STRUCTURE OF GOLDEN GATE MOUNTAIN

PIMA COUNTY, ARIZONA

by

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ABSTRACT

Golden Gate Mountain appears as a spur projecting westward from the Tucson Mountain range. It is made up of the capping Cat Mountain Rhyolite, the slope-forming Amole Formation, and a variety of intrusions of differing compositions.

The emplacement of the andesitic portion of the intrusions occurred during, and probably lasted long after, the deposition of Amole Formation. The hot magma fluidized the wet sediments. Part of the fluidized materials formed pipes and dikes of tuffisites and part was brought up into the basin and contributed to the sedimentation of Amole Formation.

During upper Amole time the intrusion of andesite increased in intensity. Part of the basin rapidly subsided and thick deltaic sediments and graywacke were formed. The development of a hinge line accompanied this subsidence.

The hinge line controlled the occurrence of fluidization which undercut the Amole beds. The beds slumped into the fluidized parts. The process culminated in forming a large orifice through which the Cat Mountain Rhyolite welled up.
The orifice is reflected in the sedimentary beds by the development of a funnel-shaped structure in the central part of which the capping of Cat Mountain Rhyolite is located. The bordering brecciated Amole beds represent the associated slump effects.
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INTRODUCTION

STATEMENT OF PROBLEM

In the Tucson Mountains the Cretaceous Amole Formation underlies the effusive Cat Mountain Rhyolite. The two rock units are associated with a complex of intrusions.

As a result of reconnaissance it has been suggested that the Cat Mountain Rhyolite was extruded as a product of fluidization and partial melting of the Amole Formation by hot magma rising into the wet sediments (Mayo, 1963). During fluidization, it is thought that parts of the Amole beds collapsed, and that the ash flow tuff welled up in the collapsed areas. Such a process should be reflected in the Amole Formation by the development of a funnel-shaped structure with the Cat Mountain Rhyolite in the center.

Golden Gate Mountain appeared to offer an especially favorable opportunity to test this hypothesis.

LOCATION AND ACCESS

The field work was carried out on the slopes around Golden Gate Mountain. The area covers Sec. 15, E 1/2 Sec. 16, NE 1/4.
Sec. 21, N 1/2 Sec. 22, and NW 1/4 Sec. 23, T. 14 S., R. 12 E. on the U. S. Geological Survey, San Xavier Mission Quadrangle map. The area is located about 12 miles west-northwest of the city of Tucson, Arizona.

The Tucson Rifle Range is located on the south-central edge of the area; Tucson Estates Parkway is close to the southern limit; and Old Tucson is near the northwest corner. Golden Gate Mountain is surrounded by Sahuararo Road on the north, Kinney Road on the west, Tucson Estates Parkway on the south, and the abandoned Eldorado Road on the east. A number of dirt roads, mostly unimproved, reach the foothills. An abandoned prospect tunnel is located in the southwestern foothills.

**PHYSIOGRAPHY AND CLIMATE**

Golden Gate Mountain forms a spur projecting from the western escarpment of the Tucson Mountain range; it extends southwestward to the low Sedimentary Hills. It is elongated in northwest direction, and is capped by the escarpment-forming Cat Mountain Rhyolite. Its towering peak is 4288 feet above sea level; the altitude decreases to less than 2600 feet on the adjacent piedmont. The hill-sides are steep; the average slope is over 30°.

The climate is nearly identical to that of Tucson and the desert region of southern Arizona. Temperature varies from below
freezing to very warm. The annual rainfall averages about 10 inches. Temperatures are very high during the summer, but in fall and winter are quite comfortable.

The vegetation consists of a variety of cacti such as saguaro, cholla, prickly pear, barrel, fish hook, hedge hog, staghorn, pin-cushion, together with occotillo, palo verde, buckhorn, yucca, ironwood, and other sonoran plants. Saguaro is the most striking and widespread plant in the area. Palo verde is predominant on the southern piedmont. Generally, the plants are abundant around the arroyos; they are scarce on the capping of Cat Mountain Rhyolite.

PREVIOUS WORK

In 1939, Brown mapped the area as a part of the Tucson Mountains. Influenced by the concept of tilted-block faulting of Basin Ranges, he considered Golden Gate Mountain a faulted block. Kinnison (1958a and 1959b) reviewed the geology of the southern part of the range and mapped Golden Gate Mountain with the same structural concepts.

The two authors thought that the Cat Mountain Rhyolite was developed unconformably upon the Amole Formation. However, their interpretations differ in regard to the regional aspects of the range. Brown postulated that a great thrust fault preceded the erosion period and that nearly all of the overthrust block was removed by
erosion. Kinnison contradicted such thrusting; instead, he postulated that the surface planed by erosion was broken by a fault scarp before the formation of the Cat Mountain Rhyolite.

Dr. Mayo (personal communication) has measured a section from Bren Mountain southwestward through Golden Gate Mountain; the cross-section shows the inclination of the sedimentary beds toward the Cat Mountain Rhyolite. He suggested the effects of fluidization on the structure of Golden Gate Mountain and questioned the inferences of block faulting and overthrusting, as well as the erosion surface.

FIELD WORK

Part of the San Xavier Quadrangle topographic map was enlarged 10 times to the scale of about 500 feet per inch. The drainage and some other land marks were plotted on the enlarged map by pacing and chain-traverse with Brunton compass; this was corrected occasionally and used as the base map.

The field work was carried out mainly during the fall semester 1963 and the following month of February.

ACKNOWLEDGMENT

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Dr. John M. Harshbarger and Dr. Willard D. Pye, the members of the thesis committee, read the manuscript and contributed criticism and advice of much benefit. Special thanks are also extended to Dr. Donald L. Bryant for valuable suggestions.
REVIEW OF GEOLOGIC SETTING OF GOLDEN GATE MOUNTAIN

GENERAL STATEMENT

Golden Gate Mountain is part of the Tucson Mountain Range, which is considered as an Arizona Basin-and-Range type (Brown, 1939). The range is situated west of Tucson, Arizona, and trends north-northwest. A reasonably complete stratigraphic column is exposed in the range.

A number of contributions to the general geological knowledge of the area are available. Among them the reports by Jenkins and Wilson (1920) and Brown (1939) are the most inclusive. The rest deal with some particular and local geologic aspects.

GEOLOGY OF THE TUCSON MOUNTAINS

In the Tucson Mountains rocks of each geologic era are found. Paleozoic formations rest unconformably upon the Precambrian Pinal Schist; another unconformity of early Mesozoic age separates these from the Cretaceous rocks. The Tertiary effusive rocks supposedly overlie the Cretaceous sediments. Finally, parts of the region are covered by Tertiary-Quaternary lake deposits, lava flows, and alluvium.
Several igneous rocks have intruded the Tertiary effusive and older sediments; they form a series of plutonic, porphyritic, and cellular rocks exhibiting a wide variety of textures, structures, and compositions (Jenkins and Wilson, 1939). The "Tucson Mountain Chaos" has been defined as another rock unit of the area (Kinnison, 1958a and 1959b). Its form, occurrence and origin are controversial. However, the fact that the chaotic blocks are intimately associated with the intrusive igneous rocks suggests their genetic relation to magmatic emplacement.

The fundamental structure of the Tucson Mountains is obscured because of the complexity of the Cretaceous and younger rocks which cover nearly the entire area. The great thrust fault and tilted blocks have been considered as typical structures of the range (Brown, 1939); but their very existence is in conflict with current geologic observations.
STRATIGRAPHY

ROCKS OLDER THAN THE CRETACEOUS AMOLE FORMATION

The lowermost part of the Amole Formation and older strata are not exposed in the thesis area. However, they constitute the structural foundation of Golden Gate Mountain. These sediments crop out in the northwest part of the Tucson Mountains and occur also as blocks in the Tucson Mountain Chaos.

PRECAMBRIAN PINAL SCHIST

The oldest formation in the Tucson Mountains is the Precambrian Pinal Schist. It crops out on the Picacho de Calera in the northwest of the region (Jenkins and Wilson, 1920). The schist is very fine grained, of satin-like sheen, and generally weathered. The weathered rock is friable and light gray-green (Brown, 1939).

PALEOZOIC FORMATIONS

The Paleozoic rocks have limited exposures on the northwest and west of the Tucson Mountains but many large and small blocks of Paleozoic formations are found in the "Chaos". They are generally recognized by their fossils. On the Picacho de Calera Hills the
Paleozoic formations form a continuous section from the Pinal Schist to the Pennsylvanian limestone (Brown, 1939).

The Cambrian basal unit is the Bolsa Quartzite which overlies the Precambrian Pinal Schist on a fault plane (Jenkins and Wilson, 1920) or on an unconformity (Brown, 1939). The rest of the system consists of limestone including some sandstone and shale units (Brown, 1939). The limestone is characteristically banded, highly metamorphosed, impregnated throughout with finely divided epidote, and siliceous with a cherty appearance (Jenkins and Wilson, 1920).

Devonian strata crop out only on the Picacho de Calera Hills, east of the Cambrian exposures. This system is divided into two units; the lower is the Picacho de Calera Formation of limestone and calcareous sandstone, and the upper is the Martin Limestone (Brown, 1939).

Mississippian outcrops are also confined to the Picacho de Calera Hills. The rocks consist of gray limestone containing shaly beds. This formation is correlated with the Escabrosa (Brown, 1939).

The Pennsylvanian section is mainly exposed in the Picacho de Calera Hills on the east side of the Mississippian rocks. It also crops out in two small hills one of which is two miles north and the other six miles south of the main outcrop. The rocks are gray
limestone containing some pink beds and chert (Brown, 1939). Among the Paleozoic limestones in the chaos, there are some quartzite blocks that are quite different from the Bolsa Quartzite. They were described as the Pennsylvanian quartzite which occurs at a higher horizon than that at the Picacho de Calera Hills (Brown, 1939).

Permian rocks occur at Snyder Hill southwest of the range. They are dark limestones and were assigned to the Snyder Hill Formation (Brown, 1939).

CRETACEOUS (?) RECREATION RED BEDS

An unconformity developed by erosion on the Paleozoic deposits in the Tucson Mountains, as in most parts of southern Arizona. It represents a hiatus extending from the close of Permian to perhaps the end of Jurassic. Therefore, the next younger rock unit, composed of the clastic sediments and lacking index fossils, is assigned a Cretaceous age. These younger sediments mostly occur south of Amole Peak; they are "a remarkably thick series of conspicuous red shales and sandstones overlain by a section of arkosic sandstones of buff color." (Jenkins and Wilson, 1920)

Brown (1939) named the red series "the Recreation Red Beds because of its color and its occurrence in the Tucson recreational area." The Recreation Red Beds were restudied by Colby (1958)
They are composed of fine-grained, brick-red, massive to thinly bedded sandstone-siltstone which intercalates with and underlies the volcanic conglomerates and tuffs. The formation grades upward into the Amole Formation (Brown, 1939). Its base is covered, and the lower contact with the underlying formation is obscured (Brown, 1939).

The major outcrop of the Recreation Red Beds occur in the Red Hills, the type locality; it is not definite whether the formation is of regional or limited extent. Whitney (1957) assigned to this rock unit the red beds exposed in the northeast of the Tucson Mountains; he also mentions the existence of "similar-appearing, fine-grained, red sandstones" in the Amole Formation. Somewhat similar red beds also are found in the central part of the Amole formation in the Golden Gate Mountain area.

CRETACEOUS AMOLE FORMATION

The sediments which overlie the Recreation Red Beds and underlie the Cat Mountain Rhyolite were mapped and named the Amole Formation by Brown (1939). No complete type section for the unit has been determined; Brown (1939) measured about 2300 feet of its lower part near the Ranger Station, Bennett (1957) described 2500 feet of the formation exposed in the Sedimentary Hills, and Kinnison (1958) estimated its total thickness as being over 5000 feet in the Amole
Mining district. The formation contains a variety of clastic sediments with some limestone beds. The arkose beds in the formation are the most pronounced rock type due to their relative resistance to erosion; nevertheless, the proportion of the arkose to other lithologic types is small.

LITHOLOGIC UNITS OF AMOLE FORMATION

The Amole Formation comprises the entire sedimentary section exposed in the Golden Gate Mountain area below the Cat Mountain Rhyolite. The sediments may be divided into seven units. Plates I and II show the occurrence of these units in the Golden Gate Mountain area; Plate III illustrates them in the columnar sections.

1. LOWER ARKOSE UNIT. The lower portion of the Amole Formation crops out on the north side of Golden Gate Mountain. The oldest bed in the area is found in the north wash. The unit consists of coarse-grained to silty, light-gray and gray-green arkose. Some beds contain abundant rounded pebbles of quartz and rock fragments imbedded in a sandy matrix. The unit contains several massive, pale-green to brownish-gray limestone beds; one of them is fractured in boudinage.

Two andesite dikes occur in this unit. A pebbly and cobbly arkose, green with chlorite, appears to cap one of them about 50 feet below the upper contact of this unit. The arkose contains rounded
fragments, up to six inches in diameter, of limestone and other rocks. Seemingly the dike reached the basin floor on which the arkose was being deposited.

The bottom of this lower unit is not exposed within the area of study. The upper part crops out only on the northeast side of Golden Gate Mountain, where about 300 feet of the lower arkose unit is exposed.

2. SILTSTONE UNIT. This unit is made up of interbedded shale, siltstones, sandstone, and arkoses. The coarser-grained sediments are lighter in color, being gray-green to light-gray; the shale is dark- to light-gray. The unit also contains several bands of varved-like, dark-gray, silty limestone and calcareous siltstone which usually contain corrugations (Fig. 1a). Some arkose beds are pebbly and occasionally contain rounded boulders of probably lower strata (Fig. 2). Ripple marks occur on some siltstones and silty sandstones. An andesite dike and two tuffisite pipes are located in this unit.

The lower contact of this shale unit is situated at the bottom of the dark-gray shale which contains the lowest varved-like beds. The unit is exposed entirely only on the northeast foothill of Golden Gate Mountain. Its thickness is about 600 feet.
Fig. 1  Slumping effects in the siltstone unit of the Amole Formation on the northeast side of Golden Gate Mountain area. Slump direction is from west to east.

a  Corrugation in varved-like limestone.

b  Interstratal fault.
Fig. 2 A boulder of arkose in a sandy to pebbly arkose bed in the siltstone unit of the Amole Formation on the north side of Golden Gate Mountain.
3. SANDSTONE UNIT. The cliff-forming beds which crop out on the northeast slopes of Golden Gate Mountain form this unit (Fig. 3). They consist of yellowish-gray to white, medium grained and pebbly, nearly silt and clay-free sandstones and arkoses. They are poorly cemented, commonly friable, and relatively cliff-forming. The unit is fairly well-bedded and is seldom cross-stratified. The contacts of this unit with the adjacent rocks are sharp because of color and lithologic contrasts. The exposures of this sandstone unit form almost a continuous belt which extends from northwest to northeast and to the slopes between Golden Gate Mountain and Bren Mountain. The sandstone unit is nearly 100 feet thick.

4. LIMEY UNIT. Bennett (1957) described the light-colored banded beds on the south side of the Sedimentary Hills as the limey unit; the unit includes bands of limestone and one of them contains pelecypod fossils.

Southeast of Golden Gate Mountain the pelecypod fossils are found in a thin bed of limestone which is associated with other light-colored carbonate rocks. This sequence seems to correlate with the limey unit of Bennett, however, it is disturbed and neither contact can be distinguished. On the west slope of Bren Mountain a fossiliferous limestone overlies dark-gray shale and banded calcareous
Fig. 3  North view of Golden Gate Mountain showing the capping of Cat Mountain Rhyolite overlying the lower Amole Formation. Note the poor-cliff forming sandstone unit at about the middle of the slope; it overlies the siltstone unit and underlies the limey unit.
beds. The sequence is underlain by coarse-grained clastic beds which possibly correlate with the sandstone unit.

In the Golden Gate Mountain area the sediments identified as the limey unit are composed of well-bedded shale, siltstone, and sandstone. The shale is dark-gray and inter-bedded with argillaceous platy limestone. The siltstone and sandstone are light-gray, yellowish-brown and olive-green. They are dense and often ripple-marked. The limestone is usually cherty.

On the north slope of Golden Gate Mountain approximately the lower 100 feet of these beds crop out above the sandstone unit. They are dark-gray shale and platy argillaceous limestone with large corrugation features (Fig. 4). On the northeast foothill of Golden Gate Mountain these beds seemingly crop out. The limestones are replaced by black chert and the exposure is poor. The limey unit also is apparently present in the northwest corner of the area on both sides of a north-south trending asymmetrical anticline of which the core is the sandstone unit. On the west side of this fold the beds dip steeply; some ripple marks near the lower contact face westward, but the position of the beds farther west is not certain. It is possible that they are repeated by folding.

In the east-central part of the area the pelecypod fossils are found in the platy limestone and siltstone in a shattered zone.
Fig. 4 Corrugation of the platy and shaly limestone beds in the limey unit of the Amole Formation on the northeast side of Golden Gate Mountain. The slump direction is from west to east.
The southeast corner of the area is covered by the limey unit that forms a possible north-south trending anticline. The structure is faulted and invaded by rhyolite in the north. On the east side of this structure about 250 feet of the limey unit lies above the pelecypod zone; on the west over 500 feet of the upper beds crop out containing abundant black chert in the limestones. A brick-red siltstone bed occurs near the top of this exposure. The siltstone is brecciated and resembles some rocks of the Recreation Red Beds.

An andesite porphyry dike intruded the rocks of this exposure near the red bed and south of some Silver Lily dikes and the light-colored phase of the Cat Mountain Rhyolite (P. I, Sec. 23, T. 14 S, R 12 E.).

The thickness of the limey unit cannot be determined with certainty. The fossil zone is estimated to be about 200 feet above the base of the unit, in the Bren Mountain exposure. This zone is estimated to be about 600 feet below the top, in the southeast part of the area. Therefore, the unit may be approximately 800 feet thick.

5. GRAYWACKE UNIT. Overlying the limey unit on the southeast side of Golden Gate Mountain is a series of chlorite-rich, olive-green siltstone and graywacke beds. The graywacke is pebbly; the pebbles are angular to subangular quartz and rock fragments. Commonly, the unit contains rounded limestone boulders up to seven
inches in diameter, and breccia blocks more than one foot in diameter. In general, the proportion of the fines seems to increase southward along the strike. To the north, the beds are intruded by the Silver Lily dikes; farther north the light-colored Cat Mountain Rhyolite is exposed. The upper beds are mostly covered in this exposure. However, the unit seems to extend upward to the base of the lighter-colored arkosic beds which contain fossil wood. The graywacke unit is measured as 1400 feet thick on the southeast side of Golden Gate Mountain.

In the northwest part of the area, olive-green siltstone and arkose are exposed. These are correlated with the graywacke unit on the basis of chlorite content and textural similarity. These rocks lie between the limey unit and the fossil wood unit. The thickness of the unit hardly reaches 100 feet in this exposure; considerable thinning occurs from southeast to northwest in the graywacke unit. The graywacke unit seems to be a facies of the fossil wood unit, which is described below.

6. FOSSIL WOOD UNIT. This unit contains black silicified wood remains. The plant fossils have not been identified; they are usually found in the form of logs about one foot in diameter in beds of coarse-grained sediments.
This unit consists of arkose, sandstone, siltstone, and argillite. The arkose and sandstone are usually free of fine fractions but are conglomeratic. The coarser particles are well-rounded, and up to two inches in diameter, averaging about one half of an inch. The strata exhibit the effects of slumping, erosion, and redeposition, and contain pink, brecciated materials. These features indicate a deltaic environment of deposition for this unit. The siltstone is olive-green, dense, and has faint bedding; several round limestone boulders were found in this siltstone (Fig. 5). The siltstone beds are predominantly in the upper part of the section. Argillite and hornfels occur in the central portion of the unit.

The outcrops of this unit are exposed in the southern and eastern parts of the area, and are identified by the appearance of fossil wood. The lower contact is ambiguous, as the olive-green arkose of the graywacke unit interbeds with the fossil wood unit; on the northwest the tree fossils are found in olive-green arkose similar to the rocks of the lower unit. The upper contact is tentatively put at a conglomerate bed, in which the pebbles reach two inches in diameter in plan parallel to bedding. This conglomerate is found on the hillside near an abandoned tunnel and on the northwest slope.

The fossil wood unit is about 200 feet thick in the southern portion of the area, where it consists of sandstone and arkose with
Fig. 5

Rounded limestone boulders in the nearly massive olive-green siltstone of the fossil wood unit of the Amole Formation on the southeast side of Golden Gate Mountain.

a. Three of these boulders

b. Detail of two boulders shown in "a"
plant fossils. The unit includes a variety of rocks on the west side of the area where it reaches a thickness of 1500 feet. This increase in thickness of the fossil wood unit is the reverse of that of the gray-wacke unit; it confirms that the units belong to two contemporaneous zones of deposition or equivalent facies. This is in accordance with the lithologic similarity of some of the beds.

The fossil wood unit is intruded by a number of the Silver Lily dikes in the southwestern part of the area near the Sedimentary Hills.

7. UPPER SHALE UNIT. This unit comprises the sediments which occur between the underlying fossil wood unit and the overlying Cat Mountain Rhyolite. The outcrops are poor and generally are disturbed. The rocks consist of interbedded green and gray shale and siltstone. One olive-green sandy zone was seen in part of this unit. Interbedded layers of dark-gray shale and grayish-green siltstone are found in the south exposures; the siltstone is corrugated (Fig. 6). A few feet below this bed, ripple marks were seen on a silty layer.

This unit is intruded by the dikes of the Silver Lily Rhyolite in the southern part of the area and of "tuffisite" in the northwestern part. The intruded rocks are silicified and hard. In the southern cliffs below the Cat Mountain Rhyolite the beds of this unit are
Fig. 6 Corrugation of siltstone interbedded with shale in the upper shale unit of the Amole Formation on the south-east side of Golden Gate Mountain.
shattered and form a chaotic mass. This mass and similar rocks are termed in this paper the brecciated Amole.

The thickness of the upper shale unit reaches a maximum of 500 feet in the western exposures. It is doubtful that this unit occurs on the north and the east of Golden Gate Mountain.

THICKNESS OF AMOLE FORMATION

The total thickness of the Amole Formation cropping out in the area amounts to about 4000 feet. The lower part of the limey unit is the youngest sedimentary rock seen on the north and the east of Golden Gate Mountain, where the section includes less than 1800 feet of the Amole beds (Pl. III). The remaining upper part of the formation is exposed on the south and west of the area. Therefore, a considerable thickness of the upper Amole is missing to the east and north.

As will be described later under the Cat Mountain Rhyolite section, a similar change in thickness occurs in the light-colored, basal unit of the Cat Mountain Rhyolite; it increases from zero on the north to over 500 feet in the southeast of the area. These possibly are the results of the local down-sinking of the basin floor during deposition of the upper Amole Formation and the lower Cat Mountain Rhyolite.
CORRELATION

Brown (1939) assigned a Cretaceous age to the Amole Formation and correlated it with other rocks of this age in southern Arizona.

The exposures of this formation in the Sedimentary Hills were divided by Bennett (1957) into a "northern argillitic unit" and a "southern limey unit". Kinnison (1958) suggested the term "Amole" be elevated to group status and divided it into four formations in the Amole Mining District; these are from oldest to youngest: Braun Formation, Dead Cow Formation, Mouse House Formation, and Echo Valley Formation.

The Braun Formation (Kinnison, 1958) is composed of light-tan to yellowish-brown shale, and thin- to medium-bedded, siltstone and arkose beds; some "thin-bedded, silty limestone is present, usually occurring as gray to black varve-like units". The rocks of such description seem to correlate with the lower Amole Formation which is exposed on the north side of Golden Gate Mountain, that is, the lower arkose unit, the siltstone unit, and the sandstone unit.

The limey unit in Golden Gate Mountain seems to correlate with the lower part of the "northern limey unit" in the Sedimentary Hills described by Bennett (1957), and the "Mouse House Formation" in the Amole Mining District described by Kinnison (1958). The rocks at these three localities are well-bedded, containing calcareous beds.
The limestones are usually silicified and one bed contains pelecypod fossils.

The pelecypod bed is more than 1300 feet above the Amole base in the Golden Gate Mountain area. At the Ranger Station the pelecypods are found between 200 to 600 feet above the contact of the Amole Formation and the Recreation Red Beds (Brown, 1939). The fossiliferous bed seems to occur at the same horizon in the above localities; therefore, the difference in the thickness of the Amole Formation is striking. That may suggest facies changes during early Amole deposition, and the possibility that the Recreation Red Beds grade southward (or laterally) into the lower Amole sediments with gray and green hues.

In the geology of the Tucson Mountains the limey unit may be considered of great importance. It is relatively a distinct unit in the Amole Formation and it contains the only widespread fossiliferous bed; moreover, it records a quiet span of time which ended with the beginning of the greatest activity in the development of the Amole Formation. This unit may be used to divide the Formation into a lower and upper part. In the present study this unit was used as a marker zone and many interpretations were based on its identification.

On the basis of the geologic map of the Sedimentary Hills, (Bennett, 1957) the limey unit underlies the "northern argillitic unit".
The latter unit extends northward to the fossil wood unit in the Golden Gate Mountain area. Although no fossil wood has been reported from the Sedimentary Hills, Bennett's description (1957) confirms the continuity of the lower part of the argillitic unit and the upper part of the fossil wood unit. The uppermost part of the former seems to correlate with the upper shale unit in the Golden Gate Mountain area.

Rocks similar to those of the fossil wood unit occur in the Amole Mining District. Kinnison (1958) described them as "the Dead Cow Formation" which consists of "white or gray arkose" and "tan, gray, and olive siltstone" with a sandy limestone bed containing ostracods. The sediments contain wood fragments, "limonite-stained conglomerate", and "angular discordances" (?) (Kinnison, 1958). In spite of differences in interpretation, similar features occur in the fossil wood unit and justify the correlation between the two units. However, Kinnison (1958) regarded this unit as stratigraphically above "the Mouse House Formation" that correlates with the limey unit. No evidence for such an interpretation has been observed, and the reverse order is unquestionable in the Golden Gate Mountain area. Therefore, it is likely that "the Dead Cow Formation" is stratigraphically above "the Mouse House Formation".

Another discrepancy occurs in correlation of "the uppermost" Amole Formation. The upper shale unit includes these sediments in Golden Gate Mountain. It correlates with the upper part of
"the northern argillitic unit" in the Sedimentary Hills, described by Bennett (1957) as light- and dark-colored siltstone and shale with some sandstone beds. In the Amole Mining District "the uppermost members of the Amole Group" were referred to as "the Echo Valley Formation" by Kinnison (1958). According to his description, "in general appearance it is identical to the Braun member and is distinguishable only by its stratigraphic position." Accordingly it seems that "the Echo Valley Formation" does not correlate with the upper shale unit.

At this point attention must be called to three suggestive facts: (1) the lower part of the limey unit resembles some beds of the siltstone unit; (2) the limey unit is the youngest unit on the north side of Golden Gate Mountain and it underlies the Cat Mountain Rhyolite, but it is not the uppermost unit of the Amole Formation; and (3) faults have always been inferred at the contacts of "the Echo Valley Formation" and the other Amole members, as can be seen on the geologic map of the Amole Mining District (Kinnison, 1958). Therefore, it is very possible that "the Echo Valley Formation" is part of "the Mouse House Formation" and correlates with the limey unit, or is identical with the same "Braun Formation".

Figure 7 illustrates the correlation based on the above discussion.
CORRELATION CHART OF THE UNITS OF
THE CRETACEOUS AMOLE FORMATION

<table>
<thead>
<tr>
<th>Fig. 7</th>
<th>Golden Gate Mountain (This thesis)</th>
<th>Sedimentary Hills (Bennett)</th>
<th>Amole Mining District (Kinnison)</th>
<th>Ranger Station (Brown)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>Cat Mountain Rhyolite</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Upper shale unit</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Fossil Wood unit</td>
<td>Northern argillitic unit</td>
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</tr>
<tr>
<td>3000</td>
<td>Graywacke unit</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Limey unit</td>
<td>Southern limey unit</td>
<td>(2): Dead Cow Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pelecypods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Sandstone unit</td>
<td></td>
<td>(3): Mouse House Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Siltstone unit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>Lower Arkose unit</td>
<td></td>
<td>(1): Braun Formation</td>
<td>Recreation Red Beds</td>
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<tr>
<td>0</td>
<td></td>
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<td></td>
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</tbody>
</table>

* the numbers in parentheses represent the original proposed stratigraphic order (Kinnison, 1958).
CONDITION OF DEPOSITION IN THE AMOLE FORMATION

The lithologic variation in the Amole Formation suggests a varied and changeable sedimentary environment.

An early stable period persisted for a time in the basin, during the time the lower arkose, siltstone, sandstone and limey units were being deposited, on a slowly subsiding floor. Among these sediments are the arkosic beds which include large numbers of rounded pebbles and cobbles of a variety of rocks, such as arkosic (Fig. 2), limestone, and andesite boulders. It was suggested during a field trip that these materials were introduced to the basin by fluidization, activated by emplacements of the andesite. This period came to a close with the end of the limey unit which may represent the most quiescent part of the Amole time. The lower Amole Formation is well bedded and exhibits a relatively high degree of maturity. Their deposition was terminated by the "pouring in" of the thick sediments of the graywacke and fossil wood units in the subsiding parts of the basin.

Subsequently a "hinge line" was developed; along this line the southwest portion of the basin sank relative to the northeast. In the subsiding portion the limey unit became the base of the upper Amole Formation; in the other portion this unit was intruded by andesite and tuffisite, including the Tucson Mountain Chaos, and was finally overlain by the basal Cat Mountain Rhyolite.
The graywacke unit was deposited upon the limey unit in the subsiding part near the hinge line. It was formed in an environment of rapid deposition on the basis of its high chlorite content, gritty texture, and fragments of andesite, limestone and clastic sediments. Of special interest is the presence of rounded cobbles and boulders in this unit.

About NE 1/4 SW 1/4 NE 1/4 Sec. 23 (Pl. 1) is an example of the rounded cobbles of andesite, limestone, and the clastic rocks with the finer materials rich in chlorite in the graywacke unit. The surfaces of the limestone fragments are pitted, corroded, and masked with andesitic materials. It is not certain if these rocks are part of a pipe or a buried mound, but their resemblance to some components of the Tucson Mountain Chaos suggests that they "were somehow pushed or carried up from below" to the basin floor.

Also about SW 1/4 NW 1/4 NE 1/4 Sec. 23 (Pl. 1) is an example of the occurrence of rounded boulders in a bed in the graywacke unit. Some of the boulders are peculiar in form. For instance, one is a well rounded, drop-form boulder about one foot in intermediate diameter. It consists of an angular cobble-size piece of laminated siltstone in fine pebbly graywacke. The cobble size piece is distorted by minute folds and faults within the surrounding materials. The boulder is hard and well cemented and rests in a graywacke bed. It seems evident that these sediments were repeatedly
disturbed. Slumping may have played a part, and the peculiar forms of some of the boulders may be due to abrasion in a fluidized system.

Perhaps, as a result of the emplacement of hot magma, gases were generated from the wet sediments. These gases may have fluidized the sediments and entrained parts of them (Mayo, 1963). Consequently, the basin could have become occupied by small mounds and by craters that promoted slumping. The undermining that could result from entrainment of fluidized sediments may have been the cause of the steep dips of the limey unit near the graywacke unit (the hinge line).

The fossil wood unit, which is apparently contemporaneous with the gray wacke unit, seems to have formed in a deltaic environment on the west and southwest sides of Golden Gate Mountain. Their thick deposits were accumulated on the subsiding basin floor. The sediments were derived from land as indicated by the fossil wood and, in part from pre-deposited strata.

In some olive-green siltstones of this unit occur large cobbles of Paleozoic limestone (Fig. 5). They are very well rounded and resemble those in the graywacke unit. These cobbles may have been entrained in fluidized pipes and contributed to the fossil wood sediments. The occurrence of these limestone cobbles suggests the concurrent development of the graywacke and fossil wood unit.
CURRENT DIRECTION. Ripple marks are seen on some silty sandstone beds of the Amole Formation in the Golden Gate Mountain area. It is assumed that these ripple marks are related to current action. On this assumption, their directions were measured and corrected for dip; then, the corresponding normals were plotted. As shown on figure 8, the point distribution suggests a north-northwest -- south-southwest direction of the predominant current in the Amole basin. During a field trip around the Piedmontite Hills the current structures which were observed indicated the same direction with a sense from north-northwest to south-southeast.

In the northwest corner of the Golden Gate Mountain area is the only ripple mark which deviates from this general attitude. The deviation is about 30 degrees (Fig. 8). It seems to be due to the rotational movement of beds around the hinge line and along the adjacent fault plane.

SLUMP FOLDS. On the northeast side of the hinge line the corrugations observed in certain beds of the lower Amole Formation seem to have been caused by eastward sliding of the sediments (Figs. 1, 4, and 6). These are evidently interstratal deformations, as their intensity gradually decreases vertically and the anticlines are not truncated. The measurements on these corrugations indicate
eastward sliding of the overlying beds (Fig. 8) which is opposite to the direction of the slump effects to be attributed to the hinge line and the funnel; it is also opposite to the actual dip of the strata.

These corrugations suggest that the sediments on the northeast of the hinge line have at some time been tilted eastward. Perhaps tilting occurred as a result of bulging of the basin floor prior to the appearance of the hinge line. The resulting bulge seems to have been destroyed as the hinge line developed. On the northwest and southeast of the area the tight anticlines may be the remnants of this bulge. These anticlines were possibly intensified and fractured as a result of the development of the hinge line and the funnel. However, they are elongated in a north-south direction in accordance with the movement suggested by the slump folds.

Therefore, it is logical to visualize, near the site of the hinge line, a series of north-south elongated anticlines which formed a bulging belt in the Amole basin at the end, or shortly after, formation of the limey unit. This belt may be responsible for the relatively small thickness of the limey unit on the northeast side of Golden Gate Mountain, as the central parts slid off or were eroded. Moreover, on the east side of Golden Gate Mountain the sandstone unit is repeated. The field relationship suggests overthrust from the west,
OCCURRENCE OF RIPPLE MARKS AND CORRUGATIONS IN THE AMOLE FORMATION IN THE GOLDEN GATE MOUNTAIN AREA, PIMA COUNTY, ARIZONA T. 14 S., 12 E.
opposite to the present dip (Pl. 1). The "overthrust" block does not reach 1000 feet length. It seems to be a submarine slide (block) which occurred as a result of the eastward tilting of this bulging belt.

**CAT MOUNTAIN RHYOLITE**

The Cat Mountain Rhyolite covers a large portion of the Tucson Mountains area and forms the conspicuous western escarpments of the range. The formation was named by Brown (1939); he described it as a layered volcanic rock. Bikerman (1962) considers it had three phases of development: nuee ardente, ash flow, and fissure filling intrusions. Mayo (1963) described this rock as ignimbrite consisting of ash flows on top and laccolithic masses below.

The rock consists of a rhyolitic ground mass containing many rock fragments; these xenoliths usually range in size from a fraction of an inch to several inches. In this rhyolite, tabular blocks of the sedimentary beds are found which may be as large as tens of feet in diameter. Abundant planar cavities define the well-developed eutaxitic, or flow structure, in the Cat Mountain Rhyolite. Around the large xenoliths and the tabular blocks the flow structure parallels the contacts (Fig. 9).
Fig. 9  A tabular block of arkose in the lower light-colored Cat Mountain Rhyolite in the southeast corner of Golden Gate Mountain. Note the flow structure around the block.
The formation constitutes the upper part of Golden Gate Mountain and overlies the Amole Formation. On the basis of the color differences and limited field studies it is mapped as two units (Pl. 1).

1. LOWER LIGHT COLORED UNIT. This unit is made up of pinkish-gray and light-pink Cat Mountain Rhyolite. The rock is friable; the cavities of the flow structure are small and abundant, and the xenoliths are usually about one fourth inch in diameter. The rock is massive and lacks stratification. In this unit are found the large block-size inclusions of hard, silicified Amole arkose. (Fig. 9).

The light-colored Cat Mountain Rhyolite is nearly absent in the northwestern part of Golden Gate Mountain. Its maximum development seems to be on the southeast side of Golden Gate Mountain where its thickness exceeds 500 feet. This rock overlies the limey unit and the micaceous andesite with the associated tuffisite on the north, east, and southeast sides of Golden Gate Mountain. It is cut by an andesite porphyry dike in the southeast.

The lower light-colored Cat Mountain Rhyolite extends eastward into the main western escarpment of the Tucson Mountains. It seems to be the "non-welded tuff" described by Bikerman (1962).
2. **UPPER DARK-COLORED UNIT.** This unit makes up the upper part of the Cat Mountain Rhyolite on the top of Golden Gate Mountain. Its dark-red color distinguishes it from the lower unit. From a distance the contact appears as a sharp line as a result of the contrast in colors of the two units. An arkose bed is locally present at the contact between the two units. The bed is highly silicified and broken. The pieces are nearly flat-lying, slightly arched upward, and usually forms roofs of small caves.

The rock of this unit is massive, hard, and resistant to weathering. Its xenoliths are larger than the average of those in the lower unit but are less abundant. The dark-colored Cat Mountain Rhyolite seems to be the "welded tuff" of Bikerman (1962).

**RELATION OF CAT MOUNTAIN RHYOLITE TO AMOLE FORMATION.** In the Golden Gate Mountain area, the Cat Mountain Rhyolite covers part of the hinge line (Pl. 1). Therefore, it overlies, on one side, the limey unit and, on the other side, the upper shale unit that is about 2000 feet stratigraphically higher. Approaching the contact, all of the underlying Amole beds which are located adjacent to Cat Mountain tend to dip toward the Cat Mountain Rhyolite and form a funnel-shaped structure. The funnel is elongated north-westward parallel to the hinge line which seems to have been the controlling structure.
At the southeastern end, the basal Cat Mountain Rhyolite joins to the east the main line of the western escarpments covering the limey unit of the Amole Formation. The peculiar contact of the graywacke unit and the Cat Mountain Rhyolite also modifies the pattern of funnel structure. The lower beds of the graywacke unit seem to extend northward into the basal Cat Mountain Rhyolite. Moreover, the flow structure of the latter and the bedding of the former dip together westward. Farther west, the upper beds of the Amole Formation gradually swing to the east and tend to dip toward the Cat Mountain Rhyolite. These beds are separated from the rhyolite by a disturbed zone of the Amole Formation which becomes gradually mixed with the andesitic rocks and Cat Mountain Rhyolite. This zone is shown on Plates I and II as the brecciated Amole.

On the southeastern side of Golden Gate Mountain is the best exposed and probably the best developed part of the brecciated Amole. On the other sides the contact between the Amole Formation and the Cat Mountain Rhyolite is covered by talus. However, the few exposures suggest that the disturbed zone becomes thin and the brecciated Amole becomes insignificant as the lower light-colored Cat Mountain Rhyolite decreases in thickness.

The funnel expresses the inward slumping of the surrounding sediments. Therefore, it may be due to the undermining effects of
fluidization, such as described earlier for the contact of the gray-wacke and limey units. Perhaps the funnel and the hinge line express a single process in different stages. The fluidization seemingly began along the hinge line, brought up materials from below and distributed them on the surface and in the graywacke basin. Thus the funnel gradually developed. During this stage, hot, tuffisized materials were inserted into the sediments, and formed the laccolithic masses of the basal Cat Mountain Rhyolite (Mayo, 1963). On this basis the development of the hinge line preceded and controlled that of the funnel, which served as the orifice for emission of the Cat Mountain Rhyolite.
INTRUSIVE ROCKS

GENERAL STATEMENT

The intrusive rocks which occur in the Golden Gate Mountain area form a series of rocks varied in occurrence and composition. They may be divided in three major groups: andesitic rocks, Silver Lily dikes, and tuffisite.

ANDESITIC ROCKS

These rocks range in composition from andesite to basalt. They occur in three forms: Microcrystalline andesite, micaceous andesite, and andesite porphyry.

1. MICROCRYSTALLINE ANDESITE. This rock is usually basaltic in appearance and has a microcrystalline texture. It forms several dikes on the northern side of Golden Gate Mountain in the lower Amole Formation.

Two of these dikes, at SE 1/4 NE 1/4 NW 1/4 Sec. 17 and NW 1/4 SE 1/4 NW 1/4 Sec. 17 (Pl. I) are separated from the sedimentary rocks by tuffisite borders; their wall rocks are occasionally brecciated. Another dike of this andesite, at NW 1/4 SW 1/4 NE 1/4 Sec. 17 (Pl. I) is in contact with an arkose bed which is green
because of its chlorite content. Fragments which have been derived from the dike are seen in the arkose. On this basis the dike seems to be a fossil volcanic vent which was active in early Amole time.

2. MICACEOUS ANDESITE. This andesite is fine to medium-grained; the grain size average about 0.5 millimeters in diameter. The rock contains abundant mica fragments and is chocolate-brown in color. Under the microscope it exhibits flow structure by a preferred orientation of grains. The rock has apparently undergone hydrothermal alteration and the mafic minerals are destroyed.

The micaceous andesite occurs in the form of an extensive intrusion on the east side of Golden Gate Mountain. It is associated with the Cat Mountain Rhyolite and the tuffisites; in places it cuts the limey unit of the Amole Formation. The sediments are shattered and engulfed into this intrusion; some large parts form a sharp syncline. There are several large blocks of the Paleozoic limestones in this intrusion. The andesite appears arenaceous near these inclusions; this sandy-appearing andesite grades westward into the typical variety.

Some rhyolitic dikes separate this igneous body from the adjacent tuffisite and Cat Mountain Rhyolite. Near the contact the andesite contains chlorite. This mineral is also abundant in rocks on the other side of the dikes.
This andesite body was mapped as the Cretaceous volcanic rocks by Brown (1939) and as part of the Tucson Mountain Chaos by Kinnison (1959). However, the petrographic study indicates the rock to be a microcrystalline (pilotaxitic) andesite and its field relationships indicate it to be an intrusive volcanic. Such rocks have been mapped by Kinnison (1959) in the Tucson Mountains.

3. ANDESITE PORPHYRY. Two dikes of andesite porphyry are found on the southeast side of Golden Gate Mountain. One is located in the lower light-colored Cat Mountain Rhyolite and the other in the upper part of the limey unit of the Amole Formation. The groundmass of the andesite is dark-gray microcrystalline; the phenocrysts are elongated plagioclase feldspars. They are over a quarter of an inch in the long dimension and commonly oriented by flow.

The two dikes seem to have a common origin on the basis of their lithologic similarity. They are possibly contemporaneous with or later than the Cat Mountain Rhyolite.

SILVER LILY DIKES

Brown (1939) described the Silver Lily Dikes as a series of east-west trending dikes south of Amole peak. They consist of yellowish brown spherulitic latite porphyry. The crystals of feldspars and quartz are up to five millimeters long and the grains are oriented by
flow parallel to the borders. By weathering the rock cleaves into chunks and by abraiding it appears porcellanous.

On the south side of Golden Gate Mountain similar dikes are present. They are confined to a band trending east to west. They all have east-west strikes with the exception of some dikes in the southeastern part of the area which strike randomly and have an irregular distribution.

The Silver Lily dikes dip steeply, usually almost vertically. They rarely reach 200 feet long and 10 feet wide. They are a finer-grained rock than the materials in the Amole Peak area. The dikes are wider and coarser-grained to the east. To the west, they appear to fill gashes and contain fine-grained materials.

Except for the gashes in the southwestern corner of the area, the Silver Lily dikes are always near and approximately parallel to the contact between the lower Cat Mountain Rhyolite and the Amole Formation. Generally the Amole beds between these dikes and the Cat Mountain Rhyolite are highly disturbed and chaotic. These features and the rock assemblage are related to each other in origin and the development. Brown (1939) stated that "the dikes appear to be the latest rocks in their vicinity.... They cut the Cat Mountain Rhyolite and the spherulitic rhyolite, which is regarded as a late intrusive into the rhyolite."
TUFFISITE

In the Golden Gate Mountain area, as well as throughout the Tucson Mountains, there are rocks which cannot be classified as sedimentary or igneous. They have a fine-grained to glassy groundmass, contain pyroclastic debris, and intrude the other rocks. Similar materials were termed "tuffisite" by Cloos in 1941 (Mayo, 1963). Reynolds (1954) proposed the application of this term as being useful "not only in distinguishing between intrusive tuff (tuffisite) and the more familiar extrusive variety but also for distinguishing cross-cutting pyroclasts from cataclastic rocks." Tuffisite may be genetically defined as "the product of fluidization" (Mayo, 1963).

In the Golden Gate Mountain area the rocks which fit the definition of tuffisite fall into three distinct grain-size classes. These are: (1) fine-grained, (2) coarse-grained, and (3) bouldery or "the Tucson Mountain Chaos" type.

1. FINE-GRAINED TUFFISITE. The best example of this tuffisite occurs in a pipe located at NE 1/4 SE 1/4 NW 1/4 Sec. 17 (Pl. 1). It consists of yellowish-gray rock. It is extremely fine-grained, thinly banded by flow, and cleaves into slabs. In thin section it appears porphyroclastic. The groundmass is cryptocrystalline, swirly, fluidal. The phenoclasts make up about ten percent of the rock and are oriented by flow. They are composed of quartz fragments, some magnetic crystals, and traces of sphene; they are
up to 0.5 millimeter in long dimension. The magnetite is altered to limonite which appears in the form of brown specks arranged parallel to the flow structure on the weathered surface. Calcite is present, probably as a secondary mineral.

On the basis of hand specimens and thin sections, the rock should be classified as "welded tuff." However, the field relationships reveal it to be intrusive. Therefore, the rock is an "intrusive tuff," that is, a "tuffisite."

About 500 feet north-northwest of this pipe a similar tuffisite occurs in a small five-inch wide dike.

Also, as was mentioned, the two microcrystalline andesite dikes are associated with tuffisites. These tuffisites are similarly fine-grained. They are dark-gray like the associated andesites. The color is the only observable difference between them and the tuffisite occurring in the pipe.

In these two dikes the tuffisite contains andesite inclusions; however, the contact of the inclusions are sharp and parallel to the flow structure of the tuffisite. The association of fine-grained tuffisite and the microcrystalline andesite provides evidence of their genetic relationship. The fluidization process which generated the former rock had been preceded by the intrusion of the latter. Therefore, the two rocks are essentially contemporaneous.
2. COARSE-GRAINED TUFFISITE. The phenoclasts of this tuffisite average three millimeters and rarely exceed one centimeter in long dimension. The rock resembles the light-colored phase of the Cat Mountain Rhyolite. It is pale greenish yellow to pinkish gray. It is generally massive and breaks irregularly. The groundmass is cryptocrystalline and rhyolitic. The coarse-grained tuffisite is found in a pipe and in a dike cutting through the Amole Formation. It also occurs at the base of the Cat Mountain Rhyolite in association with some Silver Lily dikes.

The pipe is located on the north side of Golden Gate Mountain, at NW 1/4 SW 1/4 NE 1/4 Sec. 17 (Pl. I). The tuffisite is pale greenish yellow and is spotted with phenoclasts. The rhyolitic groundmass is less than 40 percent of the volume; it shows microflow structure around the grains. The phenoclasts are about three millimeters in diameter. They consist of rock fragments, and of quartz, magnetite, hematite, and chlorite. The magnetite is usually altered to limonite. The pipe is situated in the siltstone unit of the Amole Formation. Its position is reflected in the structure of the adjacent beds by a slight doming.

The dike is located on the northwest of Golden Gate Mountain, at NE 1/4 NW 1/4 SW 1/4 Sec. 17 (Pl. I); it trends approximately east-west. The rock contains abundant biotite phenoclasts which appear as black spots on the yellowish-gray surface. The
phenoclasts are usually well-rounded quartz, feldspars, biotite and rock fragments. They rarely exceed five millimeters in size. The dike intrudes the upper shale unit of the Amole Formation and seems to project into the capping of Cat Mountain Rhyolite. This tuffisite resembles the "biotite rhyolite" which was described by Brown (1939) in the southern part of the Tucson Mountains.

On the southeast of Golden Gate Mountain the coarse-grained tuffisite occurs near the micaceous andesite and is associated with some Silver Lily dikes at the base of the Cat Mountain Rhyolite. This tuffisite contains abundant chlorite phenoclasts, possibly as a secondary mineral. Sometimes the chlorite is disseminated and the rock is evenly bluish-green. The groundmass of this tuffisite is felsitic with feldspar shards up to one millimeter long oriented by flow around the larger grains. The phenoclasts are rock fragments, quartz, and feldspar grains up to one half inch in length.

On the southwest side of Golden Gate Mountain another coarse-grained tuffisite occurs adjacent to a Silver Lily dike and the andesite porphyry dike (Pl. I). It is pinkish gray and poor in chlorite relative to the rock mentioned above. They are similar in the other lithologic aspects.

The resemblance of the coarse-grained tuffisite to, and its frequent occurrence at the base of, the lower light-colored Cat
Mountain Rhyolite suggest it to be a stage in the development of the Cat Mountain Rhyolite.

3. BOULDERY TUFTISITE OR "TUCSON MOUNTAIN CHAOS". In the wash southeast of the area are several boulders associated with the micaceous andesite. The boulders are rounded pieces of Paleozoic limestones and reach six feet in size. They are imbedded as huge clasts in a sandy-appearing andesite. These blocks are located near and in a nearly vertical fracture zone striking about north 45 degrees east. The whole intrusion is in partial contact with the limey unit of the Amole Formation. These boulders were mapped and described by Brown (1939) as a part of "a conspicuous belt of boulder-like masses of Carboniferous limestone... and less conspicuous Cretaceous volcanic rock." Presuming a "pre-Tertiary-lava erosion surface" he ascribed this belt to a hypothetical "great thrust fault" on which the older rocks have overridden the Amole Formation and to which the erosion surface was parallel. Furthermore, considering that "the belt of overthrust masses is a jumble" Brown (1939) suggested three possibilities: (1) extension of a fault onto the surface, (2) imbricate type of thrusting, or (3) removal of practically an entire overthrust by erosion "leaving numerous small klippen on the thrust."
Such interpretation lacks confirming evidence and the current geologic observations disprove the hypothetical overthrusting in the Tucson Mountains. The unique exposure of the fault is described by Brown (1939) as "a shear zone, underlain by altered Cretaceous volcanic rocks and overlain by the massive Carboniferous limestone" at the mouth of a tunnel northeast of Amole Peak. The limestone seems to be a large block; nevertheless, such a localized shear zone is inadequate as evidence of a great thrust fault. In discussing the fault Brown (1939) stated that "associated with the thrust zone in the thin-bedded Cretaceous sediments are minute thrusts,..... All these specimens were loose on the surface or in slope wash." Similar features have been found in place, as are shown in Figures 1, 4, and 6. They are interstratal deformations.

Whitney (1957) mapped a large number of the limestone blocks in the northern part of the Tucson Mountains. He inferred numerous faults closely spaced and randomly striking in order to explain the structural relationship between these blocks on the basis of the thrust faulting hypothesis.

Kinnison (1958) considered the zone containing these blocks as a rock unit and named it "the Tucson Mountain Chaos." He suggested "that the Tucson Mountain Chaos is a sedimentary formation. According to his description it includes the bouldery tuffisite and the
brecciated Amole (Kinnison, 1959). His interpretation is that the Tucson Mountain Chaos was formed as talus and mud flow on "a surface of moderate or gentle relief" in the front of a "postulated fault scarp" (Kinnison, 1959). He attributed that surface, above which rose the fault scarp, to the post-Laramide erosion and called it "the Tucson Surface" (Kinnison, 1959).

Kinnison's interpretation does not take into account the presence of igneous rocks within the Tucson Mountain Chaos. However, the intimate association between igneous rocks and blocks in chaos, such as seen on the east side of Golden Gate Mountain, is a fact which seriously challenges the sedimentary origin of the Tucson Mountain Chaos. Moreover, the very existence of "the Tucson surface is in doubt. Grenstein (1961) observed the connection between the limestone blocks and some intrusions east of the Red Hills.

Mayo (1963) notes that "the limestone blocks were somehow pushed or carried from below to their present position." Fluidization is considered by him as a probable factor in the development of the Tucson Mountain Chaos. Although all factors involved in the origin of this unit may not be properly evaluated, it is here considered to be an extremely coarse tuffisite of regional dimensions.
STRUCTURE

MAJOR STRUCTURAL ELEMENTS

The structure of Golden Gate Mountain can be resolved into four major elements: the general attitude of the Amole Formation, the hinge line, the funnel, and the Cat Mountain Rhyolite capping.

The structural setting of Golden Gate Mountain is not precisely known. Away from the capping of Cat Mountain Rhyolite, as seen on plates I and II, the sedimentary beds assume a general attitude dipping westward to southward. Farther southwest in the Sedimentary Hills the dips are generally southwestward (Bennett, 1957 and Mayo, 1963). This general attitude suggests that the area is located in the northeastern part of a large syncline elongated nearly north-south. The dips are generally steeper in the lower Amole Formation; this reflects the rapid subsidence of the basin floor during the upper Amole deposition, and it is in agreement with the occurrence of the hinge line.

The hinge line is expressed by the sharp contrast between the structure of the upper and lower parts of the Amole Formation. It extends from the southeastern to northwestern corners of the area in
the form of a curve which is concave to southwest. On the northeast side of this line lie the beds of the upper Amole Formation which dip generally westward at moderate to steep angles. Near the hinge line they form several northsouth trending tight folds which are sometimes fractured and faulted (Pls. I and III). These structures are in part due to the bulging belt which preceded the hinge line. However, they may have been intensified as a result of the slumping along the hinge line. On the eastern slope of Golden Gate Mountain the lower Amole Formation is crumpled near the hinge line or on the side of the funnel. This "crumpling" is probably caused by down slumping of the beds around a curved edge.

The effect of the funnel is more pronounced in the upper Amole Formation southwest of the hinge line. The general dip is gently south to southwest. This general attitude is disturbed as the beds approach the funnel and the dips and strikes swing so that the beds dip toward the Cat Mountain Rhyolite. Several small anticlines and synclines appear in a zone nearly parallel to the contact with the Cat Mountain Rhyolite.

LINEAMENTS

Linear features such as dike and fracture zones traverse the Golden Gate Mountain area. The Silver Lily dikes occur mostly
in an east-west belt. Two andesite dikes also strike in this direction. The other lineaments strike predominantly northwest to north-northeast.

The hinge line and its associated fracture zones constitute a characteristic set of lineaments. Their general trend is approximately northwest.

SEQUENCE OF EVENTS

The geological events which were discussed in the preceding pages seem to have occurred in the Golden Gate Mountain area in the following chronological order:

The lower Amole Formation was deposited in a slowly subsiding basin. The concurrent magmatic activities introduced into these beds the fluidized materials from the underlying beds and formed the fine-grained tuffisite intrusions. At this time, the microcrystalline andesite dikes cut through the wet sediments. The deposition of the lower Amole Formation was terminated by more active igneous intrusion.

The intrusion of the magma raised the overlying layers, caused bulging of the basin floor, and promoted sliding of the sediments. Bulging continued until the expanding forces overcame the elastic strength of the Paleozoic basement. After breaking through the Paleozoic basement the rising hot magma encountered the wet
sediments, fluidized them, and bought them up with pieces of the
shattered Paleozoic rocks (Mayo, 1963). Some of these materials
reached the basin floor and contributed to the sediments being depos-
ited in the basin, forming the graywacke unit. Part of the magma
consolidated as intrusive rock within the sediments, such as the
micaceous andesite, and as coarse to bouldery tuffisite in the Tucson
Mountain Chaos.

The undermining effects of this process caused the overlying
Amole beds to collapse. Collapse began near the end of Limey unit
and increased through later Amole time. Consequently the bulge sub-
sided and was replaced by the depression along the hinge line. The
hinge line became the edge of the upper basin which was rapidly
subsiding under the accumulation of the thick deposits of the gray-
wacke and fossil wood units.

The fluidization continued along a portion of the hinge line
and developed it into a funnel. From this issued the Cat Mountain
Rhyolite. Finally, andesite porphyry intruded both the Amole Forma-
tion and the Cat Mountain Rhyolite. At about this time the Silver Lily
dikes filled nearly east-west fissures.
CONCLUSION

On the basis of field studies the structure of Golden Gate Mountain is discussed in an attempt to give a rational picture of the development of the Cat Mountain Rhyolite. On the basis of present information the following conclusions have been reached:

1. No thrust or other fault of any considerable displacement occurs in the Golden Gate Mountain area.

2. The Golden Gate Mountain is not a faulted block separated from the mass of the Tucson Mountains.

3. The Tucson Mountain Chaos (bouldery tuffisite) was developed after the lower Amole Formation and its origin is igneous rather than sedimentary or tectonic.

4. The Cat Mountain Rhyolite is in part contemporaneous with and derived from the Amole Formation.

5. The Cat Mountain Rhyolite and the Amole Formation are not separated by an erosion surface.

6. Andesite intrusions occurred and were instrumental in the evolution of Golden Gate Mountain.
7. Fluidization appears to have resulted from the andeside intrusions and it produced the tuffisite and part of the Cat Mountain Rhyolite.

Certain additional studies which would help unravel the history of the area might be:

1. Paleontological and palynological studies of the Amole Formation.

2. Petrochemical studies to delineate each ash flow in the Cat Mountain Rhyolite.

3. Continued structural studies of the Cat Mountain Rhyolite.
REFERENCES CITED


PANEL DIAGRAM OF THE GOLDEN GATE MOUNTAIN AREA
PIMA COUNTY, ARIZONA
T. 14 S., R. 12 E.

FOR EXPLANATION SEE PLATE I

SCALE

500 1000 2000 in feet
vertical and horizontal

Prepared by: Mohrak Anzo
University of Arizona, May 1964
PLATE III

COLUMNAR SECTIONS

OF THE AMOLE FORMATION IN THE GOLDEN GATE MOUNTAIN AREA,
PIMA COUNTY, ARIZONA

WEST SIDE

Cat Mountain Rhyolite

Interbedded gray and green shales, green sandy siltstone, and yellowish-gray sandstone,
poorly grouped out and disturbed. The beds are interbedded by a plug of breccia, i.e.,
"blocky rhyolite".

SOUTHEAST SIDE

Interbedded gray, green, gray to chalk, white shale, sandstone, and yellowish-gray sandstone.
The beds are domed and disturbed near some Silver Lily dikes. The bed at the
north end of the Cat Mountain Rhyolite is covered.

NORTH SIDE

Cat Mountain Rhyolite

Interbedded shale, siltstone, and sandstone with varved clay to very fine dark green
calcareous siltstone and limestone usually conglomerate. Sandstone, yellowish-gray, medium-grained
to coarse, bedded, and relatively stiff, forming clasts.

SOUTHEAST CORNER

Interbedded gray, gray to chalk, white shale, sandstone, and yellowish-gray sandstone,
poorly grouped out and disturbed. The beds are domed and disturbed near some Silver Lily dikes.

EXPLANATION

1. Conglomerate
2. Rhyolite
3. Sandstone
4. Siltstone
5. Limestone
6. Bedded shale
7. Bedded sandstone

Scale: 1:50 feet

Prepared by: Mohamad Assadi
University of Arizona
May 1964