussed. No other Tertiary thrust-faulting is known unless the Tertiary (?) lake-beds are thrust over the Shorts Ranch andesite.

DISTRICT AND REGIONAL STRUCTURE

Laramide

The Amole group is folded into a broad, open syncline in the central part of the Tucson Mountains (Brown, 1939). The intricately folded synclinorium south of the Ajo Road may be a part of that structure, but a positive correlation can not be made with the data at hand. If the two structures were directly connected, the beds in the Sedimentary Hills would be expected to dip northeast, when in fact they dip southwest. Further study is required to solve these relations.
As noted previously, the southwest limb of the synclinorium exhibits generally steeper and tighter folds, which suggests that the synclinal axis is inclined asymmetrically to the northeast. It would then appear that any regional overthrust movement was toward the northeast.

**Tertiary**

The post-volcanic Tertiary structure is discussed at some length by Brown (1939), and although I do not concur with all of the implications of his remarks, I refer the reader to them for an excellent presentation of the district and regional structure.

The elements of Tertiary structure are internal faults, inferred range-boundary faults, tilted blocks, and folds. The folded structures, some, and perhaps all of which, are related to fault drag, occur south of the Ajo Road.

The faults which displace Tertiary rocks are not mapped precisely or completely enough for detailed analysis. Brown (1939) noted that east or northeast faults are nearly always downthrown on the south. This is not true in detail south of the Ajo Road, where many reversals occur, although the aggregate effect may still tend towards a downthrow on the south.

The tilted blocks and marginal boundary faults are so related that they should be discussed together. It seems likely, but not essential, that the internal faults formed at the same time as the boundary faults.
I have previously discussed the inherent error in the measurement of the structural tilt of volcanic flows, but concluded that the dip of the flow structure in most cases may be assumed to be a relatively close measure of the amount of tilting. Reconnaissance observations in the Roskruge Mountains to the west, and the Tortolita Mountains to the north, suggest that those ranges are tilted northeast or easterly. The volcanics of the Empire Mountains (Schrader, 1915) dip northeast, as do those of the Galiuro Mountains. The Catalina Mountains were believed by Davis (1931), on physiographic evidence, to have been tilted northeast or easterly.

There is little evidence to indicate whether the inferred marginal faults, buried by alluvium, are single faults along the borders of the ranges, or whether there are many faults spread out through the valleys. It is possible that there are two separate types of faults; those that distribute and are related to the tilted blocks, and others of a later age which may be responsible for the present mountain distribution. But certainly faults of some kind must be inferred to form a resultant series of downthrown blocks progressing westerly. If there were no such faults to break the easterly tilt of the ranges, a mountain several miles high at a minimum would have existed over the Roskruge Mountains. Ransome (et. al., 1910) discussed a similar problem in the Bullfrog District, Nevada, and concluded that
tilting and faulting were contemporaneous, for if either had entirely preceded the other, a preposterously high mountain would have been formed.
ORE DEPOSITS
HISTORY AND PRODUCTION

Interest and activity in the Amole Mining District has been intermittent and on a small scale. The total production is probably less than $100,000. The tabulation presented below as compiled principally from the U. S. Mineral Resources Year books, which list activity from the Amole Mining District as a unit, and in many instances it has been difficult or impossible to differentiate between production from the northern and southern sections.

1898. According to Tenney the district was quiescent until 1898, when the Saginaw Mining Company was organized. The Saginaw Mine was brought under development, and a mill consisting of three huntingtons and six concentrating tables was installed. Very little production was achieved. According to a story related to the late Mr. Seaton Williams (Personal communication), considerable underground development work was done and a mill and smelter installed. Water was piped four miles from the Santa Cruz River. Copper ore was brought from Mineral Hill (25 miles to the south) and stored underground, and then treated in the mill and smelter during a stockholders' meeting. The mill tailing, smelter slag dump, and pipeline ditch are evidence that at least part of the story is correct. The Saginaw Mining Company was

effectively inactive by 1900.

1907. The Old Pueblo Mine was under development by the Tucson Consolidated Mining Company who held the property under a stock agreement with the Old Pueblo Mining and Milling Co. One shipment of ore was made during October which ranged from 10 to 12 per cent Cu and 5 to 10 dollars combined Au and Ag. This probably came from a depth of 30 feet in the main shaft (70 feet deep) where 15 tons of chalcocite ore was sampled to assay 33 per cent Cu, 16 oz. Ag, and $2.50 Au. Workings excluding the 70-foot shaft totaled 600 feet. (The principal workings are now on a patented mining claim named Quien Sabe.)

1908 - 1911. No information.

1912. The Tucson Consolidated Copper Co. still held the Old Pueblo group. The "Quien Sabe shaft" was reported to be 517 feet deep.

1913. The Calument and Arizona Mining Company (Annual report, 1913) secured an option on the Amole copper property (Saginaw Hill and vicinity), consisting of 17 unpatented claims. On this property several shafts, ranging from 180 to 300 feet deep, had been sunk to develop gold-bearing veins in shale and limestone. These shafts were inaccessible in 1913, but it was claimed that considerable stoping was done on veins three to six feet wide, which assayed 10 to 20 dollars in gold. A diamond drilling program was planned.

1914. The Calument and Arizona annual report of
1914 describes exploration of Saginaw Hill as follows:

"This property, nine miles south of Tucson in Pima County was thoroughly prospected by diamond drilling. Work was started January 15 and stopped April 1. Five holes, totaling 1500 feet, were drilled. The mineralization in this ground is similar to that at Ajo, but is not so intense. All of the holes showed appreciable values in copper, but not enough to make commercial ore." All the drilling was done within the porphyry stock (Allen, 1920).


1917. The quartz veins in Saginaw Hill were worked by the Papago Queen Mining Company (Allen, 1920) under a bond and lease. Three carloads of copper ore were shipped. The veins assayed up to 3 per cent copper.

1918. Copper ore, and some lead-silver ore, was shipped. The output of four producers aggregated 584 tons valued at $17,222. The Copper King (Mile Wide; Northern Amole Dist.) and Saginaw properties were the most important. The copper undoubtedly came from the Mile Wide and the lead from the Saginaw -- probably meaning the Palo Verde Mine.

1919. The Arizona-Tonopah Mining and Milling Company (Beehive Peak) developed its property, but no production was reported. The Arizona-Tucson property (Ivy May) was also under development. The following description of this work is taken from Allen (1920).

Arizona-Tucson Copper Company. This company had 36
claims, including the Ivy May (presently named the Santa Margarita) and nine others that were the property of the Hermosa Copper Company. All of the operations at the time of Allen's visit (October, 1919) were confined to development of the Ivy May. Sinking on a vertical shaft had reached a depth of 25 feet. This shaft was sunk a little to the east of an old shaft which followed the ore to a depth of 100 feet, but which had caved. Ore had been stoped from this old shaft, and over 200 tons mined from near the surface. This ore was stockpiled at the time of Allen's visit, and it was claimed to assay 60 dollars in gold, silver, and copper.

Arizona-Tonopah Mining and Milling Company. Active work on this property began in the early part of 1919, and 40 claims were located, some south of the Arizona-Tucson claims. At the time of Allen's visit (October, 1919), a vertical 9 x 4-foot shaft was being sunk. The management intended to cross cut at the 200 foot level to intersect a winze sunk from an adit 100 feet above the collar of the shaft. This adit was driven 185 feet into the south side of Beehive Peak. A winze 60 feet deep had been sunk at a point 100 feet from the mouth of the adit. All the workings were in fresh rock with little or no ore.

A small prospect shaft, located 1500 feet northwest of the main shaft, was being sunk, and had reached a depth of 60 feet. It was said to have passed through a silicified rhyolite flow which contained pyrite and assayed 17
ounces in silver. Prospecting was being undertaken on some of the other claims.

1920. In March, 1920, sinking had ceased at the main shaft of the Arizona-Tonopah property, but some work was being done on the "silver" shaft to the northwest. The main shaft had reached a depth of 145 feet, and was in rhyolite which reportedly assayed 1.60 dollars in gold, three ounces in silver, and 1.6 per cent copper. The "silver" shaft had reached a depth of 100 feet, and ore had been found which was claimed to assay from 14 to 46 dollars in lead, silver, copper, and gold. Thirty feet of drifting had been done on this showing.

The Ivy May, Old Bat, and Pellegrin properties were producers of ore. The Arizona-Tucson Copper Company, operating the Ivy May, shipped three cars of high-grade copper ore containing gold.

1921. Several small lots were shipped to a smelter from the Old Bat and Pellegrin properties. The ore contained silver with a little gold.

1922. The total amount of ore mined from the district aggregated 288 tons valued at $1,178 Au, 2,325 oz. Ag, 9078 pounds Cu, and 24,920 pounds Pb, with a total value of $6,100. The Ivy May group of the Tucson Copper Company produced lead ore and copper ore containing gold and silver. This property was in the prospecting stage during 1922, and was opened by a 225-foot inclined (sic) shaft, from which 300 feet of

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1. All the shafts are vertical.
drifting had been done. A small amount of siliceous silver ore containing copper and lead was removed during development on the Helpmate (location?) claim. Silver-lead ore was produced from the Snyder Hill prospect.

1923. Four producers from the Amole district reported shipments aggregating 64 tons, containing gold, silver, and copper, with a total value of $1,084. The Old Bat and Pellegrin properties were the principal producers of gold-silver ore. This ore was taken out in an attempt to develop milling ore. The Old Bat was said to have 16,000 tons of ore in sight with an average value of four dollars in gold and eight ounces in silver. The ore from the Pellegrin property reportedly assays about ten per cent lead and a little gold and silver.

1924. Development work at the Palo Verde Mine was suspended in May pending construction of a power line. The management intended to complete a proposed 1,000-foot shaft, of which only 200 feet were sunk in 1924. The shaft had exposed sulfide ore assaying 10 dollars in gold and silver, 5 per cent lead, and 15 per cent zinc. This project was apparently never resumed.

1925. The aggregate production from the district was 150 tons from seven producers. It is uncertain how much of this total was produced from the southern section. The Beehive and Pellegrin (Arizona) were reported to have shipped ore.
1926 - 1934. Intermittent activity was reported from the southern section, but with very little production. The Southwestern Metal Mines Inc. operated some of the claims near Beehive Peak (probably the Ivy May) and shipped several cars of oxidized copper ore in 1929. This is the last year for which I have found recorded data which may pertain to the Ivy May Mine. The present owner, a Mr. Ortiz of Tucson, states that the main shaft is 700 feet deep, but that a fire destroyed the timbering and caused it to cave.

1935 - 1944. Nearly all production appears to have been from the northern section.

1945. The Palo Verde Mine was dewatered and retimbered to the 215-foot level. 172 tons were shipped which contained 5 oz. Au, 339 oz. Ag, 200 pounds Cu, 1,000 pounds Pb, and 17,000 pounds Zn, for a total of $3,172.

1946. The Palo Verde Mine operated during the first four months, and shipped 1,574 tons of lead-zinc ore. The Old Yuma Mine (northern section) shipped 1,640 tons of gold-silver ore. The aggregate production of these two was 3,214 tons which contained 167 oz. Au, 4,313 oz. Ag, 3,500 pounds Cu, 128,000 pounds Pb, 200,000 pounds Zn, for a total of $48,249. Very probably most of the lead, zinc, and copper came from the Palo Verde Mine, and most of the gold and silver from the Old Yuma Mine.

1947 - 1953. No activity reported.

1954. In February, Messrs. Coombs and Martin stope...
about 10 tons from the Palo Verde incline, which reportedly assayed 15 per cent zinc.

1955. The high price of copper incited some prospecting. The old Papago Queen was located by Art Jacobs of Tucson, who leased the property to Harris and Strong. During 1955 or 1956 the Papago Queen adit was reactivated, and a small amount of exploration and stoping was done.

1956. During 1956 and/or 1957 Ventures Ltd. drilled Saginaw Hill to test the disseminated copper mineralization.

1957. During the latter part of 1956, and in 1957, Ventures Ltd. drilled the Sedimentary Hills, testing both the disseminated copper mineralization of the quartz monzonite stock, and mineralized thrust fault zones.

GEOLOGIC FEATURES

Types of Deposits

The mineral deposits of the southern section of the Amole Mining District fall into six classifications based on type of occurrence.

Quartz veins containing copper silicates have been exploited at the Papago Queen, Ivy May, and Old Pueblo mines. These veins are characterized by banded quartz layers, commonly with cocks-comb structures and drusy cavities. They rarely exceed five feet in width and show a marked tendency to pinch and swell. At some places they consist of a solid quartz vein but also may consist of a fractured zone interlaced with thin stringers of quartz.
The majority of the deposits are replacements in limestone or limey siltstone. At the Braun Mine and the Snyder Hill prospect silver and/or lead have been mined from limestone of the Snyder Hill formation. Vein-like replacements of thin limestone beds of the Amole group are best exemplified by the Palo Verde deposit, but are common to other mines in the Saginaw area and in the Sedimentary Hills. At the Palo Verde Mine the ore contains lead and zinc, but most of the other deposits of this type contain principally pyrite, with a minor amount of copper. Alteration consists principally of silicification.

Saginaw Hill, composed of the Saginaw porphyry, has been explored to determine its potential as a porphyry copper deposit. The alteration is much weaker, but otherwise is similar to other southwestern porphyry copper deposits.

In the Sedimentary Hills, a small stock of quartz monzonite contains some disseminated copper, which Bennett (1957) believes to be a late magmatic product.

In the Sedimentary Hills, certain thrust faults have been mineralized by iron and copper sulfides.

The deposit at the Old Bat Mine is unlike any other in the district. It consists of a narrow, gently dipping vein of massive manganiferous siderite containing gold and silver.
Mineralogy of the Deposits

The ore minerals of the quartz veins are chryso-colla, and unidentified green copper stain which permeates gouge zones and some of the vein quartz. Sulfide ore is exposed neither in the accessible workings nor on the dumps. The vein quartz contains but few relict sulfide cavities, although sulfides may have once filled the vugs which are common to these veins. The copper silicates are entirely exotic, and may represent a considerable ratio of enrichment from nearly barren quartz veins.

The workings in the Snyder Hill formation show no ore minerals at all, save for a tiny fleck of galena at Snyder Hill. Barite is present in small quantities at Snyder Hill. These mines reportedly contain some silver, very likely in the form of argentiferous galena and silver halides.

The ore in the Palo Verde Mine, and that on the dump at the Saginaw Mine, consists of sphalerite and pyrite with a subordinate amount of galena. A minor amount of chalcopyrite occurs in the Palo Verde Mine. The host rock is a silicified limestone.

The sulfide minerals in the Sedimentary Hills consist largely of pyrrhotite, with subordinate pyrite and locally chalcopyrite (Bennett, 1957).

The sulfides beneath the leached capping at Saginaw Hill presumably contains pyrite, chalcopyrite, chalcocite, and minor molybdenite.
Structural Control

Those deposits which to date have been productive are associated with faults and fissures. The deposits in the vicinity of Saginaw Hill are all associated with northeasterly faults or fissures, and occur in a structural zone with pronounced northeast elements. Of the other deposits which show a definite structural control, the northwesterly direction is most common.

Oxidation

The replacement deposits in the Amole group are oxidized to very shallow depths, rarely exceeding 40 feet. The depth of oxidation in the siliceous copper bearing veins is considerably greater, and the depth to sulfides may be 200 feet or more. Since these quartz veins appear to have contained relatively little primary sulfide, and as much of it has probably been precipitated as chrysocolla in the vein, there is probably no appreciable chalcocite enrichment below the oxidized zone.

I have no knowledge concerning the depth of oxidation in the Saginaw porphyry, but it is probably greater than the surrounding sediments because it is much more fractured.

Age of Mineralization

With the exception of the Old Bat vein, the deposits all have one common characteristic, that of high silica content. The quartz-copper veins of the Papago Queen, Ivy May, and Old Pueblo mines are very similar to each other. The
Palo Verde, Arizona Tonopah "Silver" shaft, Silver Pass, the Braun and Snyder Hill Prospects, and some of the Sedimentary Hills deposits, are associated with silicification of the host rocks. The porphyry at Saginaw Hill contains numerous siliceous veinlets.

It was noted previously that the Saginaw porphyry dike cuts, and is thus definitely younger than, the Cat Mountain rhyolite. The deposits of the Saginaw Hill area are either contemporary with or younger than the Saginaw porphyry, and therefore belong to a period later in the Tertiary than Laramide time. With the possible exception of some of those in Sedimentary Hills, then, all of the deposits are post-Laramide and their similarly high silica content suggests that they are all derived from the same period of mineralization. I suggest from this evidence that at least some of the mineralization in the Sedimentary Hills, and all of the other deposits, are of the same age. The quartz vein of the Old Pueblo Mine cuts the Shorts Ranch andesite, and so I assign them to a post-Shorts Ranch andesite age, possible contemporaneous with tilting and block faulting. A possible exception is the Old Bat vein, of which it can only be said that it is post-Cat Mountain rhyolite.

Future of the District

The following comments are to be in no way construed as a judgment of the merit of individual properties, but
rather must be considered as generalized speculation based on geological possibilities and past production records.

The weakly disseminated sulfides in the Biotite rhylite, such as those on the dump of the old Arizona Tonopah shaft, appear to be a late magmatic product and will probably not occur in any great quantity unless found in association with some specific structure, such as a fault or a fissure.

The quartz-copper veins are either barren or too thin to mine over much of their length, and the explored ore shoots appear to have been mined out. There is no reliable geologic guide by which to predict the location of other commercial shoots. These veins will probably diminish in grade with depth toward the base of the oxidized zone. The disseminated sulfides on the dump of the Ivy May Mine leaves open to speculation the possibility that the quartz veins on that property may be feeders of disseminated low grade sulfide in favorable rocks at depth.

There is some ore left in the Palo Verde Mine, and very probably other similar mineralized limy beds exist under the alluvial cover adjacent to the Palo Verde fault. The future of this mine depends on the economic factors involved in mining small bodies of 15 per cent zinc ore. The ore which is or was in the Saginaw Mine is not well enough known to lead to any conclusions. The weak alteration and the fact that the Saginaw porphyry copper prospect
has been twice drilled and rejected (or apparently so) gives a discouraging outlook.

In the Sedimentary Hills area, the quartz monzonite plug contains some disseminated copper in the outcrop, which is believed by Bennett (1957) to be a late magmatic product, and therefore will probably be of limited quantity. It is problematical whether the sulfide replacement deposits of that area contain enough valuable metal to be presently classed as ore.

At the Old Bat Mine, the developed vein material reportedly contains about 14 dollars (present value of metals) combined gold and silver. Any future work on this property will be hindered by marketing or treatment of this high iron content carbonate ore.

The only major geological structure which is known to affect ore deposition is the northeasterly mineralized zone in the vicinity of Saginaw Hill. This zone is further accentuated by the northeasterly extension of the Palo Verde fault, the Saginaw porphyry dike, and the andesite dikes west of Hill 8. The southeast extension of Paleozoic limestone on the west side of the synclinorium passes within 4000 feet of the Palo Verde Mine, and the intersection of thick limestone with the southwesterly extension of the Saginaw Hill ore zone is a geologically prospective area for ore deposits.
Description of Mines

Saginaw Area

Saginaw Mine.— The main workings of the Saginaw Mine are due north of Saginaw Hill, and consist of two vertical inaccessible shafts about 150 feet apart. From the southwest shaft a four foot stulled vertical stope extends northeast for an unknown distance. Numerous other shafts and shallow pits have been dug along the principal fissure zone. Both of the main shafts were sunk on the Saginaw fissure. The smelter slag dump and shaft dumps cover most of the mineralized zone.

Where it can be seen, the Saginaw fissure consists of a fractured and sheared zone a few feet wide, with slight traces of alteration and some green copper stain. The fissure zone cuts the Amole group, and presumably the mineralization is largely confined to thin beds of limestone.

It is clear that at least some ore has been removed from the Saginaw workings, but because ore was reportedly transported to the mine for promotional purposes, it is uncertain which sulfide material now on the dump actually came from the Saginaw Mine.

Palo Verde Mine.— The Palo Verde Mine is developed by an inclined shaft which bears N. 63 degrees E. and inclines at 38 degrees. The deepest accessible level is 110 feet below the collar, but company maps show that the shaft extends to a vertical depth below the surface of about 300 feet.
The shaft was sunk along the contact between the Amole group and the Saginaw prophry. This contact is nearly vertical and is a fault with gouge and breccia up to 3 feet thick. Sphalerite, galena, pyrite, chalcopyrite, and quartz completely replace a 3-foot thick bed in the sediments. Small remnants of the original rock show that it was limestone.

The inclined shaft carries this bed of ore in the back, and is open to a stope 20 to 30 feet wide, 8 feet high, which extends to the 110-foot level. On the 110-foot level a cross cut penetrates 140 feet into Saginaw porphyry. The porphyry is altered to a soft crumbly rock consisting of quartz, sericite, clay, and carbonate. In thin-section the rock contains rounded to angular and resorbed quartz phenocrysts, set in a fine-grained, altered matrix. The feldspars are altered beyond recognition. The rock is a quartz porphyry. On the 80-foot level, a cross cut to the southwest penetrates another mineralized limy bed, about 2 feet thick, which contains more pyrite and less sphalerite than the main deposit.

At the edge of the stoped area the sulfide material gives way to unaltered limestone. The highly altered prophry contains disseminated pyrite through its explored length. There is no sign of brecciation of the sulfide ore along the Palo Verde fault. This fault, then, appears to be pre-ore in age and to have acted as a feeder for the mineralizing solutions.
Oxidation of the ore body is shallow and extends to a depth of 15 or 20 feet. Oxidation in the porphyry extends to somewhere between the 80 and 110-foot levels. The sulfide ore averages between 15 and 18 per cent zinc.

On the south side of the Palo Verde fault, a mineralized limestone bed has been developed by 2 steeply inclined shafts and several shallow pits. The ore on the dump of the deeper shafts is principally pyrite in a quartz gangue. The mineralized areas of this limestone bed appear to be restricted about groups of northeast fractures.

Papago Queen.— The quartz veins striking northeast through Saginaw Hill are developed by an adit driven into the northeast side of the hill along the main vein. The adit is approximately 150 feet long, with a 40-foot winze and a short cross cut to the south.

The vein consists of discontinuous stringers of quartz separated by segments of altered porphyry. The area near the winze is veined to a width of about 10 feet, and contains a moderate amount of chrysocolla. Much of the vein is nearly barren. The depth of oxidation is unknown.

Saginaw Porphyry Copper Prospect.— The porphyry intrusive at Saginaw Hill contains disseminated copper mineralization, and was drilled by Calument and Arizona in 1914, and recently by Ventures Ltd.

The outcrop shows sulfide limonite and veinlets typical of porphyry copper alteration. The rock between
the veins is relatively fresh. Alteration consists of prominent bands of quartz in the center of the veins, and quartz-sericite (?) - clay (?) for a few millimeters on either side. The limonite in the veins is thin and appears to be mostly derived from pyrite. Small areas containing limonite after chalcocite occur around the margin of the hill.

The sparseness of alteration and lack of appreciable quantities of limonite derived from copper sulfides suggests that a commercial ore body may not exist below the Saginaw Hill leached capping.

The mineralized fractures show a pronounced north-east pattern, although fractures of other directions are also mineralized.

Beehive Peak Area

Arizona Tonopah Mine.— These workings are located on the south slope of Beehive Peak, and are described in detail in "History and Production". The dump of the main shaft shows unaltered Biotite rhyolite with an occasional trace of pyrite and chalcopyrite. The adit in the peak is also driven in unaltered rock. No structures are apparent, except for a few steep joints in the main shaft. The sulfides that are present may be of late magmatic derivation rather than superposed hydrothermal. The presence of sulfides in a sample from the west side of Hill 8, visible in thin-section (appendix 1), suggests that a trace amount
of sulfide material may be a characteristic of deuteric alteration of the Biotite rhyolite.

The shaft sunk by the Arizona Tonopah Co., 1900 feet northeast of Beehive Peak (Pl. 3), explored a silicified rock with chrysocolla and malachite. The host rock appears to be the Safford formation, but the complete silicification makes a definite identification impossible. The shaft has been recently filled and the dump leveled. There is some float material on the surface which may have guided the original discovery.

Ivy May (Arizona Tucson, or Santa Margarita).--The Ivy May Mine is developed by a vertical shaft which is reported to be 700 feet deep, but which is caved. Water stands at a fairly shallow depth. The original work was done from a nearby vertical shaft sunk at the intersection of two quartz veins. The most prominent vein is about five feet wide and bears north to N. 22 degrees W. and is exposed in shallow cuts for a distance of about 75 feet. The other vein strikes about N. 85 degrees E. and dips 78 degrees northwest. A circular stope 10 to 15 feet in diameter, located at the intersection, extends from the surface to a depth of about 30 feet. The east-trending vein is stoped 5 feet wide from just below the surface to an unknown depth, and connects with the circular stope. These stopes were probably serviced in part by the old shaft, but may also be connected to the main shaft, located about 60 feet southeast of the vein.
intersection. Probably about one thousand tons of material have been removed from these stopes.

The northwesterly vein consists of massive banded quartz, with very little copper. The easterly vein, where exposed just above the stope, consists of thin bands of quartz separated by the country rock. The character of the stoped material is unknown. The country rock is Ivy May andesite, generally bleached white and altered to clay near the veins.

The large dump from the main shaft suggests that the reported depth is correct. The rocks penetrated, as seen on the dump, are Ivy May andesite, Safford formation, and Cat Mountain rhyolite. The Ivy May andesite on the dump is generally unaltered, but the Safford formation (siltstone and arkose) and the Cat Mountain rhyolite contain up to 15 per cent sulfides (visual estimation). The sulfide material appears to be largely pyritic, but shows a distinct bronze to yellow discoloration. The oxidized portions, although containing no visible copper, show cores of the pyritic material surrounded by a brown unidentified limonite (?). If the material was entirely pyrite it seems probable that a more complete leaching would have taken place, especially in the Cat Mountain rhyolite, which is altered to a relatively inactive aggregate of quartz, sericite (?) and clay.

Old Bat Mine (Mission Group).-- The Old Bat vein is developed by a number of gently dipping adits driven northerly into
the south side of an easterly trending ridge (Pl. 4). The vein is about four feet wide and dips about 15 to 20 degrees to the north. The country rock is Cat Mountain rhyolite, and the vein lies parallel to its flow structure.

The vein material is massive manganiferous siderite which reportedly averages four dollars in gold (valued at $20.67) and eight ounces in silver. Rough calculations indicate that the reported 16,000 tons of "ore" (vein material) blocked out is probably a reasonable estimate.

The longest adit explores the vein a distance of about 200 feet, and in the face penetrates a northwesterly fault which dips 85 degrees southwest. The fault terminates the vein, but it also appears to be a pre-mineral structure. It consists of about two feet of hematite, gouge, and siderite. Drifts and short cross cuts explore the fault for about 200 feet, and two raises have penetrated another vein 10 feet above the main vein, on the northeast side of the fault. This second vein consists of sheared rhyolite with thin seams of siderite along the flow structure.

Pellegrin Prospect

According to Wilson (et. al., 1920), the Pellegrin property is located a short distance south of the Old Bat, but I never discovered the exact location in the field.

Braun Mine

The Braun Mine is developed by a vertical shaft, now filled with water to a shallow depth, and some elongate
stopes open to the surface. These are filled with muck in the bottom, but may be connected to the shaft. There is no indication of the nature of the ore, for the walls of the accessible workings appear to be mined clean. The dump contains principally barren black limestone, but there are a few piles of silicified limestone with yellow limonite stain near the access road. Also on the dump there are a few tons of reddish well-rounded conglomerate with disseminated pyrite and chalcopyrite. I do not recognize the formation to which this might belong, unless it is from the Amole group basal conglomerate. A local miner recently reported that some of the workings assay about eight to ten dollars in silver.

Snyder Hill Prospect

The south side of Snyder Hill has been explored by several inclined shafts 10 to 30 feet deep, which follow silicified zones along the bedding. The dump material shows some yellow limonite. One shaft is vertical, about 30 feet deep, and opens to an irregular stope about 8 feet high and 15 feet wide. On one wall I found a tiny fleck of galena associated with yellow limonite. Some of the material on the dump is silicified.

Sedimentary Hills area

Porphyry copper prospect.— The quartz monzonite plug in that area contains a small amount of disseminated pyrite and chalcopyrite on the outcrop, and sparse disseminated limonite. The rock is unaltered and shows none of the
characteristics normally associated with a porphyry copper deposit. Bennett (1957) suggested that the sulfides were a late magmatic product. There is no indication that enrichment or better grade primary ore will occur at depth.

Others.— Bennett (1957) has made a detailed study of the ore deposits of that area, and I refer the reader to his report. He concludes that the widespread pyrrhotite disseminations, and deposits along thrust faults, were the first stage of mineralization. Following this, a second stage was characterized by pyrite and chalcopyrite, which in part followed the same channels, and was accompanied by sericite-clay alteration. The last stage (Bennett, 1957) was the deposition of quartz-barite-galena in northeast veins. I have noted some association of silicification with the pyritic ore on the dumps of the workings in replacement deposits of limy beds. The host rock for all the deposits, except the quartz monzonite, is the Amole group. The general character of the limy beds which are host to nearly all of the replacement deposits (Bennett's "limey argillite") suggests that it might correlate to the Mouse House formation, but this is uncertain.

Old Pueblo Mine

The Old Pueblo Mine is developed by a main shaft reportedly 517 feet deep, another shaft about 100 feet northeast of the main shaft, and a cross cut from the surface. The main shaft was sunk on a thin seam stained with
green copper minerals. The second shaft is over 100 feet deep, and was sunk on the northernmost outcrop of the main vein. This vein strikes north-northeast and is nearly vertical. It consists of massive and veined quartz varying in width from 1/2 to 2 feet. There is local copper stain on the outcrop, and in the cross cut, but most of the vein is nearly barren. The host rock is Shorts Ranch andesite, which is altered to sericite-clay along the vein. The hill on which the workings are located is cut by numerous interlaced quartz veinlets.

Silver Pass Mine

The Silver Pass Mine is located about 3/4 of a mile southwest of the Old Pueblo Mine, and is developed by two inclined shafts which follow silicified zones in the Safford formation. The sulfide ore on the dump of the deepest shaft contains principally pyrite, although the name of the mine suggests that it might also contain silver. No production of history is recorded for this property. The structural control, other than bedding, is not apparent.
BIBLIOGRAPHY


APPENDIX I

PETROGRAPHIC DESCRIPTIONS
Ivy May andesite

Sample No. 45
Location: North side of Hill 12 (Pl. 3).

Megascopic: Intrusive facies (sill). Dark brown-green matrix surrounding white, well formed plagioclase phenocrysts. No mafic minerals are visible.

Petrographic: The rock is classified as an andesite.

Composition

- 55% Plagioclase phenocrysts (An 45-55).
- 5% Siderite (?) pseudomorphic after phenocrysts of pyroxene, olivene, and sphene (?)
- 40% Ground mass.
  - 80% Andesine.
  - 10% Biotite.
  - 10% Opaque (mostly magnetite).

The phenocrysts of plagioclase (5-8 1/2 mm. in length) are set in an unoriented manner in the ground mass, and are relatively free of alteration. Minor sericite and carbonate occur as alteration along cleavage boundaries. Siderite (?) occurs as a pseudomorph after phenocrysts of pyroxene, as indicated by crystal outline and cleavage; after olivene as indicated by residual centers of olivene; and after sphene as indicated by residual (?) isotropic areas. Magnetite is distributed along remnant cleavage. The size range of the pseudomorph phenocrysts is 1.5 to 3 mm. The mineral identified as siderite (?) is colorless under plain light and is bordered by a brownish colored mineral whose other optical properties are the same. The mineral grains border each other with highly sutured boundaries, and show high interference colors above the 4th order. Many of the grains yield a uniaxial negative interference figure with many rings. In oils the mineral exhibits a wide range, one index being slightly less than 1.60 and the other considerably greater. The grains dissolve with moderate effervescence in dilute HCl. The mineral in thin-section does not show the carbonate rhombohedral cleavage, but does exhibit it under oils. The siderite (?) may have simultaneously precipitated in the voids left as the original iron rich olivene, pyroxene, and sphene were leached by surface water of the present erosion cycle, or it may be deuteric. The ground mass is dominantly composed of 0.1 mm. needle-like euhedral to anhedral andesine crystals, with a second less common size of 0.2 mm. Biotite, in elongate shreds and laths ranging in size from 0.02 to 0.1 mm., is clouded with limonite. Equigranular opaques (mostly magnetite but some limonite) are disseminated throughout in grains ranging in size from 0.02 to 0.25 mm.
Cat Mountain rhyolite

Sample No. 19a.
Location: West side of Hill 10 (Pl. 3).

Megascopic: Medium brown colored, probably equivalent to member No. 2 at Cat Mountain. Inclusions are common but not extremely large. The rock shows the typical Cat Mountain rhyolite texture described in the text.

Petrographic: The rock is classified as a rhyolitic welded tuff.

This sample in thin-section consists of about 30 per cent phenocrysts and inclusions, and 70 per cent matrix material. Quartz is the most common phenocryst mineral, and occurs in a variety of sizes up to 0.5 mm. It commonly shows rounded outlines and many resorption embayments and interior holes, which are commonly filled with sericite. Angular edges and curving convex and concave outlines are common. There are two types of feldspar. The most common is euhedral to anhedral orthoclase altered to clay and sericite in a finely laminated pattern along cleavage. This type attains a maximum size of 1 mm. The other type, which is probably plagioclase, is euhedral to subhedral, somewhat lath-shaped, and is completely altered to sericite.

The matrix consists of a fine-grained to sub-microscopic aggregate of clay, sericite, palagonite, shards, and microlites. Angular to arcuately curving tiny forms consisting of palagonite (?) are scattered throughout the matrix. I interpret these also to be altered shards (Figs. 1, 2, Pl. 15).

Compositionally the rock is rhyolite, and the shards indicate that it is a pyroclastic.
Figure 1.
Width of field: 0.35 mm.
Plain Light

Figure 2.
Width of field: 0.4 mm.
Plain Light

Altered shards in the Cat Mountain rhyolite
Plate 15
Biotite rhyolite

Sample No. 15.
Location: West slope of Hill 8 (Pl. 3).

Megascopic: Light gray Biotite rhyolite with abundant small (1/2-3 inches) inclusions. Clear quartz phenocrysts are prominent.

Petrographic: The rock is classified as a quartz latite.

Composition

30% Quartz phenocrysts.
23% Andesine phenocrysts.
17% Orthoclase phenocrysts.
10% Biotite phenocrysts.
19% Matrix material.
1% Opaque sulfide.

Thin-section shows the rock to consist of an equigranular uniformly distributed mesh of phenocrysts and crystal fragments. Quartz is clear and, except for the sharp edges of fragments, is highly rounded and embayed. Some quartz crystals show hexagonal cross sections and "rhombic" outlines. The quartz crystals are most commonly 2-4 mm. Andesine and orthoclase are less uniform in size, and on the average are slightly smaller than the quartz crystals. The feldspars occur as both euhedral crystals and as fragments. Resorption embayments are notable but not nearly so common as in the quartz crystals. The andesine is commonly zoned, and shows both albite and pericline twinning. Orthoclase occurs both twinned (carlsbad) and untwinned. Biotite occurs in laths ranging from 0.3 - 1 mm. It generally shows strong pleocroism, but some laths are so dark brown as to remain essentially opaque. The biotite laths are commonly bent or broken, especially where crowded between crystals.

Alteration is slight, and consists of minor sericitization of the feldspars. Opaque sulfide (pyrite ?) replaces feldspar in one part of the section.

This section exhibits the texture described in the text, and which is characteristic of the Biotite rhyolite. The minerals are all phenocrysts or fragments of phenocrysts, and are separated always by the matrix material (Figs. 1, 2, Pl. 16).

The matrix consists of opaque material, fine-grained patches of sericite, and devitrified glass.
Figure 1.
Width of field: 7 mm.
Plain light

Figure 2.
Width of field: 7 mm.
Crossed nicols

Texture of the Biotite rhyolite

Plate 16
SECTION A-B, LOOKING NW.

SECTION C-D, LOOKING NW.

SECTION E-F, LOOKING EAST

GEOLOGIC CROSS SECTIONS
FOR PLATE 3

HORIZONTAL & VERTICAL SCALE: 1" = 1000'