

GEOLOGY OF TUMAMOC HILL, SENTINEL PEAK AND  
VICINITY, PIMA COUNTY, ARIZONA

by

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## ABSTRACT

Stratigraphy and structure of rocks exposed on Tumamoc Hill and Sentinel Peak in Tucson, Arizona, were examined to clarify the geologic history of the Tucson Mountains and Tucson Basin. Fourteen rock units are recognized in the Tumamoc Hill-Sentinel Peak sequence which comprises over 390m of interbedded volcanic and sedimentary rocks of Late Cretaceous through Early Miocene age. These units compose the most complete section of Tertiary rocks in the Tucson Mountains, and their recognition refines and elucidates the geologic history for that epoch in this area.

Two volcanic episodes (one in the Paleocene, and one in the Late Oligocene to Early Miocene) are separated by a hiatus of erosional and probable non-depositional nature which extends from Late Paleocene to Late Oligocene. Tilting occurred in Paleocene time inclining the sequence 30-45 degrees northeastward. High-angle faulting also took place during the Paleocene along N-S or N5W strikes, and after Early Miocene along E-W or N80W, and N15E strikes.

The northeastward dipping, homoclinal attitude of the Tucson Mountains was probably derived during Laramide (Paleocene) deformation. Intensities of igneous and tectonic activity during the Tertiary in the Tucson Mountains appear to have been directly proportional to one another.

## INTRODUCTION

### Location and Accessibility

The study area is located in the City of Tucson, 1.6 kilometers west of the downtown business district (Fig. 1). The map area is approximately 3.0 square kilometers and includes parts of sections 9, 10, 11, 14, 15, 16, 22 and 23 of T.14S., R.13E.

Access to the area (Fig. 2) is provided by Anklam Road on the north and east, Grande Avenue on the east, Mission Road on the southeast, San Vincente Street on the south, 22nd Street on the south, and Greasewood Road on the west. Numerous residential streets penetrate the study area, as well as unimproved roads and trails. In addition, the Sentinel Peak Road and a private drive from Anklam Road provide routes to the summits of Sentinel Peak and Tumamoc Hill, respectively.

### Topography

The study area comprises three low hills (Fig. 3). Elevation varies from 2360 feet (715m) at the Santa Cruz River on the eastern margin of the area, to 3105 feet (941m) at Tumamoc Hill. The area is bordered on the south, west, and north by the Tucson Mountain slope, a pediment of low relief dipping gently eastward and northeastward. Tumamoc Hill and Sentinel Peak are connected by a low ridge, while the third hill, herein referred to as Powder House Hill, is isolated.

The map area is drained by the Santa Cruz River and its tributaries. The latter flow dominantly to the east and northeast, while

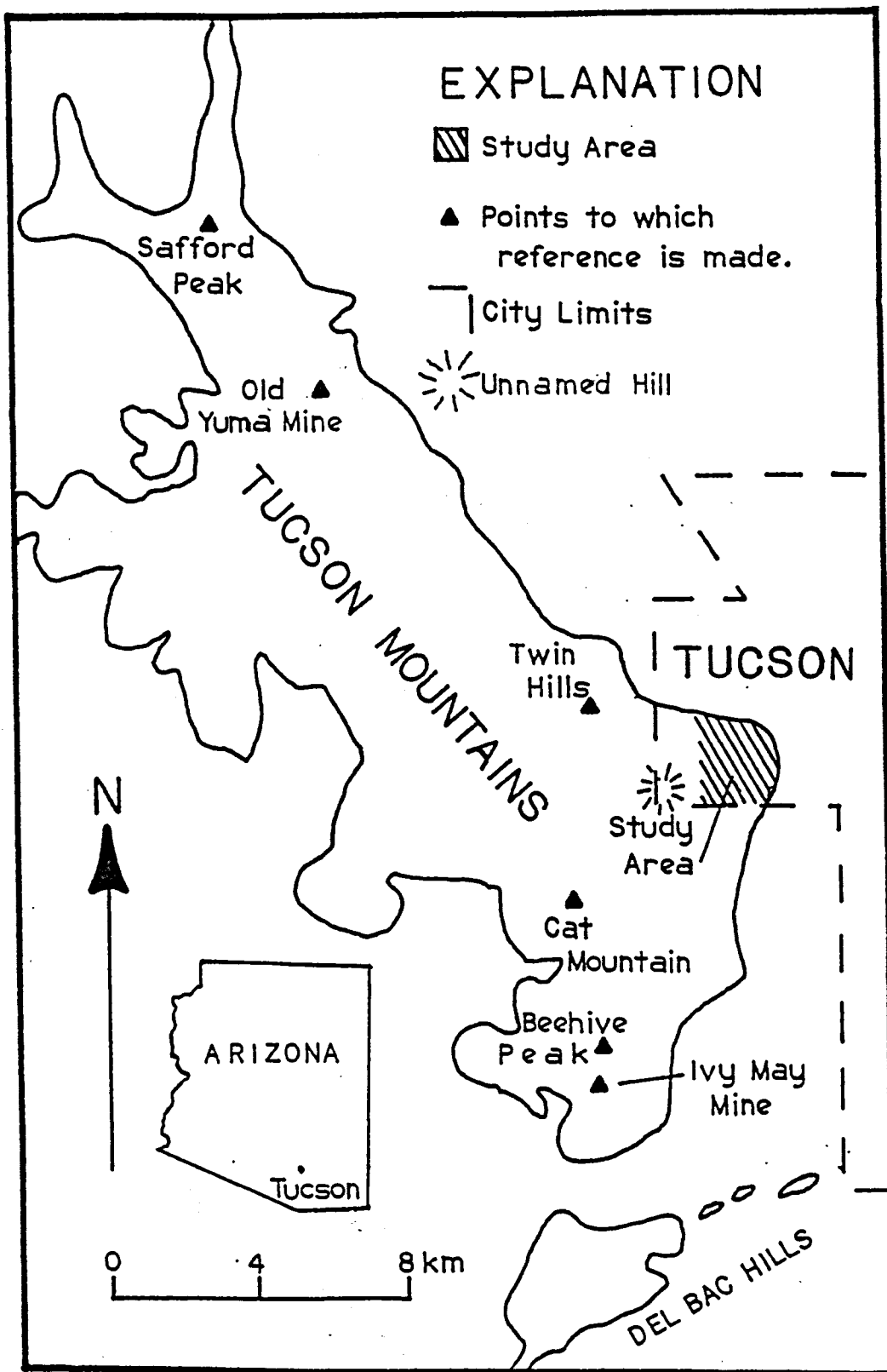


Figure 1. Location map.

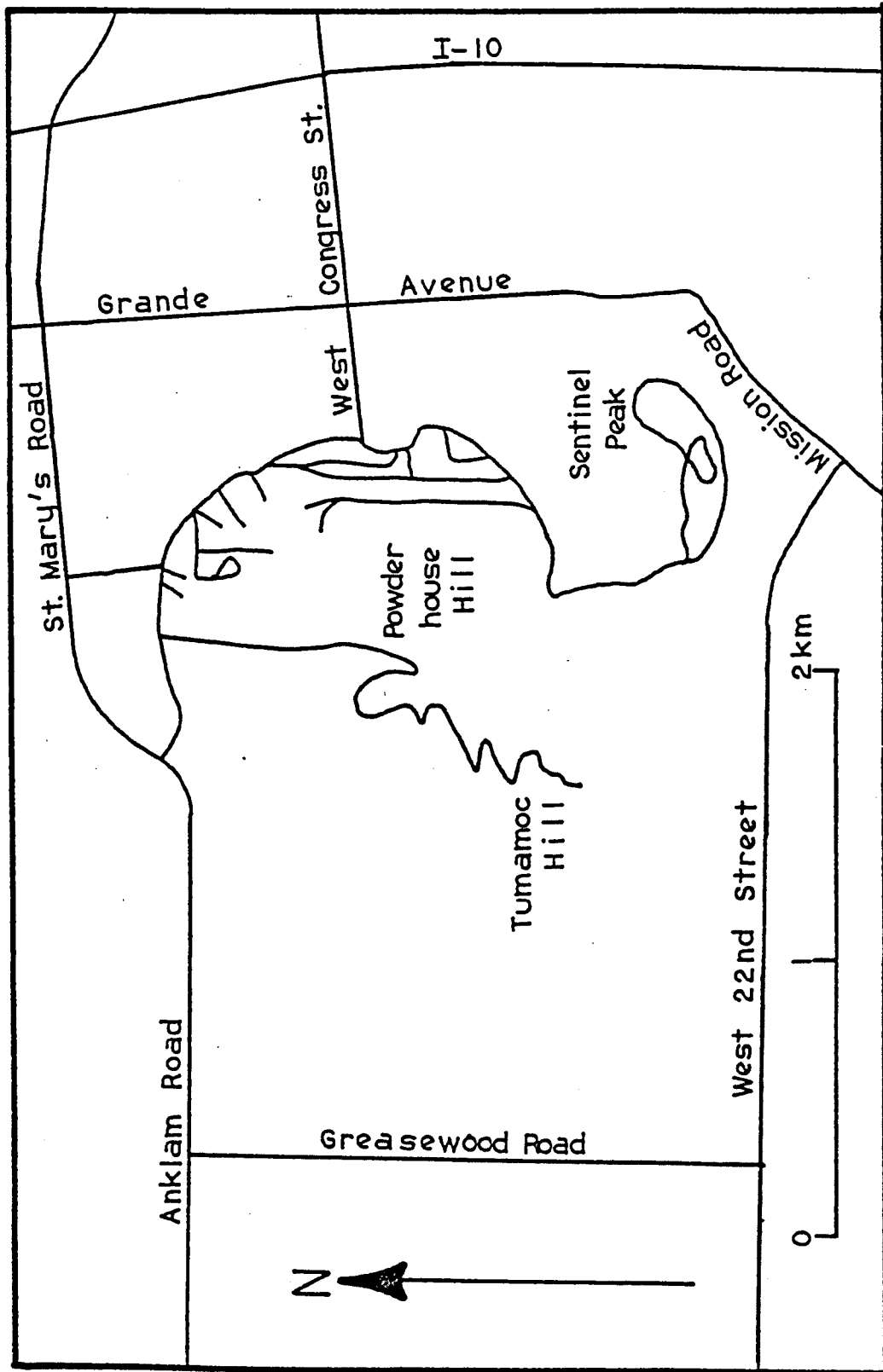


Figure 2. Access map.



Figure 3. Areal view looking southwest. -- Study area is at left center.

the Santa Cruz River flows to the northwest. Locally, radial drainage patterns have developed around areas of higher elevation. Individual water courses are deep, steep-sided arroyos, and all carry water only during and shortly after periods of intense rainfall.

#### Previous Work

The first geologic investigation of the Tumamoc Hill-Sentinel Peak area was a petrographic study of the Tucson Mountains by Guild (1905). In 1909, Tolman published a general geologic report of the area; the report is accompanied by a map and cross-sections. In his report, Tolman referred to basaltic rock units in the sequence as B<sub>1</sub> through B<sub>5</sub>, and included petrographic descriptions by Guild, who revised his earlier observations. Jenkins and Wilson (1920) and Brown (1939) mentioned the Tumamoc Hill-Sentinel Peak area in their geologic study of the Tucson Mountains. Darton (1925), Kinnison (1958), Taylor (1959, 1960), Titley (1959), Cooper (1961), Greenstein (1961), Champney (1962), and Percious (1968a, 1968b) commented briefly on the geology of this area in their studies of surrounding areas.

Halva (1961) sampled units in the Tumamoc Hill-Sentinel Peak area in his geochemical-geologic investigation of basalts, as did Mielke (1964, 1965) in his study of the Turkey Track Porphyry. Ploufs (1961) obtained gravity information for this area in a regional gravity survey. Bikerman and Damon (1966) determined an average K-Ar date of  $26.7 \pm 1.5$  m.y. for the Tumamoc Hill-Sentinel Peak volcanic-sedimentary sequence. Davis (1967) collected magnetic and gravity data for this area in an investigation of the hydrology of the Tucson Basin.

Eastwood (1970) examined the geochemistry and petrology of mid-Tertiary volcanic units in this region. Smiley (1973) summarized briefly the geology of the study area in an interdisciplinary report directed toward delineating an "Environmental Study Area."

#### Statement of Problem

The sequence of interbedded volcanic and sedimentary units exposed at Tumamoc Hill, Sentinel Peak, and vicinity are the product of geological processes which operated from Late Cretaceous through Early Miocene in the Tucson Mountain area. No complete work exists that summarizes the present level of understanding of the geology of this area. This study was undertaken to clarify the relationship of Tumamoc Hill and Sentinel Peak to the Tucson Mountains and the Tucson Basin, as well as to elucidate the interpretation of the depositional and tectonic environments during Tertiary time in the Tucson area.

#### Method of Investigation

A period from September 1975, to January 1976 was spent in the geologic mapping of the area, and in the collection of samples and data for laboratory examination and analysis.

#### Field Procedure

A detailed geologic map (Fig. 4, in pocket) was compiled with the aid of aerial photographs, topographic maps, and "brunton and pace." Aerial photographs (1:12,000 and 1:1,200) were obtained from the Arizona Department of Transportation, and from Cooper Aerial Survey. A topographic base map was produced photographically reducing existing

topographic sheets from a scale of 1:1200 to 1:3600; the contour intervals of the original sheets were modified from 4-foot and 10-foot to a 20-foot interval.

The clast composition of Tertiary alluvial unit(s) was sampled at six localities. Compositions of one hundred clasts were recorded at each location and tabulated (Table 1, see p. 36).

#### Laboratory Procedure

Thin sections were examined with a petrographic microscope as an aid to identification and classification of new rock units. Approximate plagioclase compositions were determined according to the Michel-Levy Method described by Kerr (1959, pp. 257-260). Planar and linear structural orientation data were converted to lower-hemisphere equal-area net projections through use of pole-density computer programs developed by Davis (1972). These programs employ the counting method of Noble and Eberly (1964).

#### Nomenclature

##### Lithic

Anklam Formation. The term Anklam formation was first used by Bikerman and Damon (1966) with reference to a sequence of reworked tuffs, tuffaceous arkoses, and siltstones. Kinnison (1958) referred to the Anklam formation at Sentinel Peak as "Tertiary lake beds." No measured section has been published, nor has a type locality been cited. Consequently, the term Anklam formation is used informally,

herein, and refers to rocks of similar lithology and stratigraphic position to those described by Bikerman and Damon (1966) that crop out in the Tumamoc Hill-Sentinel Peak area.

Mission Road Andesite. This unit was first referred to by Tolman (1909) as "B<sub>3</sub>," and by Guild (1909) as an amygdaloidal basalt. Stratigraphic position and appearance, similar to those of andesites found elsewhere in the Tucson Mountains, and thin-section examination suggest that the rock is also an andesite. Because it crops out along Mission Road, it is herein referred to as the Mission Road andesite.

Mission Road Tuff. This rock has not been described before in the Tumamoc Hill-Sentinel Peak area. It is a well-indurated multi-colored tuff and comprises two small outcrops in the study area. It is best exposed along Mission Road, and is herein referred to as the Mission Road tuff.

Greasewood Andesite. A dark andesite porphyry that crops out on the lower slopes of Tumamoc Hill and Sentinel Peak has not been previously described. Because of the proximity of Greasewood Road to the study area, it is herein referred to as the Greasewood andesite.

Sentinel Tuff. This unit was first recorded by Eastwood (1970, p. 12) who described it as a "red lithic welded tuff." It crops out on the lower parts of the south and southeastern slopes of Sentinel Peak and is herein referred to as the Sentinel tuff.

Tumamoc Andesite. This rock crops out on the lower southeastern slope of Tumamoc Hill. It is a dark, fine-grained andesite and is herein referred to as the Tumamoc andesite.

Tertiary Alluvium. Alluvium is intercalated with the volcanic units of the Tumamoc Hill-Sentinel Peak sequence. It is Tertiary in age, and is herein referred to as Tertiary alluvium.

Cholla Basaltic Andesite. The Cholla basaltic andesite has been described by Guild (1909) who classified it as an amygdaloidal basalt, and by Tolman (1909) who referred to it as "B<sub>1</sub>." Stratigraphic position and appearance, similar to those of basaltic andesites elsewhere in the Tumamoc Hill-Sentinel Peak sequence suggest that it is also a basaltic andesite. Due to the close proximity of Cholla High School, it is herein called the Cholla basaltic andesite.

Grande Basaltic Andesite and the A-Mountain Basaltic Andesite. These rocks were first referred to by Tolman (1909) as "B<sub>4</sub>" and by Guild (1909) as an olivine basalt. Halva (1961, Table V, p. 34) recognized a significant compositional variation within Tolman's "B<sub>4</sub>." Potassium-argon dating by Bikerman and Damon (1966, Table 1, p. 1232) supported this observation revealing marked potassium content differences within the same rock unit. At that time, these rocks were referred to as the A-Mountain basaltic andesite. Eastwood (1970) preferred the term A-Mountain olivine basaltic andesite because of the presence of olivine, recognizable in hand specimen. Recent geologic

mapping by the author has revealed two units. The older is herein referred to as the Grande basaltic andesite, because it is best exposed at the quarry behind Wing's Market on Grande Avenue. The younger is referred to as the A-Mountain basaltic andesite; it crops out on the south, west, and north slopes of A-Mountain (Sentinel Peak).

Tumamoc Tuff. This unit has been referred to as a rhyolitic tuff (Guild 1905; Tolman 1909; Jenkins and Wilson 1920; Brown 1939; and Cooper 1961), as the A-Mountain gray tuff, the A-Mountain brown tuff, or the A-Mountain crystal vitric tuff (Bikerman and Damon 1966), and as a "buff to reddish gray tuff" (Eastwood 1970). It is herein referred to as the Tumamoc tuff.

Tumamoc Basaltic Andesite. This unit has been referred to by Tolman (1909) as B<sub>5</sub>, by Guild (1909) as an olivine basalt, as the Tumamoc Hill Uppermost basaltic andesite by Bikerman and Damon (1966), and as the Tumamoc Hill basaltic andesite by Eastwood (1970). For brevity, it is herein referred to as the Tumamoc basaltic andesite.

### Geographic

Powder House Hill. The unnamed hill between Tumamoc Hill and Sentinel Peak has the remains of a small concrete structure on its west slope. The appearance of the structure is suggestive of a storage building for explosives. For ease of discussion, the hill is herein referred to as Powder House Hill.

Sentinel Peak. Sentinel Peak is the second largest hill in the study area. It is also known as A-Mountain and is recognized by a large white "A" placed near its summit by University of Arizona students. However, it is officially known as Sentinel Peak by the City of Tucson. For that reason, Sentinel Peak is used herein.

## STRATIGRAPHY

The Tumamoc Hill-Sentinel Peak sequence has a composite thickness of at least 390m and consists of interbedded volcanic and sedimentary rocks of Late Cretaceous through Early Miocene age (Fig. 5). Individual rock units thin rapidly, and few extend across the entire map area. Reference to Figures 6 and 7 will aid in understanding stratigraphic relationships described below.

### Mission Road Andesite

The Mission Road andesite is the lowest unit exposed in the Tumamoc Hill-Sentinel Peak sequence. It has been described by Guild (1909), Tolman (1909), and Brown (1939). In the study of the area, it crops out only at Sentinel Peak along Mission Road at the bottom of the cliffs (Fig. 4). The base of the Mission Road andesite is not exposed. The top of the Mission Road andesite appears to be disconformably overlain by, or intrude the fine-grained clastic beds of the Anklam formation.

The Mission Road andesite is highly weathered (Fig. 8). 'Fresh' surfaces are medium dark gray (N4) (Rock Color Chart Committee 1948), weathering olive gray (5 Y 4/1) to dark yellowish orange (10 YR 6/6). According to Guild (1909, p. 81):

It is a non-porphyrific rock, only an occasional crystal of pyroxene being easily recognized in the fresher pieces. . . . It contains in places numerous rounded cavities which have become more or less filled with siliceous matter in the form of banded agate, chalcedony, jasper, and smoky quartz. Fine

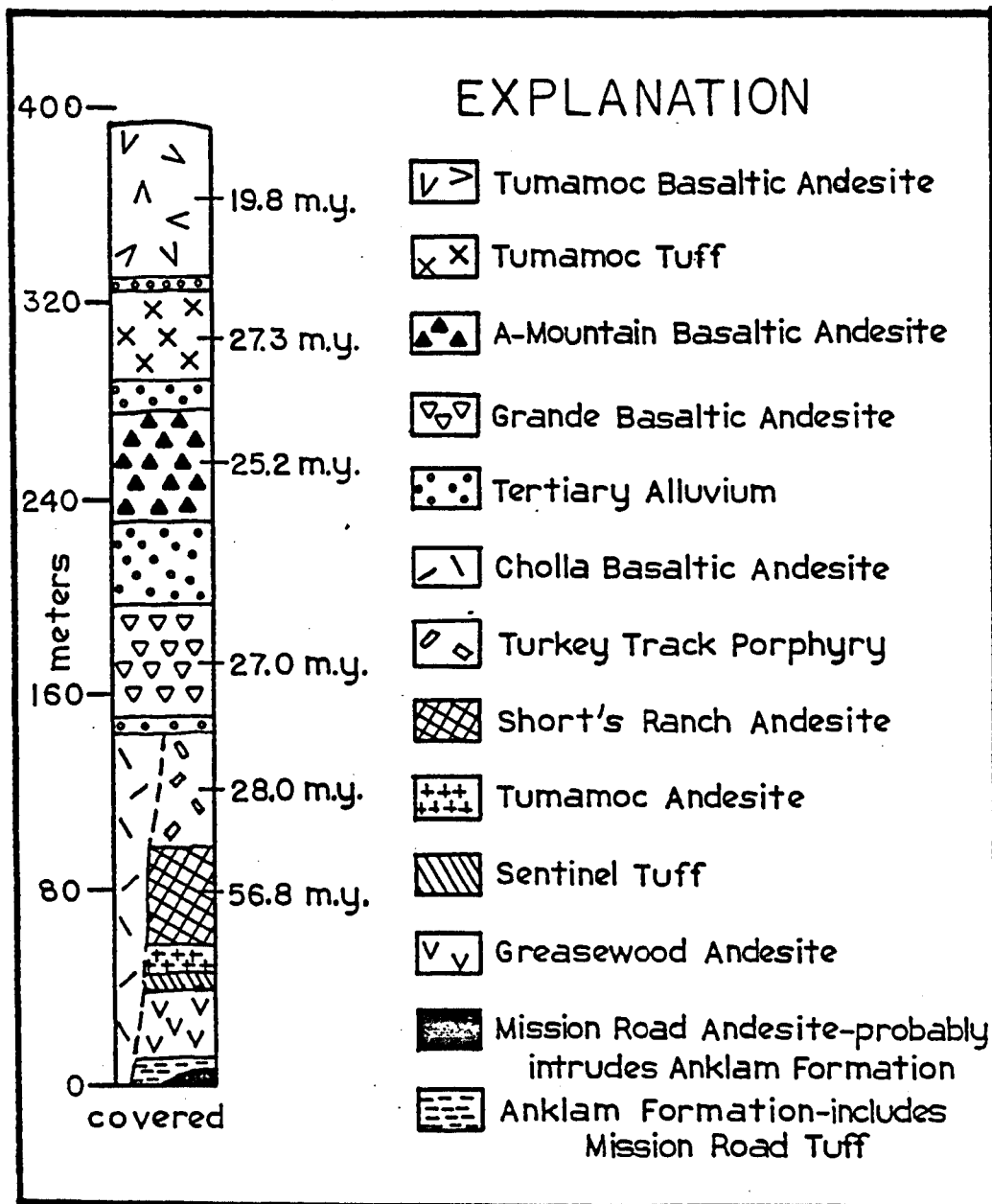


Figure 5. Composite columnar section for Tumamoc Hill, Sentinel Peak, and vicinity.



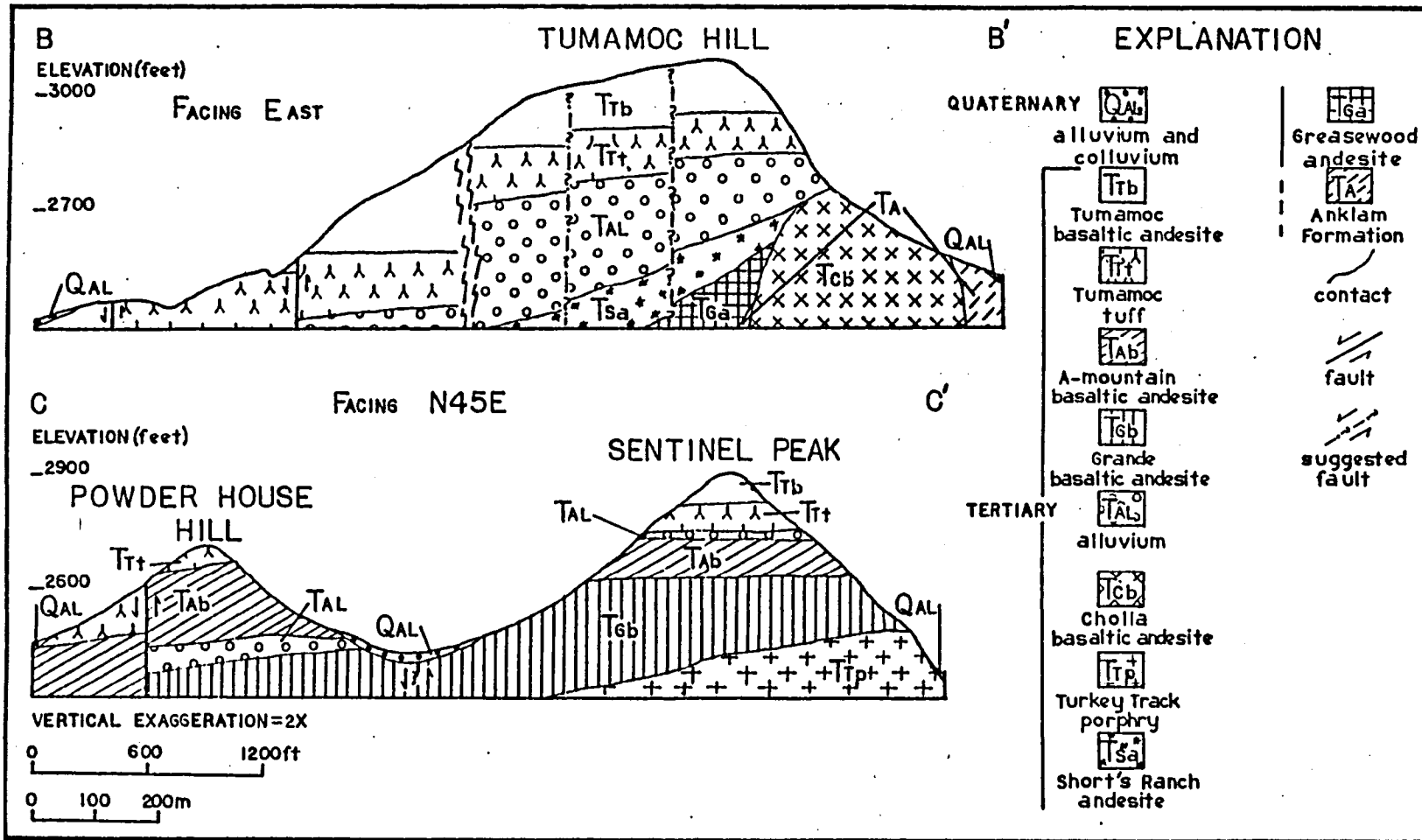


Figure 7. Geologic cross-sections B-B' and C-C'.-- See Figure 4 for locations.



Figure 8. Mission Road andesite. -- Knife blade is approximately 7 cm long.

geodes of brilliant quartz crystals have occasionally been observed. The cavities frequently have a shell of agate, the interior being either empty or filled with calcite and siderite.

Guild (1909) referred to this unit as an amygdaloidal basalt. However, thin-section examination, stratigraphic position, and general appearance suggest that it is a porphyritic andesite. Phenocrysts of plagioclase with an approximate composition of  $An_{38}$  occur in a felted groundmass of plagioclase. The outcrop of Mission Road andesite is generally massive and forms a low (5m) rounded knob at the edge of Mission Road.

#### Anklam Formation

The Anklam formation has been described by Bikerman and Damon (1966). It has never been recognized in the Tumamoc Hill-Sentinel Peak sequence, but the thin-bedded (5-40cm), fine-grained (less than .1mm) clastic sedimentary rocks and interbedded tuffaceous layers cropping out along Mission Road, and in the abandoned landfill southwest of Tumamoc Hill are herein assigned to the Anklam formation (Fig. 4). The unit also occurs as float on the lower southern slopes of Tumamoc Hill and Sentinel Peak, and as angular clasts in the Tertiary alluvium.

At Mission Road, the Anklam formation comprises pale reddish brown (10 R 5/4) to grayish orange (10 YR 7/4), finely stratified claystone bearing evidence of small-scale penecontemporaneous deformation. The claystone is interbedded with less competent, highly weathered layers, and weathers light brown (5 YR 6/4) and grayish orange (10 YR 7/4) (Fig. 9). The Anklam formation forms a partly covered slope and



Figure 9. Anklam formation at Mission Road.

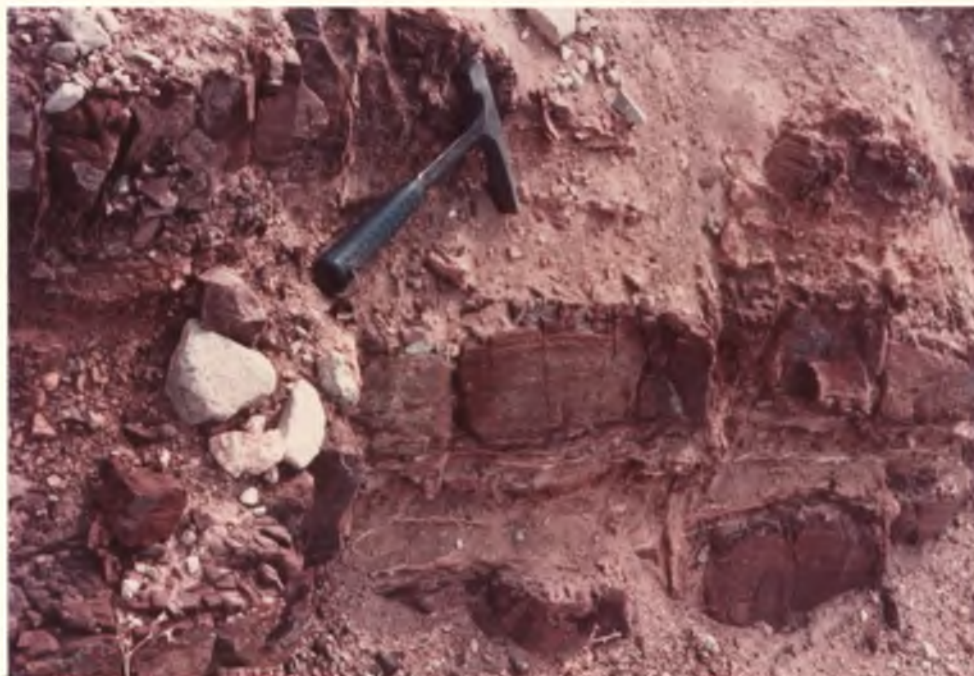


Figure 10. Anklam formation at the abandoned landfill southwest of Tumamoc Hill.

appears to overlie, or be intruded by, the Mission Road andesite.

Approximately 7m of claystone are exposed at Mission Road.

At the abandoned landfill southwest of Tumamoc Hill (Fig. 10), fine-grained (less than .1mm) clastic sedimentary rocks are moderate reddish brown (10 R 4/6), light gray (N7), and dark reddish brown (10 R 3/4), weathering grayish red (10 R 4/2), medium light gray (N6), and grayish pink (5 R 8/2). They are interstratified with white (N9) tuffaceous layers, and are thin bedded (5-15cm). Exposed thickness does not exceed 10m.

Elsewhere in the Tucson Mountains, the Anklam formation conformably overlies the Cat Mountain Rhyolite (Bikerman 1963), is intruded by the Ivy May andesite (Kinnison 1958), and is conformably overlain by the Short's Ranch Andesite (Brown 1939). The Anklam formation has a maximum recorded thickness in excess of 150m in the Tucson Mountains (Kinnison 1958).

The base of the Anklam formation is nowhere exposed in the Tumamoc Hill-Sentinel Peak area. The Anklam formation appears to be disconformably overlain by the Greasewood andesite at Mission Road and by recent colluvium at the abandoned landfill southwest of Tumamoc Hill. This upper contact can be traced along the base of the southern slope of Sentinel Peak (Fig. 4). The top of the Anklam formation is highly weathered, and lacks any semblance of its original lithic character (Fig. 11).



Figure 11. Anklam formation overlain by Greasewood andesite on the south slope of the ridge which connects Tumamoc Hill and Sentinel Peak.

### Mission Road Tuff

The Mission Road tuff crops out along Mission Road (Fig. 12) and on the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak (Fig. 4). It is well indurated and forms resistant knobs at both locations. At Mission Road the base of the tuff is not exposed. It is approximately 5m thick and is disconformably (?) overlain by a 3m-thick poorly consolidated and highly weathered layer of lithic material.

On the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak, the outcrop of Mission Road tuff appears to be enclosed in the fine-grained clastics of the Anklam formation. No contacts are exposed, however, and the Anklam formation is represented only as float. Color varies widely from pale red (5 R 6/2) and pale red purple (5 RP 6/2) to very pale red purple (5 RP 7/2) and very light gray (N8), weathering white (N9), light brownish gray (5 YR 6/1), dark yellowish orange (10 YR 6/6), grayish red purple (5 RP 4/2), and grayish red (5 R 4/2).

Thin section examination reveals euhedral to subhedral biotite phenocrysts and rounded plagioclase laths in a cryptocrystalline groundmass. Minor hematite and magnetite are dispersed throughout the groundmass. Accidental angular rock fragments having an aphanitic crystalline matrix are common. Welded glass shards are visible under plane polarized light.



Figure 12. Mission Road tuff at Mission Road.

### Greasewood Andesite

The Greasewood andesite crops out on the southeast and south slopes of Sentinel Peak, and on the south and west slopes of Tumamoc Hill (Fig. 4). It is generally the first igneous rock encountered as the drainages on the southeast, south, and southwest sides of the study area are ascended, and is best exposed in places where relief is locally high. The andesite maintains a constant stratigraphic position, i.e., immediately above the Anklam formation (Fig. 11). The Greasewood andesite has a maximum thickness of 10m and is disconformably overlain by the Sentinel tuff and the Short's Ranch Andesite. The Greasewood andesite appears to have high-angle contacts with the Cholla basaltic andesite, although no contacts with any neighboring units are exposed.

In hand specimen (Fig. 13) the Greasewood andesite ranges from medium gray (N5) to dark gray (N3), weathering brownish gray (5 YR 4/1), pale yellowish brown (10 YR 6/2), and grayish black (N2). It is porphyritic, showing small (1cm or less) phenocrysts of plagioclase and pyroxene. In thin-section, a trachytic texture is exhibited. Euhedral to subhedral phenocrysts of plagioclase dominate, having an approximate average composition of  $An_{50}$ . Greasewood andesite is highly jointed, and includes local platy jointing similar to that developed in the basaltic andesites, and forms a partially covered slope.

### Sentinel Tuff

The Sentinel tuff crops out on the south and southeast slopes of Sentinel Peak (Fig. 4). Its presence was first recorded by Eastwood (1970, p. 12) who described it as "a red lithic welded tuff." The



Figure 13. Greasewood andesite. -- Pen tip is 3mm across.

Sentinel tuff disconformably overlies the Greasewood andesite, is disconformably overlain by the Turkey Track Porphyry, and is overlapped by Tertiary alluvium. It has a maximum thickness of 6m.

The lower contact of the Sentinel tuff is not exposed. The unit contains abundant plagioclase phenocrysts as large as 6mm in length that become smaller toward the base of the unit (Fig. 14). Accidental angular rock fragments are common and increase in frequency toward the base of the tuff.

Fresh surfaces are pale red (5 R 6/2), weathering moderate grayish red (5 R 5/2). The upper contact with the Turkey Track Porphyry is marked by a 13cm-thick sandy layer bearing fragments of the Sentinel tuff. The Sentinel tuff forms a rubble-covered slope below the cliffs of the Turkey Track Porphyry.

Thin-section examination reveals dominant subhedral to rounded phenocrysts of plagioclase and rare angular, accidental, aphanitic crystalline and sedimentary rock fragments in a moderate grayish red (5 R 5/2) vitric groundmass. Biotite is minor, and the rock exhibits a eutaxitic texture. Individual plagioclase laths are broken, and have an approximate composition of  $An_{35}$ . Welded glass shards are visible under plane polarized light.

#### Tumamoc Andesite

The Tumamoc andesite has never been described before. It crops out on the lower southeastern slope of Tumamoc Hill (Fig. 4). The Tumamoc andesite disconformably overlies the Sentinel tuff, Greasewood andesite, and the Anklam formation. Disconformably overlying the

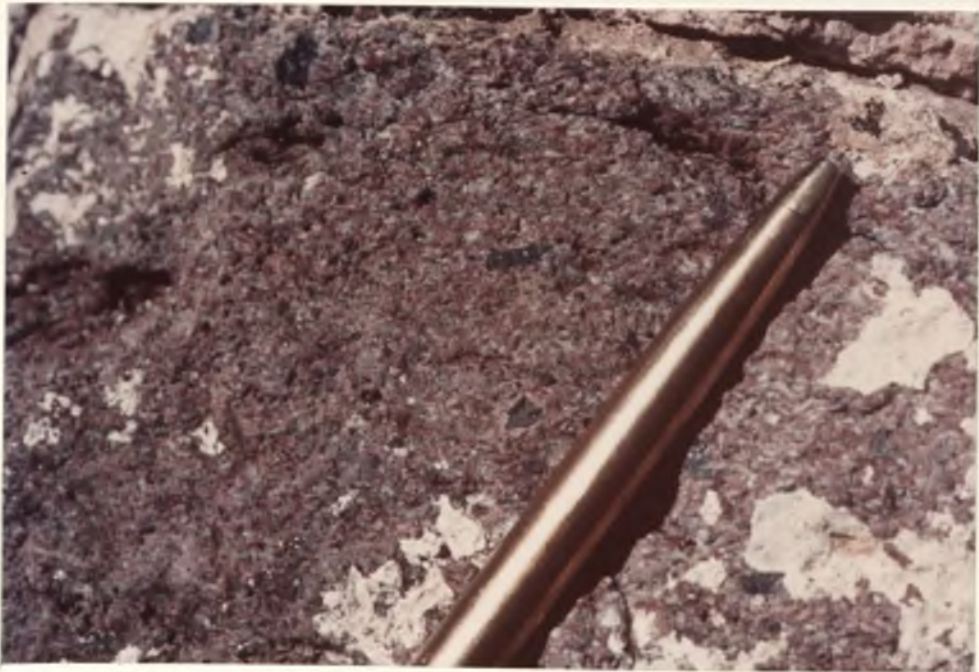


Figure 14. Sentinel tuff. -- Pen tip is 3mm across.

Tumamoc andesite is the Short's Ranch Andesite and Tertiary alluvium. No contacts with neighboring units are exposed, but outcrop distribution makes these relationships clear. The Tumamoc andesite is massive, highly jointed, and forms partially covered slopes. Maximum exposed thickness is 12m.

In hand specimen, the Tumamoc andesite is aphanitic (Fig. 15). It is light brownish gray (5 YR 6/1), weathering brownish gray (5 YR 4/1). Thin-section examination reveals a trachytic texture. Normally zoned euhedral plagioclase phenocrysts of approximate composition  $An_{34}$  dominate.

#### Short's Ranch Andesite

The Short's Ranch Andesite at Tumamoc Hill is over 39m thick, and crops out on the south and west slopes of Tumamoc Hill and on the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak (Fig. 4). A potassium-argon date of  $56.8 \pm 1.7$  m.y. (Bikerman and Damon 1966) has been obtained for this unit. The Short's Ranch Andesite has been described by Guild (1905) and Tolman (1909), and was formally defined by Brown (1939). Its color varies, but at Tumamoc Hill it is light gray (N7) weathering very light gray (N8) and pale yellowish brown (10 YR 6/2) (Fig. 16).

Although contact relationships are nowhere exposed, outcrop patterns suggest high-angle contacts with the Cholla basaltic andesite. It is apparent that the Short's Ranch Andesite disconformably overlies the Greasewood andesite, the Tumamoc andesite, and the Anklam formation, and is seen to be disconformably overlain by Tertiary alluvium.



Figure 15. Tumamoc andesite. -- Pen tip is 3mm across.



Figure 16. Short's Ranch Andesite. -- Knife is 10cm long.

The Short's Ranch Andesite is massive and dips gently east or northeast; it pinches out eastward. It forms a partially covered slope and is best exposed in the southern and western drainages of Tumamoc Hill.

At Tumamoc Hill, the Short's Ranch Andesite comprises "phenocrysts of medium oligoclase ( $An_{26}$ ), which show zoning . . . and biotite. . . . The groundmass is crystalline. . . . Magnetite occurs both as phenocrysts and in the groundmass. Quartz is rare as phenocrysts but seems to occur in the groundmass" (Brown 1939, p. 735).

#### Turkey Track Porphyry

The Turkey Track Porphyry at Sentinel Peak has been described by Guild (1909), Tolman (1909), Cooper (1961), Halva (1961), Champney (1962), Mielke (1964, 1965), Percious (1968a, 1968b), and Eastwood (1970). It crops out on the southeast and south flanks of Sentinel Peak forming the massive cliffs and steep slopes along Mission Road (Fig. 4). A potassium-argon date of  $28.0 \pm 2.6$  m.y. has been obtained for the Turkey Track at Sentinel Peak (Bikerman and Damon 1966). At Sentinel Peak, it disconformably overlies the Sentinel tuff, and, in turn, is overlapped by Tertiary alluvium, the A-Mountain basaltic andesite, and the Grande basaltic andesite. The Turkey Track Porphyry has an exposed thickness of over 45m.

A diagnostic characteristic of the Turkey Track is its abundant large plagioclase phenocrysts (2-3cm) in a black (N1) aphanitic matrix (Fig. 17). Locally the plagioclase phenocrysts are aligned sub-parallel to each other, and rare pyroxene phenocrysts as long as 4mm



Figure 17. Turkey Track Porphyry. -- Knife is approximately 17cm long.

also have been observed. "The groundmass is . . . made up chiefly of feldspar crystals varying in size from microlithic growths . . . to individuals which can be seen easily by a hand lens. . . . Accessories are magnetite, olivine, and apatite" (Guild 1909, pp. 80-81). Vuggy quartz crystals occur along fractures and in vesicles.

Within .5m of the lower contact, the Turkey Track has a pale red (5 R 6/2) matrix. An irregular 13cm-thick sandy layer with fragments of the underlying Sentinel tuff marks the contact, whereas the upper contact with the Grande basaltic andesite comprises 3m of moderately sorted, horizontally stratified, pale reddish brown (10 R 5/4) conglomerate. Individual clasts range from less than 1mm to 1cm, and the larger are scoraceous basaltic fragments. This unit weathers blackish red (5 R 2/2). The contacts between Turkey Track, the overlapping alluvium, and the A-Mountain basaltic andesite are not exposed, but their relative positions are clear.

Because of the scarcity of olivine, Guild suggested that some might call this unit a "basaltic pyroxene andesite." Halva (1961), on the basis of chemical analysis, preferred "potassic basaltic andesite."

#### Cholla Basaltic Andesite

The Cholla basaltic andesite has been described by Guild (1909) and Tolman (1909), and crops out on the south slope of Tumamoc Hill (Fig. 4). Its contacts with the Greasewood andesite and the Short's Ranch Andesite appear to be high-angle, and it is depositionally overlain by Tertiary alluvium.

In hand specimen, the andesite is light brownish gray (5 YR 6/1) and medium light gray (N6), weathering pale yellowish brown (10 YR 6/2), pale brown (5 YR 5/2) and brownish gray (5 YR 4/1). Commonly it occurs as breccia recemented by jasper (Fig. 18). Light bluish gray (5 B 7/1) chalcedony fills joints and fractures. The Cholla basaltic andesite is highly jointed and fractured, forming partially covered slopes. Platy jointing (Fig. 19) is well developed.

In thin-section, this unit exhibits trachytic texture with euhedral to subhedral plagioclase phenocrysts of an approximate composition of An<sub>50</sub>.

#### Tertiary Alluvium

Tertiary alluvium crops out on the east, west, and south slopes of Tumamoc Hill, on the south, west, and north slopes of Sentinel Peak, and on the south and west slopes of Powder House Hill (Fig. 4). It occurs at various stratigraphic horizons throughout the Tumamoc Hill-Sentinel Peak sequence. The stratigraphic relationships of the Tertiary alluvium to other rock units within the Tumamoc Hill-Sentinel Peak sequence are, perhaps more easily comprehended by referring to Figures 6 and 7. The Tertiary alluvium exposed at Tumamoc Hill, Sentinel Peak, and vicinity has been briefly described by Tolman (1909), Brown (1939), and Eastwood (1970).

#### Tumamoc Hill

A thick (36m) section of Tertiary alluvium crops out at Tumamoc Hill (Fig. 4), and disconformably overlies the Short's Ranch Andesite



Figure 18. Brecciated Cholla basaltic andesite cemented with jasper. -- Pen is 8mm across.



Figure 19. Platy jointing in basaltic andesite. -- Knife is approximately 17cm long.

and the Cholla basaltic andesite. The Tertiary alluvium, in turn, is conformably overlain by the Tumamoc tuff. Disconformably overlying the Tumamoc tuff is another, thinner (5m) section of Tertiary alluvium that is conformably overlain by the Tumamoc basaltic andesite. These relationships are best exhibited in Figure 6.

Horizontal stratification is generally well developed within the Tertiary alluvium. Locally, the unit is well sorted. Moderately preserved graded bedding is also present. Clast size varies from less than 1mm to 70cm or more, and individual fragments are angular to sub-angular (Fig. 20).

Clast composition differs throughout the Tertiary alluvium at Tumamoc Hill (Table 1). At the base of the alluvial unit, Short's Ranch Andesite clasts make up about 5% of the total number of clasts, and Anklam formation clasts account for 4%. Dark Greasewood andesite or basaltic andesite fragments compose the remainder.

Just below the Tumamoc tuff, the frequency of Short's Ranch Andesite clasts within the Tertiary alluvium increases to 50%, and those of the Anklam formation to 15%. The thin alluvial unit between the Tumamoc tuff and the Tumamoc basaltic andesite has clast frequencies of 30% for the Short's Ranch Andesite, and 8% for the Anklam formation.

### Sentinel Peak

A 3m-thick section of Tertiary alluvium at Sentinel Peak crops out along Mission Road and Grande Avenue (Fig. 4), and disconformably overlies the Turkey Track Porphyry. It, in turn, is conformably



Figure 20. Tertiary alluvium at Tumamoc Hill with clasts of Anklam formation (left of knife) and Short's Ranch Andesite (right of knife). -- Knife is 10cm long.

Table 1. Clast frequencies for Tertiary alluvium at locations A-F as shown on Figure 4.

Location	Short's Ranch Andesite	Anklam Formation	Turkey Track Porphyry	Other
A	5%	4%	0%	91%
B	50%	15%	0%	35%
C	30%	8%	0%	62%
D	0%	10%	0%	90%
E	0%	1%	80%	19%
F	60%	10%	10%	20%

overlain by the Grande basaltic andesite and exhibits moderately developed thin (1cm) stratification.

The unit is poorly sorted, and clast sizes range from less than 1mm to 1cm or larger (Fig. 21). It fills irregularities in the top of the Turkey Track Porphyry (Fig. 22), and contains abundant scoraceous fragments of the same. Its upper contact is gradational with the scoraceous base of the Grande basaltic andesite. This unit resembles the upper Tertiary alluvial unit at Sentinel Peak.

A 12m-thick section of Tertiary alluvium unconformably overlies Grande basaltic andesite, the Greasewood andesite, the Sentinel tuff, and the Turkey Track Porphyry. The Tertiary alluvium is, in turn, conformably overlain by the A-Mountain basaltic andesite. Sorting is poor and stratification moderate. Clasts are angular and do not exceed 10cm in maximum dimension. No Short's Ranch Andesite fragments were observed in the Tertiary alluvium at Sentinel Peak, but Anklam formation clasts make up 10% of the total number in this stratigraphic horizon.

Another 12m-thick section of Tertiary alluvium at Sentinel Peak unconformably overlies the A-Mountain basaltic andesite and is conformably overlain by the Tumamoc tuff. The sediments in this portion of the Tertiary alluvium are moderately stratified and moderately to well sorted. Clasts are angular and rarely exceed 2cm in maximum dimension. The Anklam formation clast frequency is less than 1%, while Turkey Track Porphyry fragments account for 80%.



Figure 21. Tertiary alluvium at Sentinel Peak with clasts of Turkey Track Porphyry. -- Knife is approximately 17cm long.



Figure 22. Tertiary alluvium along Mission Road filling a fracture in the top of the Turkey Track Porphyry. -- Grande basaltic andesite overlies the Tertiary alluvium. Fracture is approximately 1m wide.

### Powder House Hill

A 9m-thick section of Tertiary alluvium disconformably overlies the Grande basaltic andesite at Powder House Hill (Fig. 4), and is conformably overlain by the A-Mountain basaltic andesite. The Tertiary alluvium is poorly stratified and moderately sorted. Clasts are angular and reach 25cm in maximum dimension. At Powder House Hill, Short's Ranch Andesite clasts account for 60% of the clast total, and fragments derived from the Anklam formation and Turkey Track Porphyry make up about 10% each. The Tertiary alluvium generally forms covered slopes, but is well exposed in the south and west drainages of Tumamoc Hill.

### Grande Basaltic Andesite

The Grande basaltic andesite is best exposed at the quarry behind Wing's Market on Grande Avenue. It also crops out on the east and northeast slopes of Sentinel Peak and in the valley between Sentinel Peak and Powder House Hill (Fig. 4). It has been described by Guild (1909), Tolman (1909), Halva (1961), Bikerman and Damon (1966), and Eastwood (1970). A potassium-argon date of  $27.0 \pm 1.2$  m.y. (Bikerman and Damon 1966) has been obtained for this unit.

The Grande basaltic andesite rests conformably upon a thin (3m) laterally discontinuous conglomerate (Fig. 23), or, where the conglomerate is not present, directly upon the eroded upper surface of the Turkey Track Porphyry. This relationship is best exposed at Sentinel Peak along Grande Avenue, across from the baseball field. The lower contact with the conglomerate is gradational, and that with the Turkey Track Porphyry is not exposed.



Figure 23. Grande basaltic andesite along Mission Road overlying Tertiary alluvium.

The base of this unit is scoraceous breccia with angular and subangular fragments. Scoraceous zones occur irregularly throughout the unit (Fig. 24) and grade into vesicular or platy jointed (Fig. 19) and more massive layers (Fig. 25). Fresh surfaces are black (N1) to medium gray (N6), weathering light brownish gray (5 YR 6/1), light olive gray (5 Y 6/1), and grayish orange (10 YR 7/4). Massive portions form cliffs whereas those more vesicular and scoraceous form rubble-covered slopes.

Disconformably overlying the Grande basaltic andesite is Tertiary alluvium in the valley between Sentinel Peak and Powder House Hill, and the Tumamoc tuff at the quarry behind Wing's Market on Grande Avenue. Thickness is probably in excess of 45m.

Eastwood (1970) recognized subhedral olivine phenocrysts rimmed with iddingsite in a groundmass of plagioclase, pyroxene, olivine, and magnetite. Alignment of plagioclase laths imparts a pilotaxitic texture to this rock unit. Halva (1961) first noted the discrepancy in classification by petrographic methods and geochemical methods. Petrography suggests an olivine basalt, whereas chemical analysis indicates a composition closer to a basaltic andesite. The mafic mineral phenocrysts are surrounded by a potassium-rich groundmass (Bikerman and Damon 1966).

#### A-Mountain Basaltic Andesite

The A-Mountain basaltic andesite is exposed at the south end of Powder House Hill, on the north and south slopes of Sentinel Peak, and caps the ridge connecting Tumamoc Hill and Sentinel Peak (Fig. 4).



Figure 24. Scoraceous basaltic andesite. -- Knife is 10cm long.



Figure 25. Irregular zonation of scoraceous vesicular, platy jointed, and massive basaltic andesite. -- Field of view is approximately 3m wide.

It has been described by Guild (1909), Tolman (1909), Halva (1961), Bikerman and Damon (1966), and Eastwood (1970). It rests conformably upon 7 to 33m of Tertiary alluvium that thins eastward and northeastward. This contact is best exposed south of Powder House Hill along the Sentinel Peak Road, and in the west drainage of the valley between Sentinel Peak and Powder House Hill. At its eastern margin, the A-Mountain basaltic andesite rests disconformably upon the Turkey Track Porphyry. This contact is not exposed, but the relative stratigraphic positions of the two units is clear from outcrops. A potassium-argon date of  $25.2 \pm 5.8$  m.y. (Bikerman and Damon 1966) has been obtained for this unit.

The base of the A-Mountain basaltic andesite comprises scoraceous breccia with angular and subangular fragments. Scoraceous layers occur irregularly throughout the unit (Fig. 24), and grade into vesicular or platy jointed (Fig. 19), and more massive zones (Fig. 25). Fresh surfaces are black (N1) to medium gray (N6), weathering light brownish gray (5 YR 6/1), light olive gray (5 Y 6/1), and brownish gray (5 YR 4/1). Massive portions form cliffs, while those more vesicular and scoraceous form rubble-covered slopes.

Disconformably overlying the A-Mountain basaltic andesite is more Tertiary alluvium, except at Powder House Hill where it is disconformably overlain by the Tumamoc tuff. It thickens northward and probably exceeds 45m in thickness.

Eastwood (1970) recognized phenocrysts of olivine partially altered to iddingsite, and in the groundmass, plagioclase ( $An_{32-38}$ ) and

augite. This rock has an intergranular texture. Halva (1961) first noted that hand specimen and thin-section identification of this unit does not agree with that arrived at by geochemical means. The former reveals characteristics of an olivine basalt (Guild 1909), whereas the latter suggests a composition closer to a basaltic andesite. The mafic mineral phenocrysts are accompanied by a potassium-rich groundmass (Bikerman and Damon 1966).

### Tumamoc Tuff

The Tumamoc tuff has been described by Guild (1905), Tolman (1909), Jenkins and Wilson (1920), Darton (1925), Brown (1939), Cooper (1961), Bikerman and Damon (1966), and Eastwood (1970). It crops out on the east, south, and west flanks of Tumamoc Hill, at Sentinel Peak, along the crest of Powder House Hill, and as scattered patches at the quarry and in the valley between Tumamoc Hill and Powder House Hill (Fig. 4). The tuff yields an average potassium-argon date of  $27.3 \pm 0.9$  m.y. (Bikerman and Damon 1966), and can be divided into three members: 1, the white tuff member; 2, the brown tuff member; and 3, the gray tuff member. The members have a combined thickness of 30 to 36m.

### White Tuff Member

This lowermost member comprises 15cm of finely stratified, poorly consolidated, white (N9) tuff (Fig. 26) and has been described as a "crystal-vitric tuff" by Bikerman and Damon (1966). It is present at both Tumamoc Hill and Sentinel Peak. The exposures at Powder House



Figure 26. White tuff member of the Tumamoc tuff at Sentinel Peak overlying Tertiary alluvium.  
-- Knife is 10cm long.

Hill are poor, and it is uncertain whether the white tuff member is present there. A potassium-argon date of  $26.6 \pm 0.9$  m.y. (Bikerman and Damon 1966) has been obtained for this member.

The white tuff member conformably overlies the Tertiary alluvium at Tumamoc Hill and Sentinel Peak, and rests disconformably upon the A-Mountain basaltic andesite at Powder House Hill and the Grande basaltic andesite at the quarry behind Wing's Market.

#### Brown Tuff Member

The brown tuff member conformably overlies the white tuff member; the contact is gradational (Fig. 27). The thickness of the member ranges from 2m on the south slope of Tumamoc Hill, to 3m on the north slope of Sentinel Peak. Poor exposures prevent its positive identification at Powder House Hill. Color varies from white (N9) at the base to grayish orange pink (5 RY 7/2) upward, and weathering pale yellowish brown (10 YR 6/2) .5m above the lower contact. The upper .5m of the brown tuff member is grayish orange (10 YR 7/4), weathering light yellowish brown (10 YR 6/4).

Stratification is absent in this member. Induration increases upward, as does the frequency of elongated pumice fragments. The pumice inclusions locally reach 10cm in length and have a chatoyant luster. They are moderate brown (5 YR 3/4) to grayish orange pink (5 YR 7/2).

Sub-angular basaltic rock fragments also increase in abundance near the top. The inclusions are oriented sub-parallel to the attitude



Figure 27. Tumamoc tuff — brown tuff member overlain by gray tuff member at Sentinel Peak.

of the unit and display a maximum dimension of 3cm. The brown tuff member and the white tuff member are more susceptible to erosion than the overlying gray tuff member. Consequently, they form a covered slope with talus from the member above.

#### Gray Tuff Member

Conformably overlying the brown tuff member is the gray tuff member (Fig. 27). The contact between them is sharp and slightly undulatory. Its thickness is approximately 30m, and the color ranges from light gray (N7) to very light gray (N8), weathering light brownish gray (5 YR 6/1) and pale yellowish brown (10 YR 6/2). At the base is a .5 to 1m thick pale red (10 R 6/2) zone which weathers pale red (5 R 6/2).

No stratification is evident and the middle of the unit is more indurated than either the top or bottom. Angular rock fragments are most abundant, and reach a maximum size of more than 10cm near the bottom of this unit. Fragments include scoraceous basalt, white (N9), poorly consolidated tuff, and very coarse grained, poorly sorted sandstone.

Locally, the unit displays a vesicular or pitted surface where pumice lentils have weathered out. Individual pumice fragments reach 8cm in maximum dimension. The upper portion of the gray tuff member has a muddy appearance on its weathered surface. The highly indurated middle section of this unit forms a resistant cliff or ledge, while the less indurated upper and lower margins form partially covered slopes.

The Tumamoc tuff is conformably overlain by a thin, laterally discontinuous alluvial unit containing andesite and basaltic andesite clasts, or, where the alluvial unit is not present, it is disconformably overlain by the Tumamoc basaltic andesite. At Tumamoc Hill, as much as 5m of alluvium separate the tuff from the basaltic andesite above.

At Sentinel Peak, the upper contact zone is 10-15cm thick and gradational, consisting of a poorly sorted sandy layer containing angular basaltic rock fragments as large as 3cm in maximum dimension intercalated with the scoraceous base of the overlying basaltic andesite. Locally, the top of the tuff is brecciated and the interstices are filled with sandy material.

Petrographically, the brown and gray members of the Tumamoc tuff have been described as "chatoyant sanidine-bearing" (Bikerman and Damon 1966). Eastwood (1970) noted that many of the glass shards had devitrified obliterating the original texture. An average potassium-argon date of  $27.7 \pm 0.9$  m.y. (Bikerman and Damon 1966) has been obtained for the gray tuff member.

#### Tumamoc Basaltic Andesite

The Tumamoc basaltic andesite is the youngest extrusive unit in the area, and has yielded a potassium-argon date of  $19.8 \pm 3.0$  m.y. (Bikerman and Damon 1966). It crops out principally on the top and north flank of Tumamoc Hill, with small scattered outcrops on the east and west flanks of Tumamoc Hill, on the top of Sentinel Peak, and

along the crest of Powder House Hill (Fig. 4). It rests upon either a thin (3m), laterally discontinuous alluvial unit, or directly upon the Tumamoc tuff, and is over 60m thick. It has been described by Guild (1905), Tolman (1909), Brown (1939), Kinnison (1958), Taylor (1960), Halva (1961), Bikerman and Damon (1966), and Eastwood (1970).

The base of the unit is generally breccia composed of dominantly angular to subangular scoraceous fragments. The clasts range in size from less than 1mm to .5m and the smaller clasts fill the interstices between the larger. The Tumamoc basaltic andesite conformably overlies Tertiary alluvium at Tumamoc Hill and disconformably overlies the Tumamoc tuff at Powderhouse Hill and Sentinel Peak. Scoraceous layers occur irregularly throughout the unit (Fig. 26), and grade into vesicular or platy jointed (Fig. 19), and more massive clasts (Fig. 25). Fresh surfaces are black (N1) to medium gray (N5), weathering medium light gray (N6), pale yellowish brown (10 YR 6/2), and grayish orange (10 YR 7/4).

The surface of this unit resembles clinker in some outcrops. The massive portions form cliffs as high as 10m, while the more vesicular and scoraceous parts form partially covered slopes.

Halva (1961) noted that although hand-specimen and petrographic examination of this unit indicate an olivine basalt (Guild 1909), chemical analysis reveals a composition closer to basaltic andesite. Mafic mineral phenocrysts of olivine, augite, magnetite, and plagioclase occur in a potassium-rich groundmass (Bikerman and Damon 1966). This rock has a pilotaxitic texture. An appreciable iron content causes a

deflection of the compass needle when it is brought within 1.5m of the outcrop.

Vuggy, white (N9) to clear quartz and calcite are locally present as secondary minerals in cavities. Vesicles predominate over amygdules and both are usually flattened, though spherical and irregular cavities also occur. These features may reach 3-4cm in maximum dimensions.

## STRUCTURE

The Tumamoc Hill-Sentinel Peak sequence has an overall strike of approximately N54W, and dips northeastward. Dip magnitudes range from 45 degrees for the basal Anklam formation to less than 5 degrees for the capping Tumamoc basaltic andesite. The amount of northeastward dip decreases progressively upward. Faulting and the irregular shape of the basaltic andesite flows causes local variations in these attitudes (Figs. 6 and 7).

### Morphology and Attitude of Rock Units

#### Mission Road Andesite

The Mission Road andesite occurs as a small rounded knob along Mission Road. Approximately 5m of andesite are exposed vertically. Outcrop area probably does not exceed 50m<sup>2</sup>. The attitude of the Mission Road andesite cannot be determined. At Mission Road (Fig. 4), the Mission Road andesite is in fault contact with the Mission Road tuff.

#### Anklam Formation

The Anklam formation at Tumamoc Hill, Sentinel Peak, and vicinity dips generally to the northeast, although locally it dips to the north and northwest (Fig. 4). Dip magnitudes are moderate, ranging from 30 to 45 degrees. Exposed thickness varies from 7m at Mission Road, to 10m at the abandoned landfill southwest of Tumamoc Hill. The

upper contact has an approximate strike of N65W, and dips 65NE. The Anklam formation is in fault contact with the Mission Road tuff at Mission Road, and the Greasewood andesite on the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak. The strata of the Anklam formation generally strike N50W, and dip 45NE.

#### Mission Road Tuff

The Mission Road tuff crops out as small rounded knobs along Mission Road, and on the lower portion of the southern slope of the ridge connecting Tumamoc Hill and Sentinel Peak (Fig. 4). At Mission Road, the tuff is in fault contact with the Mission Road andesite and the Anklam formation. Approximately 5m of Mission Road tuff are exposed vertically along Mission Road. Less than 1m is exposed vertically on the south slope of the ridge connecting Tumanoc Hill and Sentinel Peak. Outcrop area is not more than 40m<sup>2</sup> at either location. The Mission Road tuff has an apparent strike of N80E, dipping 33N at Mission Road.

#### Greasewood Andesite

The Greasewood andesite is an irregular mass of roughly tabular shape. Its lower surface gently undulates, maintaining approximately the same elevation throughout its outcrop. At Mission Road this unit is abruptly truncated by faulting (Fig. 4). It is in fault contact with the Anklam formation on the slope south of the ridge connecting Tumamoc Hill and Sentinel Peak. Thickness varies from 5m to 10m. The surface upon which the Greasewood andesite rests has an approximate

attitude of N70W, 65NE. This attitude may, in part, be due to faulting and is discussed under major faults.

### Sentinel Tuff

The Sentinel tuff is a wedge-shaped mass thickening westward from 3 to 18m, where it is truncated (Fig. 4). With the exception of the western end of the mass, the contacts of the Sentinel tuff are of low relief. The surface upon which the Sentinel tuff rests has an attitude of N79W, 19NE.

### Tumamoc Andesite

The Tumamoc andesite is an irregular mass and occupies an area of high relief in the upper surface of the Sentinel tuff (Fig. 4). The Tumamoc andesite rests upon a curvilinear surface, the exposures of which do not allow determination of an overall attitude.

### Short's Ranch Andesite

The Short's Ranch Andesite at Tumamoc Hill (Fig. 4) is of uniform thickness (21m) throughout its western half. It thickens eastward abruptly to 36m, and then rapidly thins out in the same direction. The irregularity of the lower surface of the Short's Ranch Andesite does not allow determination of an attitude for that surface.

### Turkey Track Porphyry

The Turkey Track Porphyry at Sentinel Peak (Fig. 4) is a wedge-shaped mass thickening eastward to 45m, and pinching out to the west. Its lower surface is gently undulating, and has an attitude of N8W, 10E.

### Cholla Basaltic Andesite

Cholla basaltic andesite is an oblate, vertical, pipe-like mass (Fig. 4), with a long dimension along a northwest-southeast line. Areal extent is probably in excess of  $48,600\text{m}^2$ .

### Tertiary Alluvium

Tertiary alluvium interfingers with the basaltic andesite flows and the Tumamoc tuff (Fig. 4), and has an average attitude of  $N54W, 14NE$ . The basal surface of the Tertiary alluvial unit has an attitude of  $N87E, 27N$ . Above the A-Mountain basaltic andesite at Sentinel Peak, the alluvium rests upon a surface striking  $N55E$ , and dipping  $39NW$ . At Tumamoc Hill above the Tumamoc tuff, the lower surface of the Tertiary alluvium has an attitude of  $N79W, 6NE$ .

### Grande Basaltic Andesite

The Grande basaltic andesite is a wedge-shaped mass thinning to the west and south, and thickening northeastward in excess of  $45\text{m}$  (Fig. 4). The surface upon which it rests strikes  $N76W$ , and dips  $8 NE$ .

### A-Mountain Basaltic Andesite

The A-Mountain basaltic andesite is a wedge-shaped mass which thins to the southwest and east, and thickens northward to  $45\text{m}$  (Fig. 4). The lower surface of the A-Mountain basaltic andesite is essentially planar striking  $N74W$ , and dipping  $4NE$ .

### Tumamoc Tuff

The Tumamoc tuff is a tabular mass of nearly uniform thickness (35m). It thickens slightly northward (Fig. 4). The Tumamoc tuff rests upon a surface which strikes N87E, and dips 3N.

### Tumamoc Basaltic Andesite

The Tumamoc basaltic andesite maintains a nearly constant thickness (65m) at Tumamoc Hill (Fig. 4). It is somewhat thinner at Sentinel Peak (24m) and Powder House Hill (30m). At Tumamoc Hill, it rests on a surface whose approximate attitude is N86W, 10N, while at Sentinel Peak the same surface has an attitude of N40E, 1NW. Poor exposure at Powder House Hill does not permit a confident determination of the attitude of the Tumamoc basaltic andesite's lower surface.

### Joints

Jointing pervades all of the igneous units present in the Tumamoc Hill-Sentinel Peak sequence. But only in the Tumamoc tuff and the Tumamoc basaltic andesite are joints well enough exposed to allow meaningful description and statistical treatment.

### Tumamoc Tuff

Attitudes of 138 joints in the Tumamoc tuff were measured. The poles to joint planes are plotted as a pole-density diagram in Figure 28a. Several nearly vertical joint sets are well developed as suggested by the maxima around the periphery of the pole-density plot. These have strikes of N38E, N35W, N63W, and E-W. A less well developed

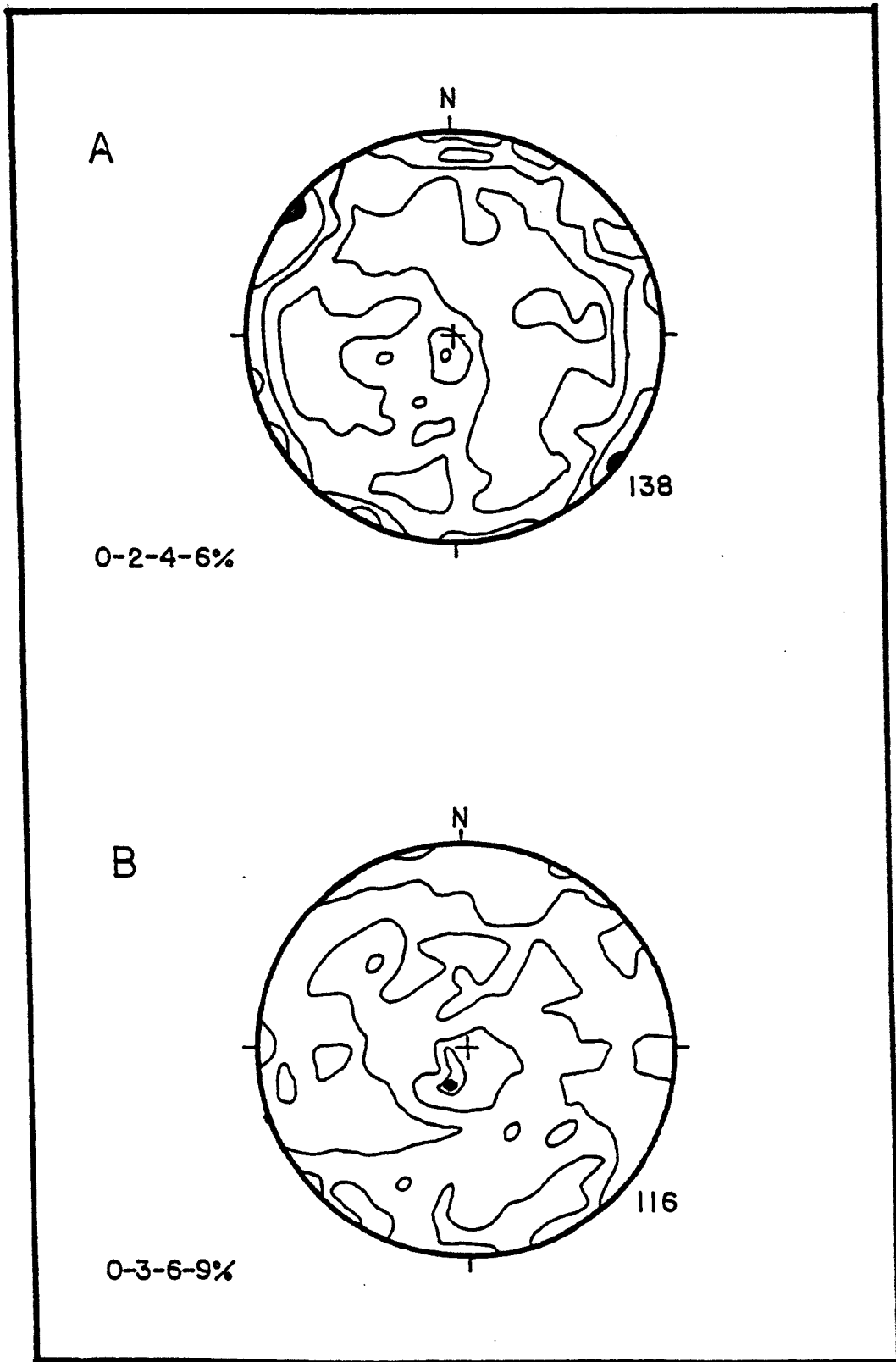


Figure 28. Pole-density plots. -- A, Plot of joints in the Tumamoc tuff. B, Plot of platy joints in the Tumamoc basaltic andesite.

nearly horizontal set is also present as suggested by the maximum mode in the southwest quadrant of the plot. It strikes N<sup>4</sup>9W, and dips 7NE.

#### Tumamoc Basaltic Andesite

A characteristic of the basaltic andesite flows in the Tumamoc Hill-Sentinel Peak sequence is locally well developed platy jointing (Fig. 19). Other joints are also present, but are randomly distributed and do not lend themselves to meaningful statistical analysis. The Tumamoc basaltic andesite is the most completely preserved of these flows, and consequently best displays platy jointing. Attitudes of 116 platy joints were measured in the Tumamoc basaltic andesite. The poles to joint planes are plotted as a pole-density diagram in Figure 28b. A maximum mode occurs in the southwest quadrant. This mode represents a plane striking N60W, and dipping 18NE.

#### Major Faults

In the context of this discussion, major faults are those with displacement magnitudes greater than 3m. Three major faults sets occur in the Tumamoc Hill-Sentinel Peak area (Fig. 4); these strike N-S to N5W, N15E, and N80W to E-W. The traces of the faults within these sets are nowhere exposed in the study area. The positions, orientations, and magnitudes of displacement of the faults can, however, be approximated by examining both the resultant topographic expression and stratigraphic offset.

High-angle faults truncate the Greasewood andesite at both Mission Road, and on the lower southern slope of the ridge connecting

Tumamoc Hill and Sentinel Peak. The fault at Mission Road is the best exposed in the area, having an attitude of N5W, 48W. The rocks are intensely jointed near the fault plane. Prominent joint sets have attitudes of N55E, 55SE, and N80E, 82SE. Magnitude and sense of displacement are not evident. The fault on the lower southern slope of the ridge connecting Tumamoc Hill and Sentinel Peak is not exposed, but its presence is suggested by the abrupt truncation of the Greasewood andesite. It appears to be high angle with a N-S strike.

High-angle faults are also evident at the western edge of the study area, and on the eastern slope of Tumamoc Hill (Fig. 4); they strike N15E. Although the direction and magnitude of dip is indeterminate, the sense and magnitude of displacement of the fault at the western edge of the study area are reflected by the elevated positions of the Short's Ranch Andesite and the Tumamoc basaltic andesite at Tumamoc Hill, relative to corresponding outcrops of those units to the west. Displacement magnitude of this fault may be as great as 90m, and the apparent sense of movement is down to the west. A fault of similar strike to the fault just described is detected in a like manner on the east slope of Tumamoc Hill. Its sense of displacement is down to the east. Displacement magnitude is approximately 12m.

A third set of high-angle faults strikes N80W to E-W. Dip direction and magnitude cannot be determined. Sense of movement along faults of this set is systematically down to the north (Figs. 4 and 7). These faults are most evident at Tumamoc Hill (Fig. 4), although displacement of units at Powder House Hill also reveals their presence.

Movement appears to have been accommodated parallel to the contact of the Anklam formation and the Greasewood andesite (Fig. 11), which has a strike similar to this fault set. Displacement magnitudes along individual faults may exceed 48m.

#### Minor Faults

Minor faults, as described herein, are those with displacement magnitudes of 3m or less. They are present on the south and southwest slopes of Tumamoc Hill (Fig. 4) at the contacts between the brown and white tuff members of the Tumamoc tuff, and at the lower contact of the Tumamoc tuff with the Tertiary alluvium. All are normal faults down to the southeast. They strike from N32E to N68E and dip from 70 to 89 degrees southeast. Displacement varies from .3m to 2m. The fault plane comprises a thin (4cm) zone of fine-grained breccia. Movement of undeterminable magnitude and sense has also been accommodated along the Anklam formation-Greasewood andesite contact.

## INTERPRETATIONS

### Joint Analysis

Joint sets in the Tumamoc tuff (Fig. 28a) have orientations similar to those predicted for a welded ash flow tuff (Smith 1960a, 1960b; Ross and Smith 1961). Several approximately vertical joint sets are developed, as well as a nearly horizontal set which reflects the general attitude of the unit. Based upon this evidence, the Tumamoc tuff has an overall attitude of approximately N49W, 7NE.

Platy jointing in lava flows (Fig. 19) is thought to be derived from rapid cooling (Rittmann 1962), or the result of "the weathering out of an obscure flow structure" (Ollier 1969, p. 55). If the latter origin is true, statistical treatment may reveal flow directions. In the pole-density plot of platy joints in the Tumamoc basaltic andesite (Fig. 28b), the maximum mode in the southwest quadrant represents a plane which strikes N60W, 18NE. It is subparallel to the overall attitude of flow of the Tumamoc basaltic andesite. This orientation is similar to the slope upon which the Tumamoc basaltic andesite rests.

Joint sets accompanying the trace of the fault at Mission Road (Fig. 4) have a conjugate relationship. Their attitudes suggest a principal stress direction oriented along a line which trends S43W and plunges 44 degrees.

### Geologic History

Geologic events, as recorded by the Tumamoc Hill-Sentinel Peak rock sequence, begin with the deposition of the Anklam formation in Late Cretaceous or Early Tertiary time. That volcanism was active during this period is suggested by the presence of tuffaceous interbeds.

The fine-grained clastic nature of the Anklam formation at Tumamoc Hill and Sentinel Peak, coupled with the lack of primary sedimentary structures (other than horizontal stratification) indicate a lacustrine depositional environment. Kinnison (1958) suggested such an environment of deposition for the Anklam formation. The tuffaceous interbeds may be air fall tuffs, or sediments derived from earlier tuffs.

The age of the Anklam formation is constrained by potassium-argon age determinations by Bikerman and Damon (1966). The older, underlying Cat Mountain Rhyolite yielded ages of  $65.6 \pm 2.8$  m.y. and  $70.3 \pm 2.3$  m.y. The Anklam formation has been demonstrated to be older than the Biotite rhyolite (Brown 1939). The Biotite rhyolite yielded a potassium-argon age of  $60.5 \pm 1.8$  m.y. Thus, the time of deposition of the Anklam formation is placed in Late Cretaceous or Early Paleocene time using the time scale of Kulp (1961).

The Mission Road tuff shares a close spatial relationship with the Anklam formation, the exact nature of which is not clearly understood (Fig. 4). At Mission Road, a fault contact between the Anklam formation and the Mission Road tuff exists. On the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak, the Mission Road tuff

appears to be part of the Anklam formation. These relationships allow several interpretations: 1, the Mission Road tuff and the Anklam formation are two distinct units whose age relationships are unknown; 2, the two outcrops of Mission Road tuff are unrelated to each other; and 3, the Mission Road tuff is part of the Anklam formation and might yield an accurate date for the same. Field evidence eliminates none of these. If the first interpretation is valid, two variations are possible. The Mission Road tuff is either older or younger than the Anklam formation. Kinnison (1958) presented evidence that the base of the Anklam formation is composed of reworked Cat Mountain tuffs. If the Mission Road tuff is older than the Anklam formation, the tuff may be correlative with the tuffs of the Cat Mountain Rhyolite. If the Mission Road tuff is younger than the Anklam formation, no reasonable regional correlations can be made on the basis of geologic studies of surrounding areas. The possibility that the two outcrops of Mission Road tuff are unrelated cannot be ruled out. If true, as many as three distinct rock units can be acknowledged, i.e., the Anklam formation, and two tuff units. The last interpretation is the most attractive because of its simplicity and future research potential. It implies that only one rock unit be recognized, i.e., the Anklam formation. The third interpretation also suggests that the Anklam formation may be isotopically dated. The intimate association of the Anklam formation with welded tuffs is not restricted to the Tumamoc Hill-Sentinel Peak area. Similar relationships occur immediately south of the Hill 2.4m

west of Tumamoc Hill. In the context of this discussion, the Mission Road tuff is assumed to be part of the Anklam formation.

Following deposition of the Anklam formation, andesite intrusion and extrusion occurred in the forms of the Mission Road andesite and the Greasewood andesite respectively. The Greasewood andesite everywhere overlies the Anklam formation in the study area. The Mission Road andesite may either underlie the Anklam formation or intrude it, because the field evidence is equivocal. In the southern Tucson Mountains, the Ivy May andesite has been observed to intrude and overlie the Anklam formation (Kinnison 1958). Consequently, it is suggested that the Mission Road andesite intrudes the Anklam formation along Mission Road, and that the Mission Road andesite and the Greasewood andesite may be correlative with the Ivy May andesite.

If this is true, the age of the Mission Road andesite and the Greasewood andesite can be constrained in a manner similar to that in which the age of the Anklam formation was delimited. The Ivy May is younger than the Anklam formation (60.5-65.6 m.y.), and older than the Biotite rhyolite (60.5 m.y.). The time of emplacement of the Mission Road andesite and the Greasewood andesite is post-Anklam formation, but in the time interval of 60.5-65.5 m.y.

Faulting took place along N-S to N5W striking faults displacing the Anklam formation, Mission Road tuff, Mission Road andesite, and the Greasewood andesite. Two such faults were mapped (Fig. 4); one on the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak, and the other along Mission Road. Only the fault along Mission Road is

clearly exposed; it dips 48W. Assuming the Mission Road tuff to be part of the Anklam formation, the strata between the two faults were dropped down relative to their counterparts on the east and west. Displacement magnitude cannot be determined. Because these faults do not displace the overlying Short's Ranch Andesite ( $56.8 \pm$  m.y., Bikerman and Damon 1966), their age can be delimited to the mid-Paleocene.

A northeastward tilting of the sequence to 30-45 degrees also took place during the mid-Paleocene. This is evidenced by the general lack of oversteepened paleoslopes higher in the sequence. It is clear that tilting took place after deposition of the Anklam formation. But whether it occurred before or after emplacement of the Greasewood andesite and the Mission Road andesite is not known. Elsewhere in the Tucson Mountains, "structural deformation in the form of local tilting occurred in the interval between deposition of the Safford Formation\* and extrusion of the Short's Ranch andesite" (Kinnison 1958, p. 88). Kinnison also presents evidence that tilting accompanied emplacement of the Ivy May andesite ( $60.5 \pm 1.8$  m.y., Bikerman and Damon 1966). It seems likely that tilting of the Tumamoc Hill-Sentinel Peak sequence is correlative with mid-Paleocene tilting described in other parts of the Tucson Mountains.

Emplacement of the Sentinel tuff followed the mid-Paleocene faulting. Extrusion of the Sentinel tuff may be another manifestation of the Biotite rhyolite event in the Tucson Mountains (60.5 m.y. b.p.).

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\*The Safford Formation of Kinnison (1958) and the Anklam formation of Bikerman and Damon (1966) are the same. See the section on Nomenclature.

Kinnison (1958, p. 68) found evidence of pre-Biotite rhyolite faulting and suggests "that the Biotite rhyolite was deposited against moderately well eroded fault scarps." These relationships are similar to those of the Sentinel tuff in the Tumamoc Hill-Sentinel Peak sequence (Fig. 6). Geochemical work would verify this idea.

A topographic low was eroded in the Sentinel tuff, and the Tumamoc andesite was extruded, filling this depression (Fig. 6). The Tumamoc andesite was then eroded and overlapped by the extruded Short's Ranch Andesite ( $56.8 \pm 1.7$  m.y., Bikerman and Damon 1966) in Late Paleocene time.

A hiatus exists in the Tumamoc Hill-Sentinel Peak sequence for the time interval of 56.8 m.y. to 28.0 m.y. Some erosion must have occurred during this period exposing the Tumamoc andesite and the Sentinel tuff. In Late Oligocene, the Turkey Track Porphyry ( $28.0 \pm 2.6$  m.y., Bikerman and Damon 1966) was extruded. According to Percious (1968a, 1968b), the Turkey Track Porphyry, in other localities throughout southeastern Arizona, usually signals the initiation of basaltic andesite volcanism. This is true of the Tumamoc Hill-Sentinel Peak area as well, for the basaltic andesite rock units there formed subsequent to 28.0 m.y.. The Turkey Track Porphyry flow at Sentinel Peak suffered some erosion as evidenced by the alluvial units overlying it which contain abundant fragments of the porphyry.

The Cholla basaltic andesite intruded the Short's Ranch Andesite sometime after the extrusion of the Turkey Track Porphyry. Tolman (1909) interpreted it to be an eroded volcanic neck, which seems reasonable. Weathering processes have removed any field evidence

connecting this volcanic neck or vent to any of the basaltic andesite flows. Geochemical work must, again, be called upon to determine the relation of the Cholla basaltic andesite to the basaltic andesite flows.

Alluvium began to enter the area during Late Oligocene and has continued to the present. The occurrence of alluvium after a long period of quiescence (29 m.y.) suggests that tectonism accompanied basaltic andesite volcanism. Continuous influx is indicated by the interfingering nature of the alluvium with the basaltic andesite flows and the Tumamoc tuff. Recent alluvium, similar to the Tertiary alluvium intercalated with the Tumamoc Hill-Sentinel Peak sequence, occurs on the Tucson Mountain slope on the west side of the study area.

The Grande basaltic andesite flow(s) ( $27.0 \pm 1.2$  m.y., Bikerman and Damon 1966) and the A-Mountain basaltic andesite flow(s) ( $25.2 \pm 5.8$  m.y., Bikerman and Damon 1966) followed the Turkey Track Porphyry flow. The structural characteristics of these and the capping Tumamoc basaltic andesite flow(s) suggest that they were highly viscous when erupted, perhaps analogous to the aa flows described by Wentworth and MacDonald (1953). The irregular gradation of scoraceous, vesicular, platy jointed and massive zones (Fig. 25) indicates that each of these rock units probably contains multiple flows. Their extreme variance in thickness is probably due in part to erosion and to modification of the underlying topography.

Shortly after the extrusion of the A-Mountain basaltic andesite flow, the Tumamoc tuff was emplaced. Its deposition was initiated by

an air fall tuff (white tuff member). Immediately following were two ash flows. That the Tumamoc tuff was deposited within a very short time is indicated by the preservation of the primary air fall tuff, and by the density zoning observed in the field. The unconsolidated nature of an air fall tuff implies that it will be quickly removed by normal weathering processes. The density zoning patterns of the Tumamoc tuff is identical to that described by Ross and Smith (1961) and Smith (1960a, 1960b) for a multiple-ash flow simple cooling unit. The brown tuff member could not have cooled significantly before the gray tuff member was emplaced. The Tumamoc tuff was probably deposited within days, or even hours. Exposed at the time of extrusion were the A-Mountain basaltic andesite, the Grande basaltic andesite, and Tertiary alluvium.

Following the Tumamoc tuff, alluvium again began to enter the area. Its presence above the tuff, only at Tumamoc Hill, suggests the source of the alluvium was in a westerly direction. This argument is supported by the fact that all present outcrops of Short's Ranch Andesite (the major clast constituent of the alluvium) are to the west and southwest.

Local erosion accompanied alluvial influx and influenced clast composition throughout the alluvial unit. For example, the alluvium between the A-Mountain basaltic andesite and the Tumamoc tuff at Sentinel Peak contains little or no Short's Ranch andesite clasts. Instead, Turkey Track Porphyry fragments dominantly compose the unit. The A-Mountain basaltic andesite flow probably created a topographic high producing a barrier to sediment influx from the west. As a result,

only Turkey Track Porphyry fragments could enter the area, possibly from the south or southeast.

In Early Miocene, the Tumamoc basaltic andesite was erupted upon a nearly horizontal surface. Exposed at that time were the Tumamoc tuff and Tertiary alluvium. Although the Tumamoc basaltic andesite has yielded a potassium-argon date of 19.8 m.y. (Bikerman and Damon 1966), the error of the date is excessive ( $\pm 3.0$  m.y.). The sequence of interbedded basaltic andesite flows and alluvial units in the Del Bac Hills 17.4 km to the south (Fig. 1), as recorded by Percious (1968a, 1968b) is similar to the upper portion of the Tumamoc Hill-Sentinel Peak sequence above the Short's Ranch Andesite (Fig. 5). The uppermost basaltic andesite flows in the Del Bac Hills yield ages ranging from  $23.5 \pm 0.7$  m.y. to  $24.8 \pm 0.7$  m.y. (Percious 1968a, 1968b). Redating of the Tumamoc basaltic andesite probably will produce a date closer to those figures.

Two high-angle fault sets, which post-date the Tumamoc basaltic andesite, have displaced the Tumamoc Hill-Sentinel Peak sequence in the manner of block faulting (Fig. 4). Relative movement along N15E striking faults uplifted part of the sequence above the Tucson Mountain slope to the west. Faults striking N80W to E-W systematically dropped the sequence down to the north. It is noteworthy that the Cholla basaltic andesite appears to have intruded along a similar trend of N55W. The trace of the range-front fault on the east side of the study area cannot be located by field examination. Ploufs (1961) concluded that gravity patterns in the Tucson Mountain area indicated that the

range was fault-bound. However, water well records yield little information which may be used to locate these faults. Slump or landslide blocks of Tumamoc tuff and Tumamoc basaltic andesite occur on the east and west slopes of Tumamoc Hill. The faults described herein as minor faults are probably related to slump accompanying the major faulting. The relative ages of the faults which post-date the Tumamoc basaltic andesite are indeterminate on the basis of field evidence. Erosion has since modified the fault scarps so that they are not easily recognized. Recent colluvium mantles Tumamoc Hill, Sentinel Peak, and vicinity, and alluvial deposits surround the topographic highs.

#### Source and Extent of Rock Units

The areal extents of the rock units within the Tumamoc Hill-Sentinel Peak sequence are probably only fractions of their original areas. Faulting and tilting have disrupted these Tertiary strata so they cannot be traced any great distances, and correlation becomes tenuous. Nevertheless, estimates of areal extent can be made.

The Anklam formation probably covered a minimum area of  $110\text{km}^2$ . The exposures in the Tumamoc Hill-Sentinel Peak area are the farthest east that the formation is preserved. Other limiting outcrops are 900m southeast of the Ivy May mine on the south, 1.1km north of Cat Mountain on the west, and 1.8km southeast of the Old Yuma mine on the north (Fig. 1). At least one source for the clastics in the Anklam formation was the Cretaceous Amole Formation (Kinnison 1958).

Paleocene igneous activity in the Tucson Mountains is represented by widespread andestic intrusives and extrusives occurring

within an area of over  $80\text{km}^2$ . Several episodes of volcanism and plutonism took place during this series. Some of these episodes are represented in the Tumamoc Hill-Sentinel Peak sequence as the Mission Road andesite, the Greasewood andesite, the Tumamoc andesite, and the Short's Ranch Andesite. The Mission Road andesite cannot be confidently extended beyond its present outcrop limits (Fig. 4). The Greasewood andesite covered an area of at least  $6\text{km}^2$ , and may have extended to the base of the hill  $2.4\text{km}$  west of Tumamoc Hill, where a similar appearing rock unit is in contact with the Short's Ranch Andesite (Fig. 1). The Tumamoc andesite may have flowed down a Paleocene valley (Fig. 4), however, it cannot be confidently extended beyond its present outcrop limits ( $3\text{km}^2$ ). The Short's Ranch Andesite crops out over an area of approximately  $80\text{km}^2$  in the southern Tucson Mountains. The outcrop pattern of Short's Ranch Andesite on the south slope of the ridge connecting Tumamoc Hill and Sentinel Peak (Fig. 4) is suggestive of what may be the eastern margin of that rock unit. Two possible sources for this rock unit have been described by Kinnison (1958); at Twin Hills,  $4.2\text{km}$  northwest of Tumamoc Hill, and  $1.7\text{km}$  south of the Ivy May mine ( $10.8\text{km}$  southwest of the study area) (Fig. 1).

The former extent of the Sentinel tuff is difficult to determine. Evidence within the study area suggests that the ash flow covered at least  $162,000\text{m}^2$  (Fig. 4). If it is related to the emplacement of the Biotite rhyolite, a likely source might be in the vicinity of Beehive Peak,  $8\text{km}$  to the southwest (Fig. 1).

The Turkey Track Porphyry is a widespread unit in southeastern Arizona (Tolman 1909; Brown 1939; Cooper 1961; Halva 1961; Mielke 1964, 1965), and is both intrusive and extrusive. The flow at Sentinel Peak covered an area of at least  $729,000\text{m}^2$ . Percious (1968a, 1968b) suggested that the source for this flow might be the Turkey Track Porphyry dikes in the Del Bac Hills 17.4km southwest of the study area (Fig. 1). This seems unlikely because of the highly viscous nature of the Sentinel Peak Turkey Track flow. High viscosity is indicated by the aa characteristics of the Turkey Track Porphyry and the overlying basaltic andesite flows in the Tumamoc Hill-Sentinel Peak sequence. A local source is more probable although it could be argued that the aa lava of the Turkey Track flow at Sentinel Peak is the distal end of a more fluid flow originating in the Del Bac Hills.

The Grande basaltic andesite and the A-Mountain basaltic andesite flows had minimum areal extents of  $875,000\text{m}^2$  each. Their sources were probably local, although argument can again be raised in a manner similar to that in the preceding paragraph. No distal source is evident.

The Tumamoc tuff has a minimum areal extent of  $2.7\text{km}^2$  within the study area (Fig. 4), but its former extent must have been considerably greater. Density zoning within the tuff implies that the section preserved at Tumamoc Hill is not at the distal end of the ash flow sequence. It was deposited on a slope which dipped gently (less than  $10^\circ$ ) to the north or northeast. It may be argued, however, that post-Tumamoc tuff tilting took place, which renders paleo-slope dip

directions indeterminable. Such tilting is possible, though unlikely because to introduce additional tilting unnecessarily adds to the deformation required to account for the present attitude of the sequence. Rhyolitic volcanic activity, synchronous with the Tumamoc tuff, took place in the Safford Peak area 20.4km northwest of the study area (Fig. 1). Rhyolitic rocks present at Safford Peak have been dated by Bikerman and Damon (1966) yielding potassium-argon ages of  $24.5 \pm 0.9$  m.y. for the Safford Dacite neck and  $27.9 \pm 1.9$  m.y. for the Upper andesite.\* These rocks are described in greater detail by Inswiler (1959) and Eastwood (1970). The lithologic and chronologic similarity of these rocks to the Tumamoc tuff implies a possible source for the latter in the Safford Peak area. The white tuff member (air fall tuff) of the Tumamoc tuff lends no supportive evidence to source direction.

The Tumamoc basaltic andesite had a minimum areal extent of  $2.7\text{km}^2$ . This minimum estimate assumes that the capping basaltic andesite flow(s) at Sentinel Peak is part of the Tumamoc basaltic andesite. None of the older basaltic andesite flows extends across the entire study area. The possibility that the basaltic andesite on top of Sentinel Peak is a rock unit separate from the Tumamoc basaltic andesite cannot be ruled out. Since the Tumamoc basaltic andesite is the best preserved of the basaltic andesite flows, its minimum areal extent is probably a close approximation of the former extent of the earlier basaltic andesite flows. Tolman (1909) suggested that the source of

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\*The Safford Dacite neck and the Upper andesite have been described as rhyolites by Eastwood (1970).

the Tumamoc basaltic andesite was beneath the summit of Tumamoc Hill, citing the reversal of dip toward the center of the hill as evidence. Reference to the geologic map (Fig. 4) reveals that these data are inconclusive. The source was probably local, but its exact placement cannot be determined.

### Tilting

Tilting of strata in the Tumamoc Hill-Sentinel Peak sequence took place after Greasewood andesite emplacement, but prior to Sentinel tuff extrusion. Further tilting of the sequence in order to account for the present attitude of any of the rock units above the Greasewood andesite is not necessary. Modification of a north or northeastward dipping slope through erosion and the "blanketing" effect of extruded volcanic units fully explains the apparent angular relationship between the top and bottom of the sequence. Supportive of this is the progressive decrease in northerly dip of the rock units upward, and the nearly flat lying attitude of the Tumamoc tuff and capping Tumamoc basaltic andesite (Fig. 29). To call upon further tilting would unnecessarily complicate the tectonic history of this area.

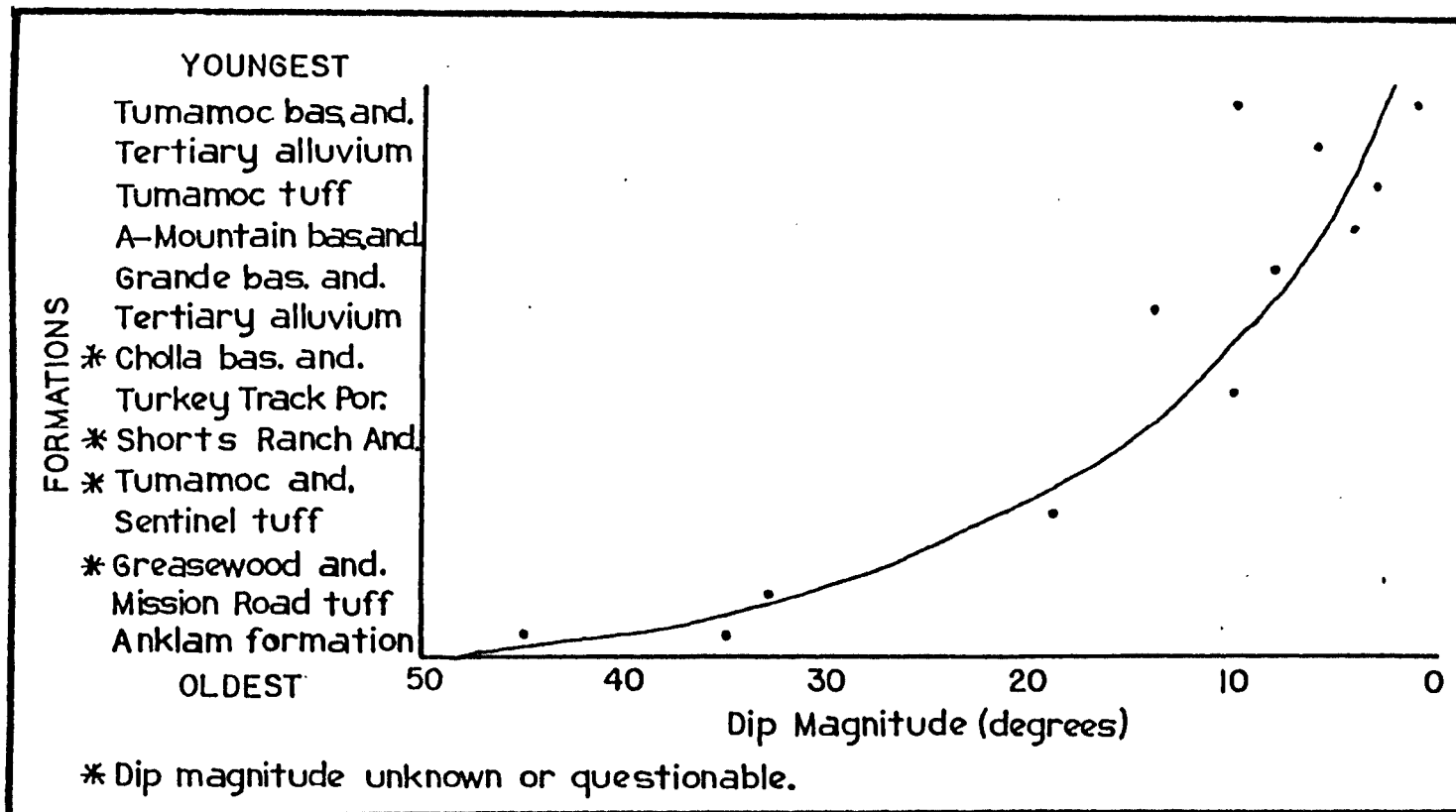


Figure 29. Graph showing the relationship between the ages and dip magnitudes of rock units in the Tumamoc Hill-Sentinel Peak area.

## CONCLUSIONS

### Chronology

Dates yielded by basaltic andesite units in the Tumamoc Hill-Sentinel Peak sequence are ambiguous, relative to one another. The ambiguity can be explained by the close relations of these units in time. In the study area, the Turkey Track Porphyry, the overlying basaltic andesite flows, and the Tumamoc tuff were probably emplaced within a span of five million years. Dates from the similar stratigraphic section in the Del Bac Hills to the south indicate a duration of approximately four million years for the basaltic andesite igneous activity. Referring to the basaltic andesites and the Tumamoc tuff in the Tumamoc Hill-Sentinel Peak sequence, Bikerman and Damon (1966, pp. 1230-31) state, "The differences in actual age of the individual units considered here cannot be determined without a statistically meaningful number of replicate analyses of each unit considered."

### Tectonic Implications

The Tumamoc Hill-Sentinel Peak sequence is the most complete section of Tertiary rocks in the Tucson Mountains. Geologic processes which operated during Late Cretaceous through Early Miocene time in the Tucson Mountains are recorded within this sequence. The general north-eastward dipping homoclinal attitude of the Tucson Mountains was probably derived during the mid-Paleocene tilting event recorded in the

Tumamoc Hill-Sentinel Peak sequence. No other evidence of significant tilting is preserved in this sequence.

The hiatus from 56.8 m.y. b.p. to 28.0 m.y. b.p. (Fig. 5) is synchronous with the interlude between Laramide and mid-Tertiary igneous activity described by Bikerman and Damon (1966). Only erosion is indicated for this time interval by the Tumamoc Hill-Sentinel Peak sequence. This evidence suggests that the period between Laramide and mid-Tertiary, in which relatively little volcanic activity is recorded, was also a period of tectonic quiescence.

Tectonic activity in mid-Tertiary time is recorded in the Tumamoc Hill-Sentinel Peak sequence as Tertiary alluvium. The Tumamoc Hill-Sentinel Peak area "suddenly" became an area of deposition. Clearly a source area was created for the alluvial units. The Anklam formation, Short's Ranch Andesite, the darker andesites, and the Turkey Track Porphyry served as sources. Source directions were to the southeast, south, and southwest. Basaltic andesite volcanism accompanied this tectonism, and was, perhaps, structurally controlled. The outcrop pattern of the Cholla basaltic andesite, elongated along a N55W trend, supports this suggestion (Fig. 4).

Following intrusion of the Tumamoc basaltic andesite, high-angle faulting took place along N15E, E-W, and N80W trends. This faulting probably accompanied Basin and Range block-faulting.

#### Further Work

Potential for further stratigraphic, geochemical, petrologic, and geochronologic work in the Tumamoc Hill-Sentinel Peak area is

great. A type location, measured section, and accurate description of the Anklam formation is necessary. Until such is obtained, use of the term Anklam formation must be considered informal. Clarification of Paleocene andesitic igneous activity should be carried out. The Tumamoc tuff offers opportunities to study in detail, what appears to be an ideal multiple ash flow, simple cooling unit. Because the Tumamoc Hill-Sentinel Peak sequence records geologic events in the Tucson Mountains from Late Cretaceous to at least Early Miocene, and because it is a "type section" for that period in the Tucson area, meaningful petrologic, geochemical, and geochronological studies can now be made of geologic events that took place during that time in the vicinity of Tucson.

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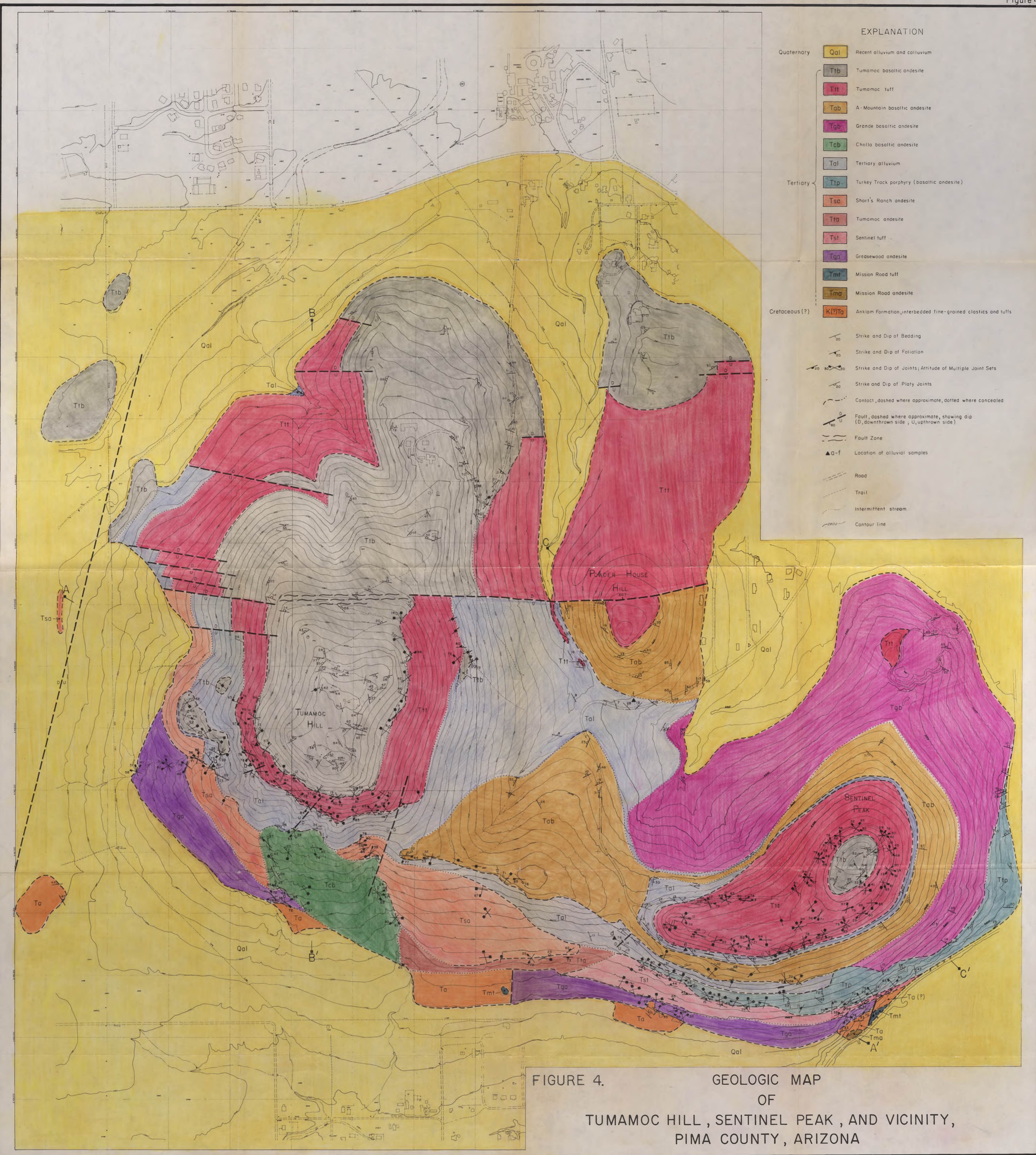
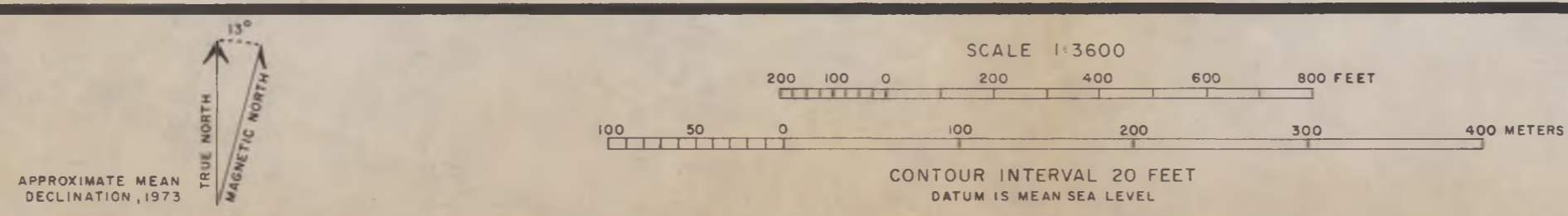


FIGURE 4. GEOLOGIC MAP OF TUMAMOC HILL, SENTINEL PEAK, AND VICINITY, PIMA COUNTY, ARIZONA

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