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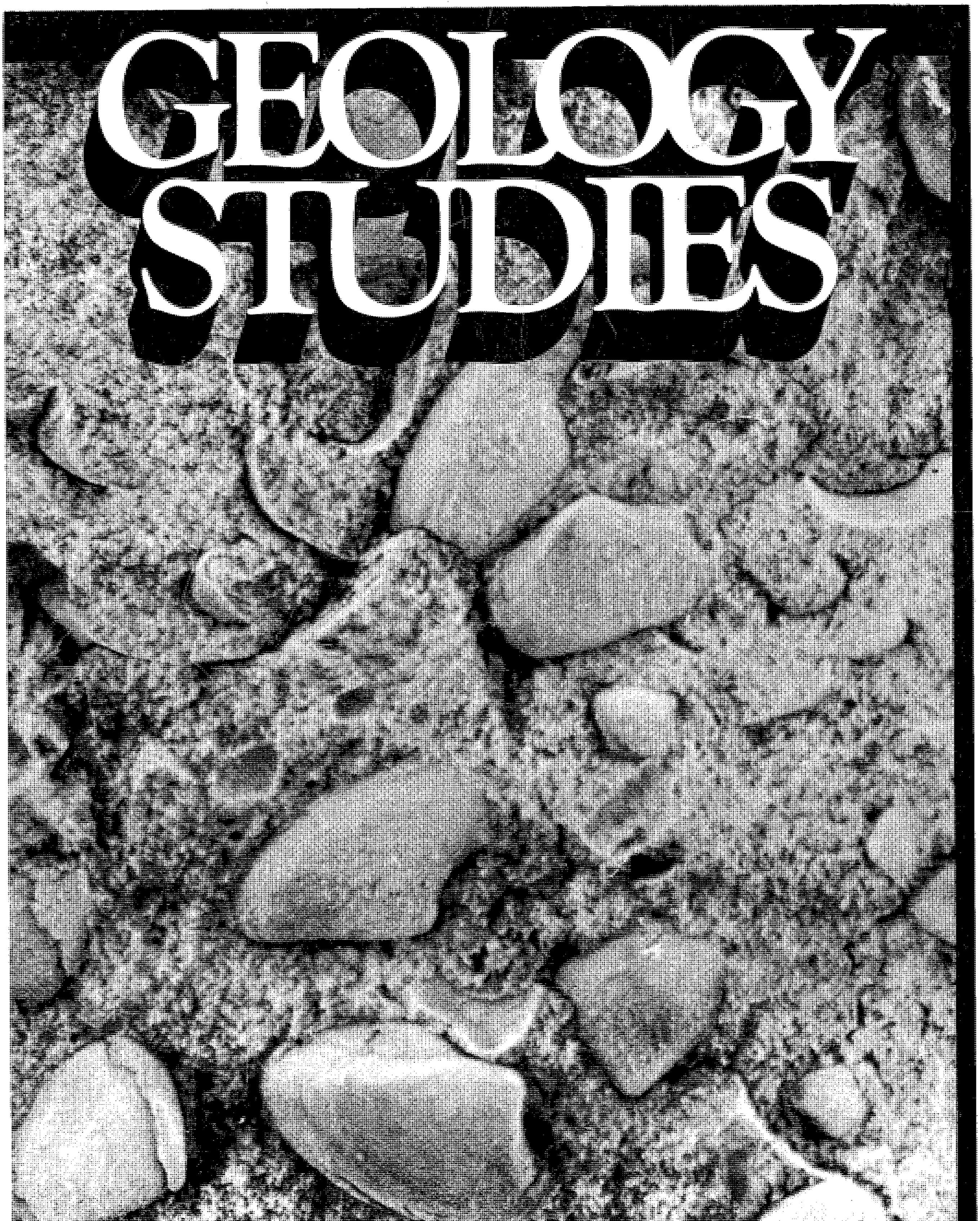

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CONTENTS

Cover: Slab of bivalves showing Myalina-Pleuroma *suite, from Torrey section, Sinbad Limestone Member, Moenkopi Formation in the Teasdale Dome Area, Wayne County, Utah. Photo courtesy James Scott Dean.*

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CONTENTS

Geology of the Antelope Peak Area of the Southern San Francisco Mountains, Beaver County, Utah*

VINCE L. FELT
Amoco Production Company
Amoco Building
Denver, Colorado 80202

ABSTRACT.—Volcanic rocks of Oligocene and Miocene age unconformably overlie Paleozoic and Mesozoic rocks in the Antelope Peak area in the southern San Francisco Mountains in southwestern Utah. Oligocene rocks include the Dacite of Shauntie Hills, the Needles Range Formation, and the Isom Formation. Early Miocene and younger volcanic rocks are collectively referred to as the Formation of Blawn Wash, and include (in ascending stratigraphic order): (1) Tuff Member of Sevey's Well, (2) Quartz Latite Member of Squaw Peak, (3) lower tuff member, (4) sandstone member, (5) upper tuff member, (6) rhyolite flow member, and (7) lava flow member.

The volcanic rocks dip chiefly to the east and southeast, and are cut by three sets of high-angle normal faults: (1) a northeast-trending set, (2) a northwest-trending set, and (3) an east-trending set. At least three episodes of tectonism can be established: (1) late Oligocene to early Miocene (development of the northeast-trending faults as part of a northeast-trending tectonomagmatic belt; (2) mid-Miocene (development of the northwest- and east-trending faults); and (3) post mid-Miocene recurrent movement along existing faults, associated with basin-and-range faulting.

The geologic history of the Antelope Peak area can be divided into three time intervals. From early Tertiary to middle Oligocene, the Antelope Peak area was part of a depositional basin, flooded by lava flows late in the interval. From middle Oligocene to late Oligocene, doming occurred north of the Antelope Peak area, and was accompanied by the deposition of the Needles Range and Isom Formations; the Wallace Peak Tuff Member may be genetically related to the granodiorite stocks of the San Francisco and Beaver Lake Mountains. In early Miocene time a topographic depression appears to have developed in the southern San Francisco Mountains as part of a regional northeast-trending belt of tectonomagmatic activity.

Hydrothermal solutions were introduced into the Antelope Peak area apparently during the Miocene magmatic activity, producing silicification, argillization, and hematitic-limonitic staining.

INTRODUCTION

The complex volcanic stratigraphy and structure of the southern San Francisco Mountains has remained somewhat of a puzzle for many years. Recent volcanic studies and economic mineral discoveries in surrounding areas have now made it desirable to unravel the complex geology of this area.

Lemmon and Morris (1979a,b) mapped the geology of the southern San Francisco Mountains on a scale of 1:48,000 as part of a larger USGS mapping project covering the Frisco and Milford 15-minute Quadrangles. From their work and recent work done in the southern Wah Wah Mountains, it became evident that the southern San Francisco Mountains are part of the same northeast-trending belt of Miocene tectonism and magmatism that cuts through the southern Wah Wah Mountains. This tie with the established volcanic stratigraphy and structure of the southern Wah Wah Mountains offers a foundation from which the geologic framework of the southern San Francisco Mountains can be constructed.

Establishment of the stratigraphy and structure of the southern San Francisco Mountains is desirable from an economic point of view. Several factors indicate the area has economic mineral potential at depth. These factors are (1) large areas of hydrothermal alteration, (2) pervasive structural disturbance, (3) surface uranium mineralization, (4) the occurrence of subeconomic deposits of iron, fluorspar, uranium, kaolinite, and alunite in the northeast-trending tectonomagmatic belt in the southern Wah Wah Mountains, and (5) the virtual surrounding of the southern San Francisco Mountains by mining districts.

This paper is concerned with the geology of the central portion of the southern San Francisco Mountains, informally named the Antelope Peak area. The geology of the southern end of the southern San Francisco Mountains, or the Shauntie Hills, is presently being studied by Dan Haymond (personal communication 1980; article herein). Haymond is also working on the Paleozoic and Mesozoic geology of the entire southern San Francisco Mountains.

Objectives

The primary objective of this thesis is to map and describe the volcanic rocks of the Antelope Peak area. A secondary objective is to interpret the geologic history of the area and show how it relates to the regional geologic framework. A general discussion of hydrothermal alteration is included.

Location

The Antelope Peak area is located 25 km west of Milford, Utah, in the southern San Francisco Mountains (fig. 1). The area covers approximately 98 km² and is located for the most part in the Frisco 15-minute Quadrangle with a small portion on the Milford sheet. Physiographically it is an area of hilly terrain and relatively low relief compared with surrounding mountain ranges. Utah 21 provides access to a network of reasonably good dirt roads that cross the area.

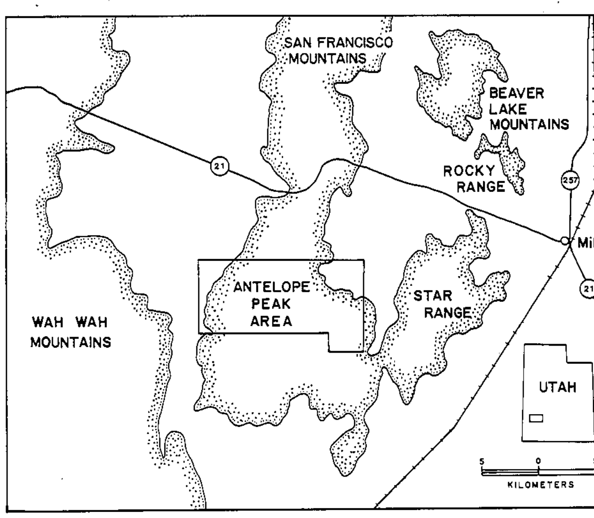

FIGURE 1.—Index map of the Antelope Peak area.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, December 1980. Thesis chairman: J. L. Baer.

Previous Work

An unpublished map of the southern San Francisco Mountains was compiled by Erickson (1961). This map was later used to establish a map of the regional geology of southwestern Utah, compiled by Hintze (1963). A study of alteration zones in the San Francisco Mountains was conducted in the 1960s by Stringham (1963, 1964). John P. Brooke assisted Stringham in these studies and later submitted his findings as a dissertation on the alteration and trace elements in the San Francisco Mountains (Brooke 1964). To date, the most detailed study of the stratigraphy and structure of the southern San Francisco Mountains (available to the public) is included in the U.S. Geological Survey preliminary reports and maps of the Frisco and Milford Quadrangles (Lemmon and Morris 1979a,b).

Geologic studies of areas near the southern San Francisco Mountains include Butler (1913) and East (1966) on the San Francisco Mountains; Baer (1962) on the structure and stratigraphy of the Star Range; Weaver (1980) and Best and others (1973, 1979) on the Paleozoic and volcanic rocks of the southern and central Wah Wah Mountains. Wheeler (1980) recently mapped the Paleozoic rocks of the central Wah Wah Mountains.

Geologic Setting

With the exception of the Paleozoic carbonate rocks underlying White Mountain and Long Lick Mountain, much of the southern San Francisco Mountains consists of exposures of silicic and intermediate volcanic rocks locally obscured by patches of alluvium and hydrothermal alteration. The volcanic rocks are Oligocene and Miocene in age, dip to the east, and lie within the San Francisco Mountain basin-and-range fault block. The southern San Francisco Mountains are flanked to the north and east by Miocene and Oligocene stocks of silicic and intermediate composition.

A northeast-trending tectonomagmatic belt of Miocene age extends through the southern Wah Wah and southern San Francisco Mountains. This belt is characterized by northeast-striking faults, locally derived mafic to rhyolitic volcanic rocks, and hydrothermal alteration and mineralization. It lies within the more extensive east-northeast-trending Pioche–Wah Wah–Tushar mineral belt, characterized by northeast- to east-northeast-striking faults and significant anomalies of gold, silver, lead, zinc, tungsten, uranium, fluorine, manganese, copper, and alunite (Shaw and Stewart 1976).

The southern San Francisco Mountains are part of the Basin and Range Province and lie near its border with the Colorado Plateau Province.

Acknowledgments

Special thanks are offered to my parents for their many years of moral and financial support, particularly to my father, Lowell J. Felt, who taught me how to "grab the bull by the horns."

I am grateful to Robert C. Berry of Exxon Minerals Co. USA for arranging financial support and for his helpful suggestions in the field.

Many thanks to Drs. James L. Baer, Myron G. Best, and Kenneth C. Bullock for their suggestions and critiques of this thesis.

I would like to express my love and appreciation to my wife Alyson for her many hours of typing and moral support.

STRATIGRAPHY

General Statement

Paleozoic and Mesozoic sedimentary rocks of the Antelope Peak area are unconformably overlain by volcanic rocks of Oligocene and Miocene age. Oligocene rocks include the Dacite of Shauntie Hills, the Needles Range Formation, and the Isom Formation. Early Miocene and younger volcanic rocks comprise the Formation of Blawn Wash (fig. 2). The thickness of these units was not measured because of poor exposures; therefore, only approximate thicknesses are given in the descriptions. For a description of the pre-Tertiary rocks refer to Lemmon and Morris (1979a,b).

Dacite of Shauntie Hills

The Dacite of Shauntie Hills embodies several compositionally and texturally similar dacitic lava flows. The base of this unit is not well exposed, but poor outcrops suggest the presence of a basal autoclastic breccia.

Unaltered rocks are dark brown to gray and generally porphyritic. They exhibit a weak flow-foliation expressed by subparallel orientation of plagioclase laths. Flow-foliation facilitates breakage into slabs upon weathering. Altered rocks are greenish-gray and generally weather to slopes in contrast to the more resistant ledge outcrops of unaltered rock. Phenocrysts are 1–2 mm in diameter and include 15–20 percent plagioclase, 3–5 percent green pyroxene, and trace amounts of hornblende and Fe-Ti oxides.

The most common alteration product is greenish-blue celadonite, first recognized in the southern San Francisco Mountains by Brooke (1964). In the Antelope Peak area celadonite has the appearance of azurite-malachite mineralization. Propylitic, zeolitic, and silicic alteration are also common.

Lemmon and Morris (1979a,b) first described and named the Dacite of Shauntie Hills and suggested that it is equivalent to the Horn Silver Andesite of Stringham (1967). I agree with this correlation and further suggest that this unit may correlate with the Escalante Desert Formation as described by Weaver (1980) from the southern Wah Wah Mountains. This correlation is strengthened by the occurrence of small outcrops of tuff within the Dacite of Shauntie Hills unit that are similar to the Lamerdorf Tuff Member of the Escalante Desert Formation (Campbell 1979).

The thickness of the Dacite of Shauntie Hills is estimated to exceed 375 m and locally may be as thick as 900 m; the age is unknown.

Needles Range Formation

The Needles Range Formation is a sequence of crystal-rich, moderately welded, dacitic ash-flow tuffs. Although regionally extensive over most of southwest Utah and adjacent eastern Nevada, these tuffs are exposed only in the southern part of the Antelope Peak area and appear to pinch out to the north. Best and others (1973) have subdivided this formation into four members, listed here in ascending stratigraphic order: (1) Cottonwood Wash Tuff Member, (2) Wah Wah Springs Tuff Member, (3) Lund Tuff Member, and (4) Wallaces Peak Tuff Member. All but the Cottonwood Wash Tuff are exposed in the Antelope Peak area; however, in some localities the formation was not subdivided because contacts are obscured by alteration and complex faulting. Argillic and silicic alteration, accompanied by hematite staining, have locally affected much of the Needles Range Formation. Silicified rocks weather in ragged relief compared to argillized rocks. The Needles Range Formation is about 29 m.y. old (Fleck and others 1975) and ranges from 0 to 300 m thick.

Wah Wah Springs Tuff Member

The presence of obvious hornblende phenocrysts, 2–3 mm in diameter, and the small size of sparse quartz phenocrysts distinguish the Wah Wah Springs Tuff Member from the overlying members. Where relatively unaltered, the unit is light gray, but the hornblendes are usually completely to partially chloritized. Most phenocrysts are of plagioclase; biotite is minor.

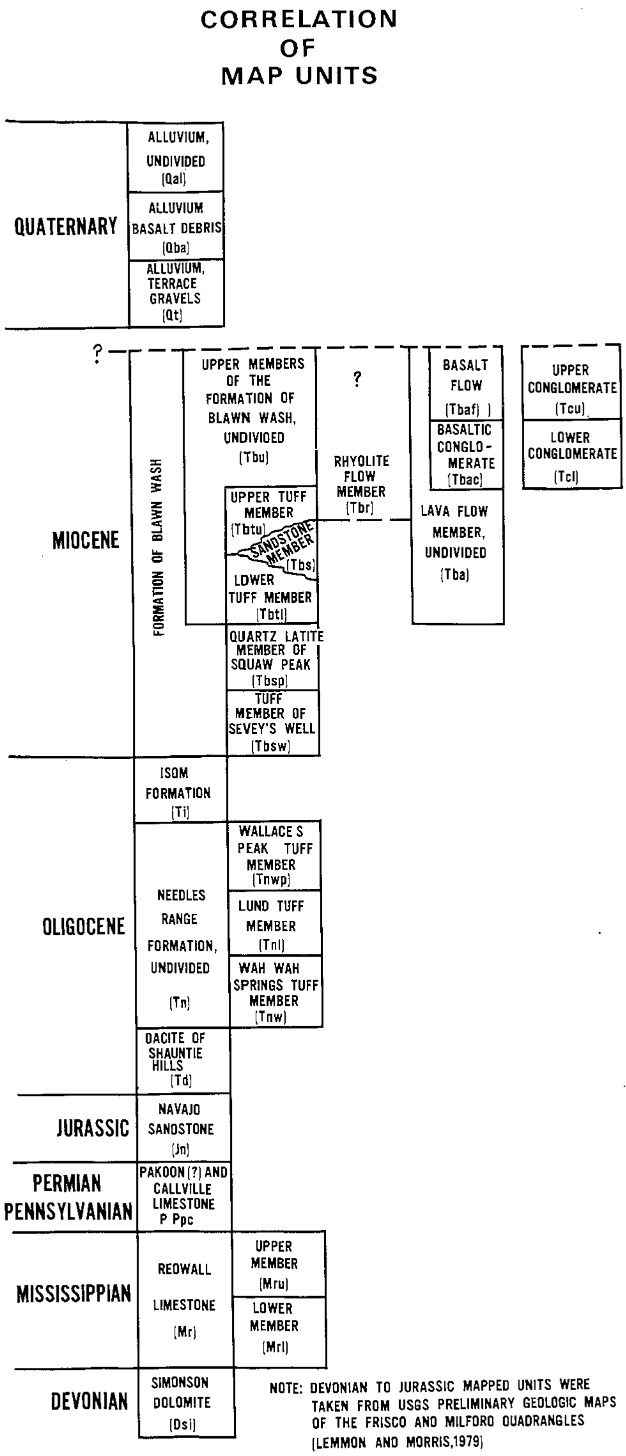

FIGURE 2.—Correlation of map units.

Lund Tuff Member

The Lund Tuff Member has a relatively large proportion of quartz phenocrysts 2–4 mm in diameter in addition to the dominant plagioclase and lesser biotite.

Wallaces Peak Tuff Member

Flattened white pumice lapilli, dark-colored lithic clasts, and large (3–4 mm) white blocky plagioclase phenocrysts characterize the Wallaces Peak Tuff Member.

The presence of lithic clasts (2–5 cm in diameter) in the southern San Francisco Mountains, but not elsewhere, suggests a local source. Unaltered outcrops are light gray to light brown and consist of less than 3 percent lithic clasts, 20–30 percent plagioclase, 1 percent quartz, and 2–3 percent biotite.

Isom Formation

The Isom Formation is an excellent stratigraphic marker, recognized by its thin, welded nature and persistent outcrops. Like the underlying Needles Range Formation, this unit is regionally extensive over much of southwest Utah, but crops out only in the southern part of the Antelope Peak area and appears to pinch out northward. Unaltered outcrops are red brown whereas altered outcrops are yellow brown. The unit is crystal poor, consisting of sparse plagioclase phenocrysts and thin blades of flattened pumice lapilli, 5 mm to 5 cm in length. These lapilli are now recrystallized to quartz. The extremely fine-grained matrix is stained with hematite. This unit gives anomalously high scintillometer readings (350–700 counts per second against a background of 150 counts per second).

A K-Ar age of about 25 m.y. has been assigned to the Isom Formation by Fleck and others (1975). The Isom Formation has a rather consistent thickness of 50 m throughout the Antelope Peak area.

Formation of Blawn Wash

The Formation of Blawn Wash includes several locally derived silicic and intermediate flows of Miocene age. This sequence is well exposed in Blawn Wash in the Wah Wah Mountains (Best and Keith 1979). The southern limit of this formation roughly follows a northeast tectonic trend that cuts through the southern Wah Wah Mountains and the southern San Francisco Mountains. Within the southern San Francisco Mountains, the Formation of Blawn Wash is mostly confined to the area north of White Mountain and Long Lick Mountain.

Informal members of the formation in the Antelope Peak area are, in ascending stratigraphic order: (1) Tuff Member of Sevey's Well, (2) Quartz Latite Member of Squaw Peak, (3) lower tuff member, (4) sandstone member, (5) upper tuff member, (6) rhyolite flow member, and (7) lava flow member. All members above the Quartz Latite Member of Squaw Peak are interlayered with the lava flow member, and are informally referred to in this paper as the upper members of the Formation of Blawn Wash. Figure 2 illustrates the intercalated and overlapping relationships of these upper members.

Tuff Member of Sevey's Well

Essentially an accumulation of crystal-poor rhyolitic tuffs, the Tuff Member of Sevey's Well varies in composition, texture, color, and mode of emplacement. Ash-flow tuffs comprise most of the unit and occur predominately at the base, but interfinger with air-fall tuffs near the top. This heterogeneity, combined with stratigraphic position, permits recognition of the unit. Most of the tuffs have experienced argillic and/or silicic alteration and are then generally white to pink, forming slopes of clay and grus. Relatively unaltered tuffs are light brown to gray and weather spheroidally (fig. 3).

Proportions of phenocrysts, lithic fragments, and pumice lapilli vary considerably in hand samples. Generally broken phenocrysts consist of quartz, biotite, sanidine, and traces of plagioclase, altogether comprising 1-3 percent of the rock. Large clasts of the Isom Formation (24 cm in diameter) are incorporated in the basal ash-flow tuffs. The thickness ranges widely, exceeding 150 m in places.

Quartz Latite Member of Squaw Peak

The Quartz Latite Member of Squaw Peak appears to be areally restricted to the southern San Francisco Mountains in the area immediately north of White Mountain and Long Lick Mountain. It is comprised of several gray to red brown, porphyritic andesite-latite lava flows interbedded with autoclastic breccias. Clasts from these breccias average 3–15 cm in diameter, with some as large as 2 m. These autoclastic subunits suggest a local source for the Quartz Latite Member of Squaw Peak.

Most of the topographic relief in the Antelope Peak area is attributed to variations in the thickness of this unit and its varying resistance to weathering. Outcrops weather spheroidally and exhibit a popcorn texture surface (fig. 4).

Phenocrysts include zoned plagioclase (10–25 percent), 2–10 mm in diameter, commonly occurring in clots 0.5 to 15 mm in diameter (fig. 5). The remaining phenocrysts are 1–2 mm in diameter and include 1–2 percent biotite, and 1–2 percent Fe-Ti oxides. Thin sections reveal traces of sanidine, hornblende, and clinopyroxene. The groundmass consists of a felted matrix of plagioclase microlites. All the phenocrysts are subhedral, showing embayments and broken forms.

Lemmon and Morris (1979b) informally named this unit from exposures near Squaw Peak in section 35, T. 27 S, R. 13 W. I did not observe quartz in hand samples or thin sections from the Antelope Peak area, but, because I did observe quartz in exposures of the unit in other areas of the San Francisco Mountains, the original name was retained. Because of its age and position in the stratigraphic record, this unit has been placed as a member of the Formation of Blawn Wash.

Biotite from exposures of the Quartz Latite Member of Squaw Peak in the south central part of section 19, T. 27 S, R. 12 W, gives a K-Ar age of about 22.4 m.y. (Lemmon and others 1973, p. 23). The thickness of this unit ranges considerably and is estimated to exceed 500 m locally.

Lower Tuff Member

The lower tuff member is thin (0–70 m) and exposed only at the east and west ends of the Antelope Peak area. It is thickest in the southern part of the area and pinches out to the north. Unaltered rock is light gray and weathers to resistant ledges. Altered rock is light brown. Subparallel orientation of sanidine and biotite phenocrysts in a moderately welded matrix produces a subtle flow foliation. Phenocrysts are unbroken, 1–2 mm in diameter; they consist of 5 percent sanidine, 2 percent biotite, and a trace of quartz.

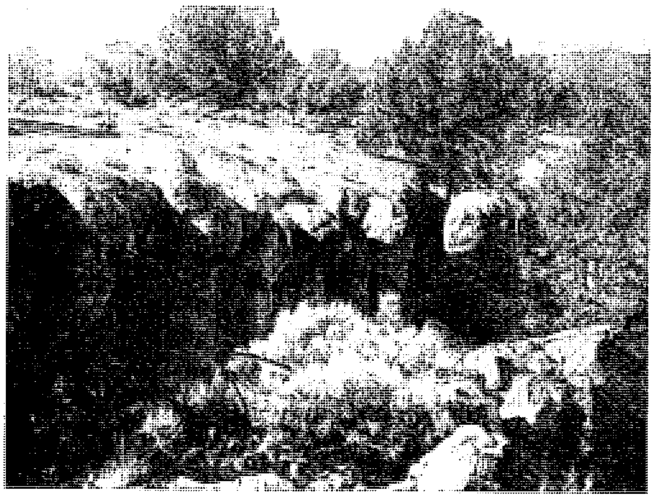

FIGURE 3.–Tuff Member of Sevey's Well overlying the Isom Formation, NE ¼, section 33, T. 28 S, R. 13 W.

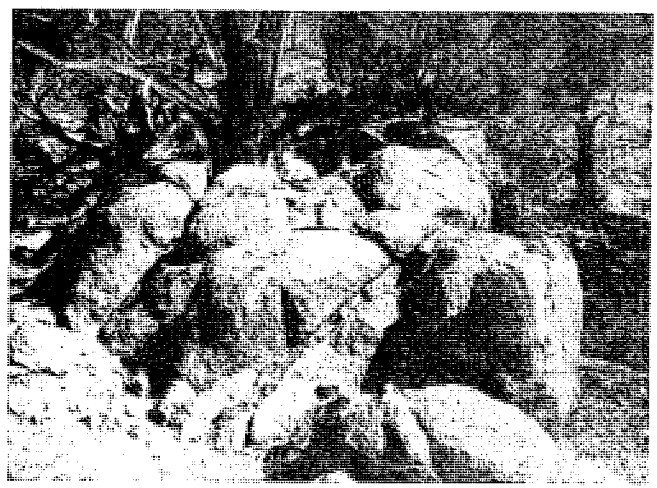

FIGURE 4.–Quartz Latite Member of Squaw Peak, showing typical spheroidal weathering and popcorn texture, SW ¼, section 28, T. 28 S, R. 13 W.

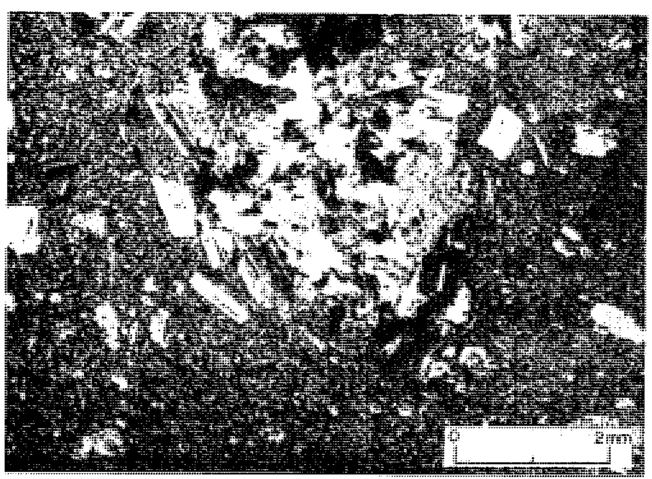

FIGURE 5.–Photomicrograph (crossed nicols) of the Quartz Latite Member of Squaw Peak.

Sandstone Member

A very local unit exposed only in the NW¼ of section 30, T. 28 S, R. 13 W, where it appears to have been deposited in a paleochannel, possibly against a fault scarp, the sandstone member is a reddish gray, fine-grained, thin-bedded, and well-indurated quartzite. Its hardness is probably due to silicification associated with the intrusion of rhyolitic dikes into the unit. The thickest section of this unit is estimated to be 100 m.

Upper Tuff Member

A white, lithic, vitric ash-flow tuff exposed chiefly in the southern part of the Antelope Peak area, the upper tuff member appears to pinch out northward. Outcrops of this unit form ledges and slopes covered with grus. Clasts of flow-layered rhyolite incorporated in this ash-flow tuff suggest deposition after or during the deposition of the rhyolite flow member. However, stratigraphic relationships in section 36, T. 28 S, R. 14 W, indicate this ash-flow tuff was deposited before the rhyolite flow member. This contradiction suggests one of two situations: deposition of the two units was contemporaneous, or there exists a pre-upper tuff rhyolite flow not exposed in the Antelope Peak area.

In thin section, phenocrysts are moderately broken, measure 1–3 mm in diameter, and include 7–10 percent sanidine, 2 percent biotite, less than 2 percent quartz, traces of subhedral zoned plagioclase, and traces of Fe-Ti oxides less than 1 mm in diameter. Angular clasts of flow-layered rhyolite 1–5 cm in diameter comprise 2–3 percent of the tuff. The remainder of the rock is pumice lapilli and ash.

The thickness of the unit within the Antelope Peak area ranges from 100 m in the east to more than 400 m in the west.

Rhyolite Flow Member

In addition to flow-layered rhyolite, the rhyolite flow member includes autoclastic breccias and green brown perlite. In general, the unit is light brown to dark red brown, flow-layered, porphyritic, and, in most cases, silicified. It comprises such structures as domes, dikes, and plugs located chiefly in the north and southwest parts of the Antelope Peak area. Most of the outcrops are expressed as steep hills covered with talus. Phenocrysts are 1–2 mm in diameter and include 1–2 percent sanidine, 1 percent quartz, 1–2 percent biotite, and a trace of plagioclase. Lithophysae are abundant and commonly lined with quartz.

Lemmon and Morris (1979a) first described this unit in the Antelope Peak area and informally named it the flow member of the rhyolite of Willow Creek area. It now seems preferable to place the unit as a member of the formation with Blawn Wash because of its compositional, textural, and genetic similarity to rhyolite flows of the Formation of Blawn Wash mapped in the Wah Wah Mountains.

The age of this unit is unknown, but intrusive rhyolite near the Staats Mine in the Wah Wah Mountains yields a K-Ar age of 19.7 ± 0.8 m.y. (Rowley and others 1978).

Lava Flow Member

The lava flow member includes several lava flows of intermediate composition deposited after the Quartz Latite Member of Squaw Peak and contemporaneously with the upper members of the Formation of Blawn Wash. A local origin is consistent with the distribution and intercalated relationship to other units, and with the existence of a mafic dike in section 15, T. 28 S, R. 13 W.

In hand sample, it is virtually impossible to distinguish between this unit and the Dacite of Shauntie Hills. The lava flow member is slightly porphyritic with phenocrysts 1–3 mm in diameter of green pyroxene (0–10 percent), a trace of plagioclase, a trace of hornblende altered to Fe-Ti oxides, and small proportions of what appears in hand sample to be "quartz." In thin section this "quartz" was determined to be xenocrysts of subhedral sanidine and plagioclase, enclosed in reaction rims (fig. 6). The groundmass consists of a felted matrix of plagioclase microlites and displays pervasive hematite staining and calcite overgrowths on the microlites. Amygdules are common in this unit and are filled with chalcedony, calcite, opal, or zeolites. The proportions of pyroxene varies considerably among the flows. Most of the rocks in outcrop display red liesegang banding, which seems to be a characteristic feature of the unit in this area and of exposures of an apparently equivalent unit the Wah Wah Mountains (M. G. Best personal communication 1980). Unbanded rocks are gray and weather to grus.

There are two units in the Antelope Peak area, different in texture but very similar in composition and stratigraphic position relative to the lava flow member. Lemmon and Morris (1979a) refer to them as the basalt of Brimstone Reservoir and suggest they might be Pliocene in age. Because the age is uncertain, I have decided to place these two units as informal subunits of the lava flow member on the basis of similarities in composition and stratigraphic position.

Basaltic Conglomerate. An unconsolidated deposit of cobbles and boulders of basalt and older rock, including Paleozoic sedimentary rocks, the basaltic conglomerate occurs primarily in the middle of the Antelope Peak area. The total thickness of this unit is unknown, but probably exceeds 70 m.

Basalt Flow. In outcrop the rock of the basalt flow is black to gray, fine grained, and vesicular. No phenocrysts were observed in hand sample, but a thin section of this rock reveals traces of olivine, hornblende, and pyroxene in a felted matrix of plagioclase microlites (fig. 7). The thickness of this unit in the Antelope Peak area probably exceeds 70 m.

This flow is similar in texture and stratigraphic position to the aphyric member of the Formation of Brimstone Reservoir (Morris, Best, and Abbot 1980). Both flows are gray to black and nonporphyritic with microcrystalline matrix. Partial chemical analysis of four samples of the aphyric member indicates 3.5–3.8 percent K_2O. Chemical analysis of the basalt flow indicates 2.5 percent K_2O.

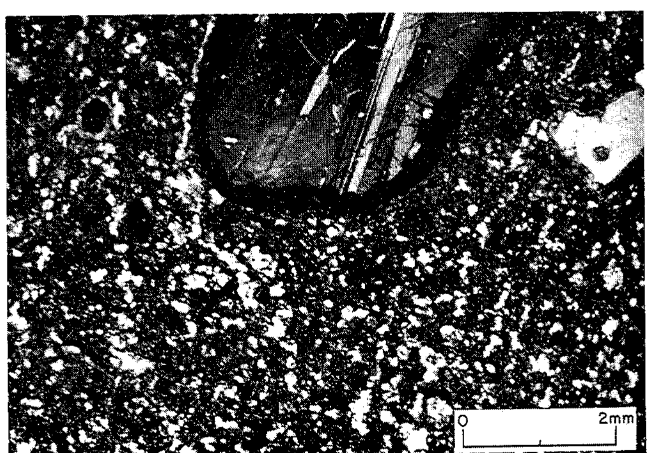

FIGURE 6.—Photomicrograph (crossed nicols) showing xenocrysts of subhedral plagioclase enclosed in a reaction rim in the lava flow member, Formation of Blawn Wash.

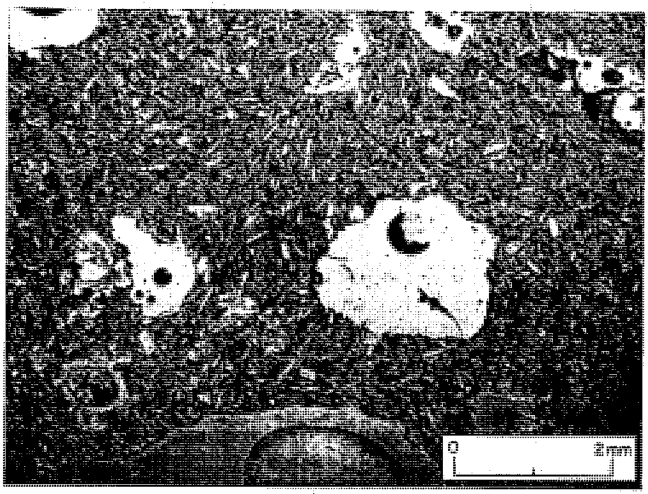

FIGURE 7.–Photomicrograph (crossed nicols) showing felted matrix of plagioclase microlites in the basalt flow unit of the lava flow member of the Formation of Blawn Wash.

Lower Conglomerate

A deposit of interbedded volcanic sandstone, gritstone, and conglomerate exposed only in the southern part of the Antelope Peak area, in outcrop the lower conglomerate is light brown to orange pink and weathers to slopes covered with alluvium. Some water-laid tuffs and mudflows also occur within this unit.

Sandstone beds are fine to medium grained, friable, and composed essentially of quartz and feldspar. Gritstones and conglomerates are also friable, generally consisting of subangular clasts (2 mm–3 cm in diameter) derived from the Quartz Latite Member of Squaw Peak.

This unit overlies the upper tuff member of the Formation of Blawn Wash in the SW¼, section 27, T. 28 S, R. 13 W, and because of its 40° dip, it must be older than the last tectonic event. Maximum thickness is estimated to be 170 m.

Upper Conglomerate

Capping the lower conglomerate unit in the northern part of section 36, T. 28 S, R. 13 W is a semiconsolidated deposit of cobbles and boulders derived chiefly from the Quartz Latite Member of Squaw Peak. The exact character of this upper conglomerate is masked by a mantle of soil, cobbles, and boulders weathered from the unit itself. Its thickness probably exceeds 70 m.

Alluvium

Included under the heading of alluvium are unconsolidated deposits of valley and basin fill, stream sediments, pediment gravels, and colluvium occurring in the Antelope Peak area.

STRUCTURE

General Statement

The volcanic rocks in the Antelope Peak area dip chiefly to the east and southeast and are cut by three sets of high-angle, normal faults: (1) a northeast-trending set, (2) a northwest-trending set, and (3) an east-trending set (fig. 8). The northeast-trending faults dominate the structure of the entire Antelope Peak area whereas the east-trending faults occur only in the eastern portion of the Antelope Peak area, and the northwest-trending faults are essentially restricted to the western portion. Displacement along the majority of the faults can be described only qualitatively because of the uncertain thicknesses of the volcanic rock units. This uncertainty is also the reason for the absence of a cross section through the area.

Northeast-Trending Faults

Faults and joints of this system range in strike from N 40 E to N 70 E. A major drainage lineament, striking N 50 E, cuts through the entire southern San Francisco Mountains. This lineament enters the Antelope Peak area in the SE¼, of section 32, T. 28 S, R. 13 W and leaves in the NW¼, of section 18, T. 28 S, R. 12 W, where it is expressed by the Big Wash to the northeast. Northeast-trending drainage lineaments follow all of the major northeast-trending faults in the Antelope Peak area. Alluvium in these drainage lineaments covers extensive areas and thus creates some uncertainty about the structure and stratigraphy.

Four major northeast-trending fault zones divide the Antelope Peak area into roughly four northeast-trending fault blocks in which most of the volcanic rocks dip to the east and southeast. The concealed northeast-trending fault on the west side of the area is undoubtedly part of the basin-and-range fault zone bordering the entire west side of the San Francisco Mountains. Wheeler (1980) suggests this fault or one(s) buried in the Wah Wah valley to the west is (are) downward-flattening listric fault(s) (Stewart 1978) that have rotated the Wah Wah Mountain fault block to the east. If this is true, the four major northeast-trending fault zones in the Antelope Peak area could be subordinate listric faults, along which the four fault blocks in the area have rotated to the east in like manner to the Wah Wah Mountain fault block (fig. 9). Movement along these faults was substantial enough to displace Miocene age rocks against Oligocene rocks (plate 1).

Northwest-Trending Faults

Northwest-trending faults strike N 50 W to N 80 W and occur predominately in the west part of the Antelope Peak area. These faults appear to cut the northeast-trending fault zone west of Antelope Peak, but the alluvial cover over the intersections creates some doubt.

The most significant northwest-trending fault is the Grover Wash Fault in the southwest corner of the area. This fault is somewhat arcuate, and displacement along its length is considerable; Miocene and Oligocene age rocks are downfaulted to the northeast against Oligocene and Paleozoic rocks to the southwest.

The Grover Wash Fault also forms the southwest boundary of the Grover Wash graben, involving the northwest-trending faults to the north. The center of the graben is defined by thick deposits of upper members of the Formation of Blawn Wash. These units thicken in the graben, pinch out to the northeast, and are interbedded with thick accumulations of clastic material. A similar situation exists in sections 5 and 6, T. 29 S, R. 12 W, where these same stratigraphic units thicken to the south, pinch out to the north, and lie in angular unconformity over the lower members of the Formation of Blawn Wash.

East-Trending Faults

The east-trending fault system occurs in the east and southeast part of the Antelope Peak area. Faults of this system near Woodhouse Spring definitely cut northeast-trending faults, but the displacement is comparatively small. Substantial dis-

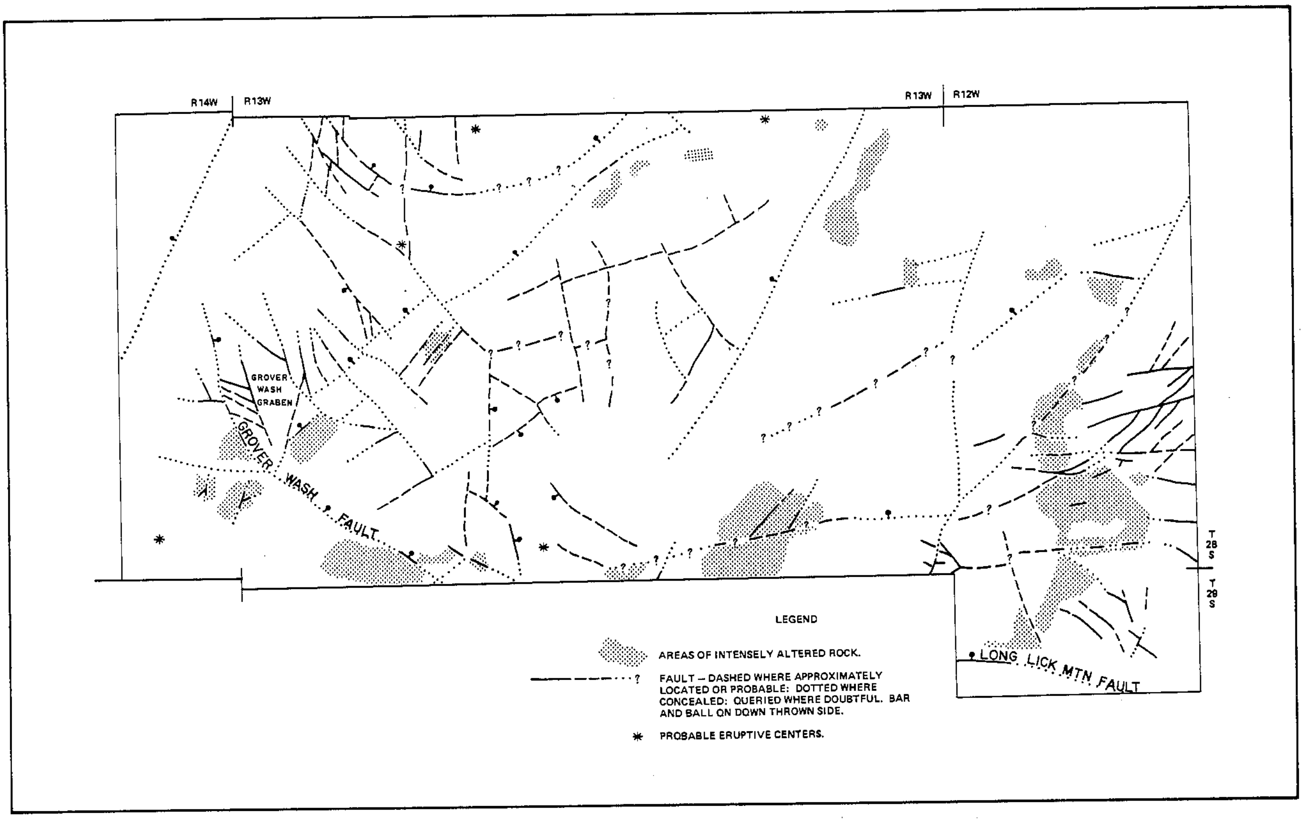

FIGURE 8.–Map of fault patterns and intensely altered rocks in the Antelope Peak area.

placement, however, occurs along the eastward-trending Long Lick Mountain Fault located in sections 5 and 6, T. 29 S, R. 12 W, and which apparently continues to the east. Here Oligocene and Miocene age rocks are downfaulted to the north against Paleozoic and Oligocene age rocks to the south. It is interesting to note that this same magnitude of displacement occurs along the Grover Wash Fault (plate 1).

Eruptive Centers

Several rhyolitic eruptive centers are thought to exist in the area. One located just east of Antelope Springs is defined by a body of flow-layered rhyolite, apparently downfaulted into a circular collapse structure defined by arcuate faults. Another eruptive center exists to the east and appears to be flanked by ring dikes in sections 22 and 13.

Age of Faulting

At least three episodes of tectonism, associated with the fault systems, can be established in the Antelope Peak area: (1) Oligocene to early Miocene (northeast-trending fault system), (2) mid-Miocene (northwest- and east-trending fault system), and (3) post-mid-Miocene (recurrent movement along all of the fault systems).

Oligocene to Early Miocene Faulting

An Oligocene to early Miocene period of faulting is suggested by the fact that the northwest- and east-trending fault systems appear to cut northeast-trending faults, with few exceptions. Although there is little evidence to support it, I suggest that the northeast fault system originated with the initial development of the northeast-trending tectonomagmatic belt.

Mid-Miocene Faulting

Several unconformities in the Antelope Peak area indicate a period of tectonism during mid-Miocene time. It has been suggested that movement along the Grover Wash Fault created the Grover Wash graben into which thick deposits of the upper members of the Formation of Blawn Wash were deposited. A similar situation may hold true for the Long Lick Mountain Fault. Angular unconformities between the Quartz Latite Member of Squaw Peak and the upper members of the Formation of Blawn Wash (section 5, T. 29 S, R. 12 W, and section

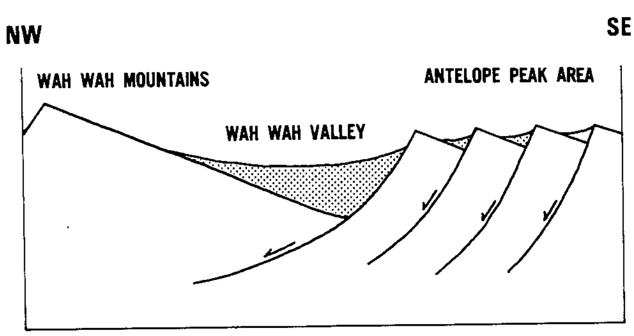

FIGURE 9.–Diagrammatic cross section illustrating the concept of northeast-striking subordinate listric faults in the Antelope Peak area in relationship to the suggested major listric fault that rotated the Wah Wah Mountain fault block.

32, T. 28 S, R. 12 W), document this period of mid-Miocene tectonism. Probably the northwest- and east-trending fault systems were active and may have originated during a mid-Miocene period of tectonism. It is also likely that this tectonism is associated with the northeast-trending tectonomagmatic belt.

Post-Mid-Miocene Basin-and-Range Faulting

The youngest tectonic event is post-mid-Miocene in age, on the basis of the obvious fact that movement along most of the faults postdates even the youngest volcanic rocks. This event undoubtedly falls in the time domain of basin-and-range tectonism.

Summary

It appears that the northeast-trending fault system is associated with the oldest period of tectonism in the Antelope Peak area. This tectonic episode was followed or may have been continued in mid-Miocene time by another period of tectonism in which the northwest- and east-trending fault systems developed. All three fault systems are thought to have originated with the development of the northeast-trending tectonomagmatic belt. A post-mid-Miocene period of tectonism (basin and range) caused significant recurrent movement along all of the fault systems. Recurrent movement along the northeast-trending faults, which may have developed into subordinate listric faults, is chiefly responsible for the east- to southeast-dipping altitude of most of the volcanic rocks in the area. This movement in turn caused recurrent movement along the Grover Wash–Long Lick Mountain Faults and other northwest- and east-trending faults. This period of repeated movement accounts for much of the confusing structure seen in the Antelope Peak area.

GEOLOGIC HISTORY

The geologic history of the Antelope Peak area can be divided into three time intervals. The first period was from early Tertiary to middle Oligocene, during which time the Antelope Peak area was part of a depositional basin later flooded by lava flows. During the second period, from middle Oligocene to late Oligocene, emplacement of granodiorite stocks and consequent doming occurred to the north of the Antelope Peak area. This activity was accompanied by the deposition of the Needles Range and Isom Formations. During the third period of time from early Miocene to Recent time, a depression formed as part of a regional northeast-trending belt of tectonomagmatic activity. Following the development of the depression, basin-and-range faulting reactivated many of the faults associated with the Miocene tectonomagmatic belt.

Early Tertiary to Middle Oligocene

During early Tertiary time the Antelope Peak area appears to have been part of a depositional basin, which was bounded to the south by an east-trending highland of Paleozoic carbonate rock. The highland apparently had sufficient relief that it escaped complete burial by Oligocene and Miocene volcanic rocks and now exists as White Mountain and Long Lick Mountain (fig. 10).

Schmoker (1972, p. 7) interprets a gravity low centered over the Antelope Peak area (fig. 11) as representing "either an area where the lower density volcanic rocks thicken considerably or a small down-faulted area which filled with alluvium prior to being covered by volcanics." My observations indicate the gravity low is due to a combination of both of Schmoker's ideas. The idea of thick accumulations of lower-density volcanic rocks will be discussed later in the paper. Schmoker's second idea of "a small down-faulted area which filled with alluvium prior to being covered by volcanics" agrees with the depositional model suggested for the early Tertiary to middle Oligocene. Schmoker's concept of downfaulting in the Antelope Peak area is supported by the fact that Paleozoic and Mesozoic rocks of the Star Range and Wah Wah Mountains are cut by pre-Oligocene, east-trending faults (Baer 1960; Wheeler 1980). It is conceivable that this east-trending fault system was responsible for downfaulting in the Antelope Peak area and the consequent development of the basin and the east-trending White–Long Lick Mountain trend. Alluvium was then deposited in the basin and later covered by the Dacite of Shauntie Hills and the equivalent Horn Silver Andesite. A similar east-trending early Tertiary depositional basin in the northern Needle Range was proposed by Campbell (1978).

Middle Oligocene to Late Oligocene

Following the extrusion of the pre-Needles Range lava flows, the San Francisco and Beaver Lake Mountains were locally intruded by granodiorite stocks. About this same time the Needles Range Formation was deposited in the southern San Francisco Mountains and throughout southwest Utah and eastern Nevada.

The Needles Range Formation appears to pinch out northward; however, it is not apparent from surface outcrops whether this pinchout is erosional or depositional. In either case the pinchout suggests that positive relief existed north of the Antelope Peak area during or after the extrusion of the pre-Needles Range lava flows. This relief could be interpreted as surface doming caused by the intrusion of one or more stocks. The existence of a magnetic high in the northern part of the Antelope Peak area could represent a shallow intrusion which may have generated surface doming. Butler (1913) and East (1965) both suggest doming was associated with the intrusion of stocks in the San Francisco and Beaver Lake Mountains during late Oligocene time.

Temporal and spatial relationships suggest the possibility that the granodiorite stocks of the San Francisco and Beaver Lake Mountains may be genetically related to the dacitic flows of the Wallaces Peak Tuff. Lemmon, Silberman, and Kistler (1973) have dated both of these stocks; biotite from the Cactus stock (San Francisco Mountains) yielded a K-Ar age of 28.0 $\pm$ 0.5 m.y., and hornblende from the Beaver Lake Mountains stock yielded a K-Ar age of 28.4 $\pm$ 0.5 m.y. These ages compare favorably with the K-Ar age of 28.9 m.y. for the oldest member of the Needles Range Formation by Fleck and others (1975). The age of the Wallaces Peak Tuff is therefore fixed somewhere between 28.9 m.y. and 25 m.y. (Isom Formation).

The distribution of the Wallaces Peak Tuff is limited to the southern San Francisco and Wah Wah Mountains (M. G. Best unpublished map of the Wah Wah Mountains 1980). A local source for the Wallaces Peak Tuff is supported by the occurrence of lithic clasts (some as large as 15 cm in diameter) in exposures of the tuff in the southern San Francisco Mountains, in contrast to the total absence of lithic clasts in exposures of the tuff in the Wah Wah Mountains (Best and others 1973).

Early Miocene to Recent

During Miocene time the Antelope Peak area lay within a northeast-trending belt of tectonomagmatic activity that extended through the southern Wah Wah and southern San Francisco Mountains. Although the boundaries of this belt are

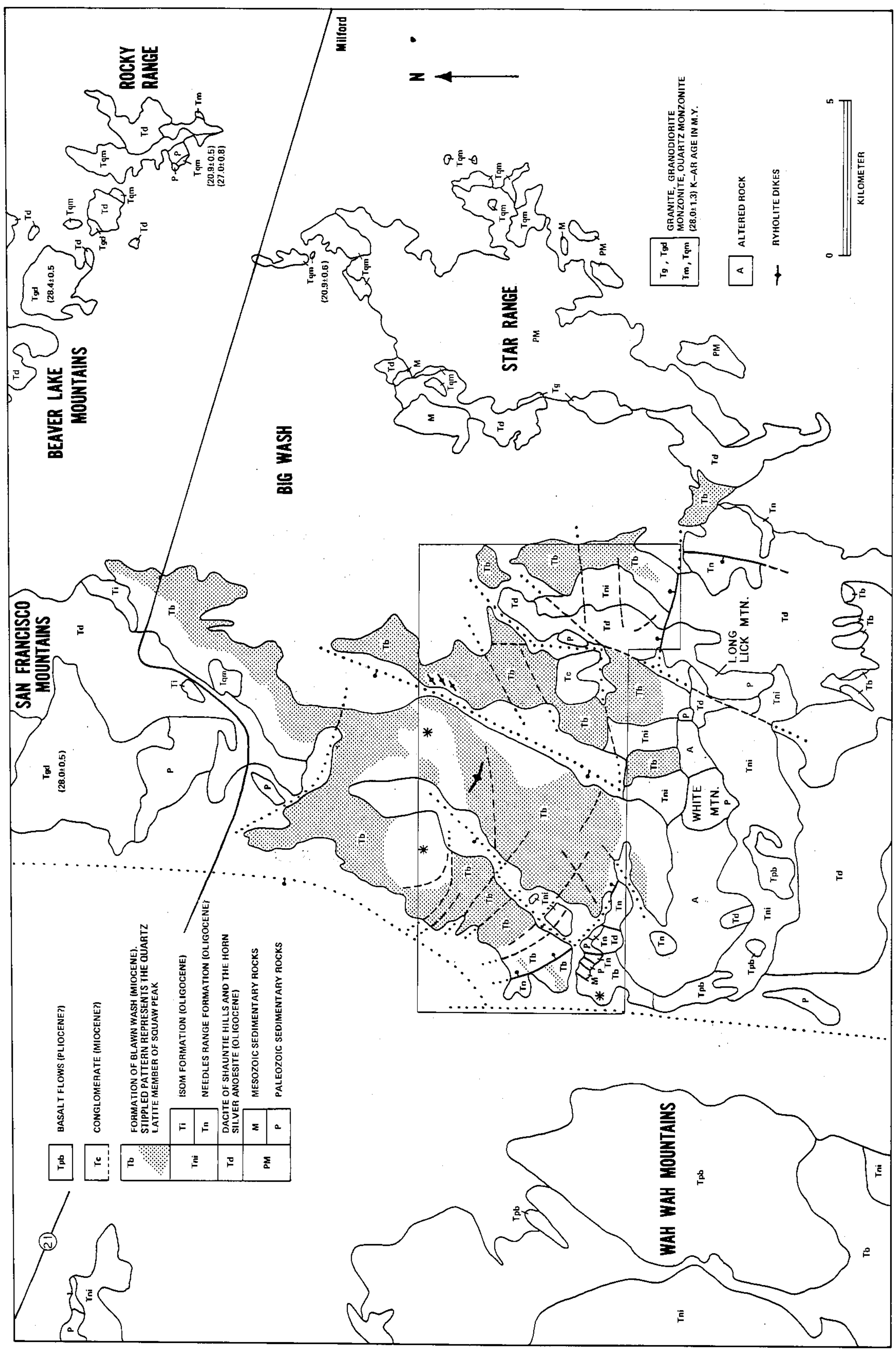

Figure 10.–Regional geologic map (modified from Lemmon and Morris 1979a, b).

not well established, it is defined by northeast-striking high-angle faults and locally derived rhyolitic to intermediate-silicic rocks that comprise the Formation of Blawn Wash. Rhyolite flows, as well as compositionally similar silicic ash-flow tuffs, are locally derived. The Quartz Latite Member of Squaw Peak was also erupted from local vents as demonstrated by interbedded coarse-block autobreccias in several exposures (fig. 12).

Miocene Depression

Several features suggest that an elliptical depression (fig. 13) developed in the southern San Francisco Mountains during the Miocene. This is demonstrated by (1) the pattern of exposure and thickness of the Quartz Latite Member of Squaw Peak (fig. 10), which was apparently extruded into a topographic low; (2) the displacement of Miocene volcanic rocks along the Grover Wash and Long Lick Mountain Faults; (3) Miocene age stocks in the Star Range and possibly the Rocky Range peripheral to the volcanic pile; and (4) the enclosure to the north by the stocks of the San Francisco and Beaver Lake Mountains. These features define an elliptical depression that lies within and parallel to the northeast-trending tectonomagmatic belt. The dimensions of this depression are approximately 30 km along the major axis and 12 km along the minor axis. The depth is unknown. Basin-and-range faulting and subsequent erosion have made interpretations of the depression difficult and speculative, to say the least.

It is not clear at what point in time the depression developed or whether the development was catastrophic or gradual. In any case, if during the late Oligocene the southern San Francisco Mountains were the site of positive relief (as suggested by the absence of the Isom and Needles Range Formations), then the development of the depression must have occurred sometime after the deposition of the Isom Formation.

Schmoker (1972) recognized two gravity lows within the southern San Francisco Mountains (fig. 11). The larger north-trending gravity low over Big Wash is interpreted by Schmoker to be a small, deep-seated, basin-and-range graben with a maximum thickness of fill of about 915 m. As previously discussed, he interprets the smaller gravity low centered over the Antelope Peak area as representing "either an area where the lower-density volcanic rocks thicken considerably or a small down-faulted area which filled with alluvium prior to being covered by volcanics," or a combination of both. It has already been shown that a combination of these interpretations agrees with the model of a clastic depositional basin in the Antelope Peak area during early Tertiary.

Schmoker's interpretation that the gravity low was due to thick accumulations of low-density volcanic rocks supports the concept of a Miocene depression in the southern San Francisco Mountains area. By process of elimination, we can determine that the only volcanic rock that could create this gravity low is the Tuff Member of Sevey's Well. Without question the high density rocks in the Antelope Peak area (Dacite of Shauntie Hills, Quartz Latite Member of Squaw Peak, and the lava flow member) create in contrast, a gravity high. The Needles Range and Isom Formations, thought to have pinched out in this

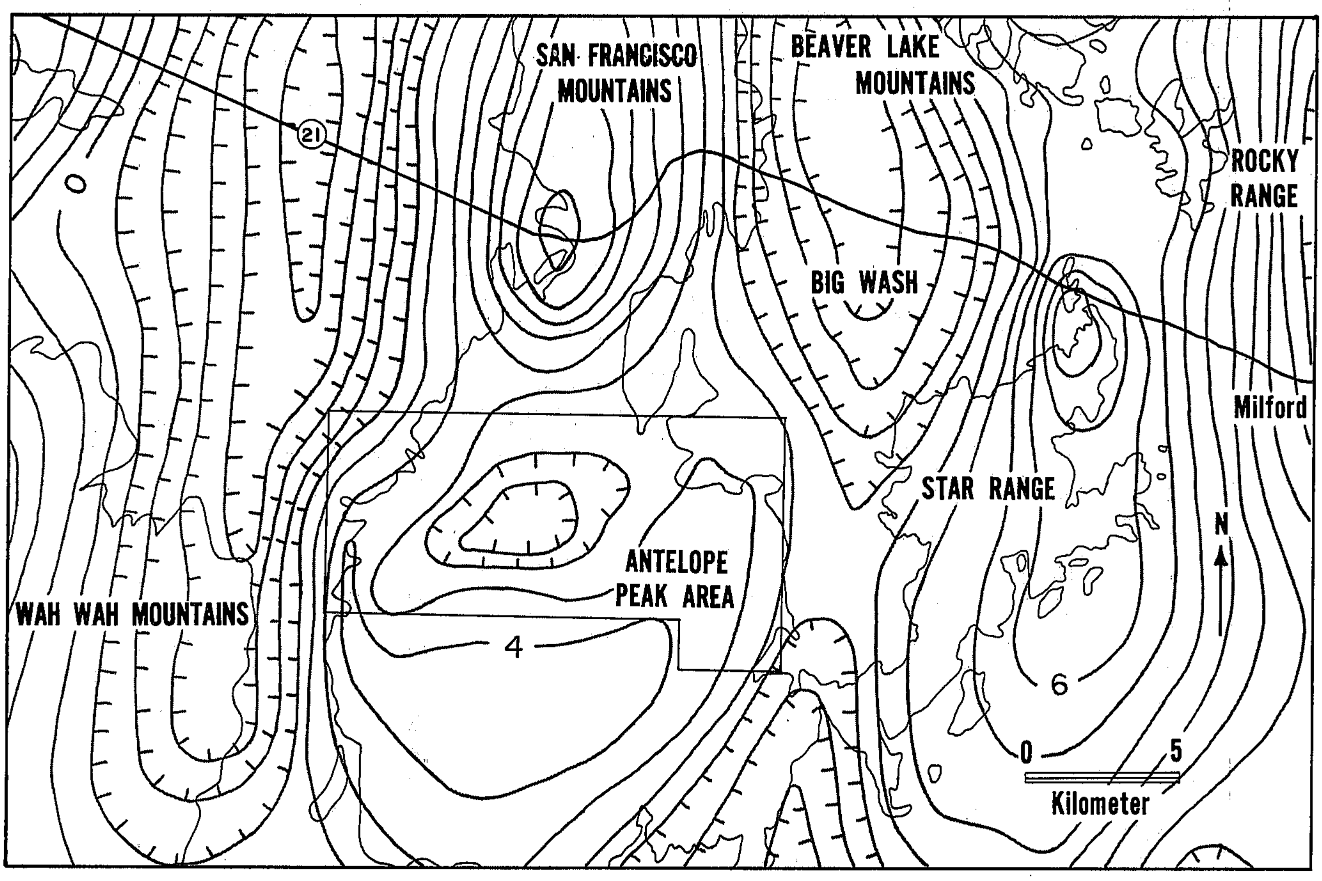

FIGURE 11.–Gravity map (taken from Schmoker 1972). Contour interval = 2 milligals.

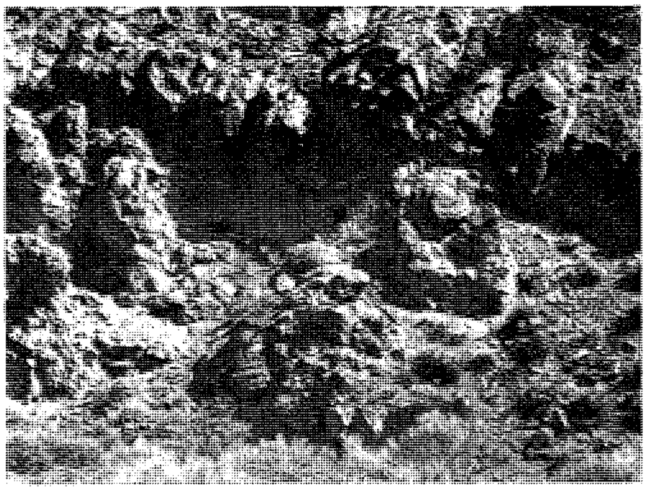

FIGURE 12.–Autoclastic breccia unit in the Quartz Latite Member of Squaw Peak, NE ¼, T. 29 S, R. 14 W.

area, would have no influence. And last, the low-density upper and lower tuff members of the Formation of Blawn Wash are of limited occurrence and likely contributed little to the gravity low.

Schmoker estimates the low-density fill creating this gravity low is about 1,130 m thick. The Tuff Member of Sevey's Well is estimated from exposures to exceed 150 m locally. However, the extreme range of thickness and heterogeneity of this unit implies that it may have been deposited in a chaotic environment (like that found in a tectonically disturbed area). If so, thicker accumulations of the Tuff Member of Sevey's Well may be concealed by the overlying rocks.

The depression is interpreted to be a graben associated with the northeast-trending belt of Miocene tectonomagmatic activity. This model is supported by (1) the depression's alignment with the northeast-trending belt, (2) early Miocene northeast-trending faults, (3) the apparent early Miocene age of the depression, (4) the Miocene-age stocks that border the depression, and (5) the Miocene volcanic rocks that fill the depression.

A caldera was seriously considered as an explanation for the depression. This interpretation is suggested by (1) a possible ring-fracture zone defined by the Grover Wash–Long Lick Mountain Faults and the stocks of the Star Range and Rocky Range, and (2) the circular rhyolitic collapse structures in the northern part of the Antelope Peak area. This interpretation is, however, weakened considerably by the obvious lack of a large volume of contemporaneous ash-flow tuff as is found associated with calderas caused by explosive pyroclastic eruptions (Smith and Bailey 1968).

ALTERATION

Most of the volcanic rocks in the Antelope Peak area have experienced some degree of alteration. Weak hematitic staining is by far the most pervasive type. Intense zones of alteration (shown in fig. 9) are usually characterized by a network of silicified rocks in joints and faults surrounded by argillized rocks and strong hematitic and limonitic staining. Propylitic and zeo-

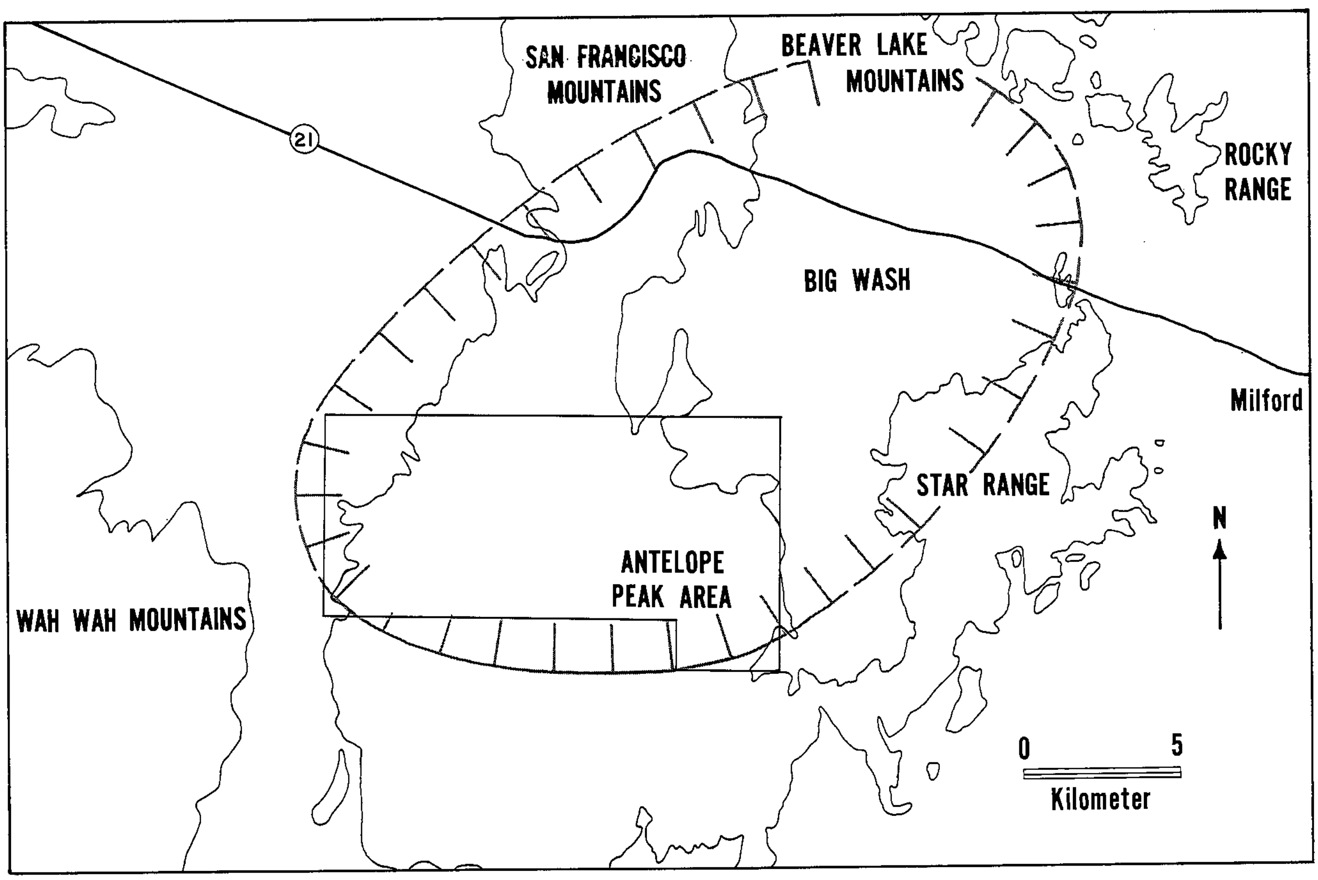

FIGURE 13.–Approximate location of Miocene depression.

litic alteration are common in the intermediate volcanic rocks, and celadonite is particularly common in the Dacite of Shauntie Hills.

The Needles Range Formation has experienced by far the most intense argillic and silicic alteration and, in fact, accounts for much of the altered rock seen in the Antelope Peak area. In most exposures the Needles Range Formation appears bleached with patchy areas of strong hematitic staining. In some localities the Lund Tuff Member has been altered so intensely by argillization and later by silicification that it takes on the appearance of a "rhyolite quartz porphyry." Intense alteration of this kind is best seen in Grover Wash in the SW¼, section 32, T. 28 S, R. 13 W.

Most of the alteration occurs in and near fault zones. Silicified rocks, most commonly found in these fault zones, stand out in ragged relief compared to the surrounding argillized rocks. Silicification is expressed in a variety of forms, such as banded chalcedony, jasper, drusy quartz fillings, and massive chalcedony. Pyrite is often found disseminated in the massive chalcedony. Calcite veins are also common in the fault zones and in some places range from .5 to 2 m thick.

In addition to the above mentioned alteration, Brooks (1964) and Stringham (1963a,b, 1967) recognized significant amounts of alunite and kaolinite.

The porous texture of the Needles Range Formation could easily have allowed the hydrothermal fluids to use this unit as a primary host. This sytem was probably enhanced by the fact that the Needles Range Formation is interbedded between two rather impermeable volcanic units, the underlying Dacite of Shauntie Hills and the overlying Isom Formation. This system may still be acting as an aquifer today, as Woodhouse Spring, Sevey's Well, and small unnamed springs are located near the top and bottom of outcrops of the Needles Range Formation.

Most of the alteration is likely a result of percolating hydrothermal solutions that accompanied the Miocene magmatic activity. Schmoker (1972; fig. 14) shows magnetic highs over all of the exposed stocks in the Star Range and Rocky Range except the granite stock in the southern Star Range. Schmoker believes this absence of a magnetic high is due to the destruction of magnetite in the granite by hydrothermal alteration. It is interesting then to speculate that the same situation could apply to the areas of alteration in and around the Antelope Peak area. The presence of nearby eruptive centers certainly implies a buried intrusion.

CONCLUSIONS

1. From early Tertiary to middle Oligocene, the Antelope Peak area appears to have been a depositional basin that was flooded by locally derived lava flows of the Dacite of Shauntie Hills. These lava flows are thought to be equivalent to the Horn Silver Andesite to the north and possibly equivalent to the Escalante Desert Formation to the south.

2. During middle Oligocene to late Oligocene, ash-flow tuffs of the Needles Range and Isom Formations were deposited in the southern portion of the Antelope Peak area (pinching out northward). This pinching out is thought to be an ero-

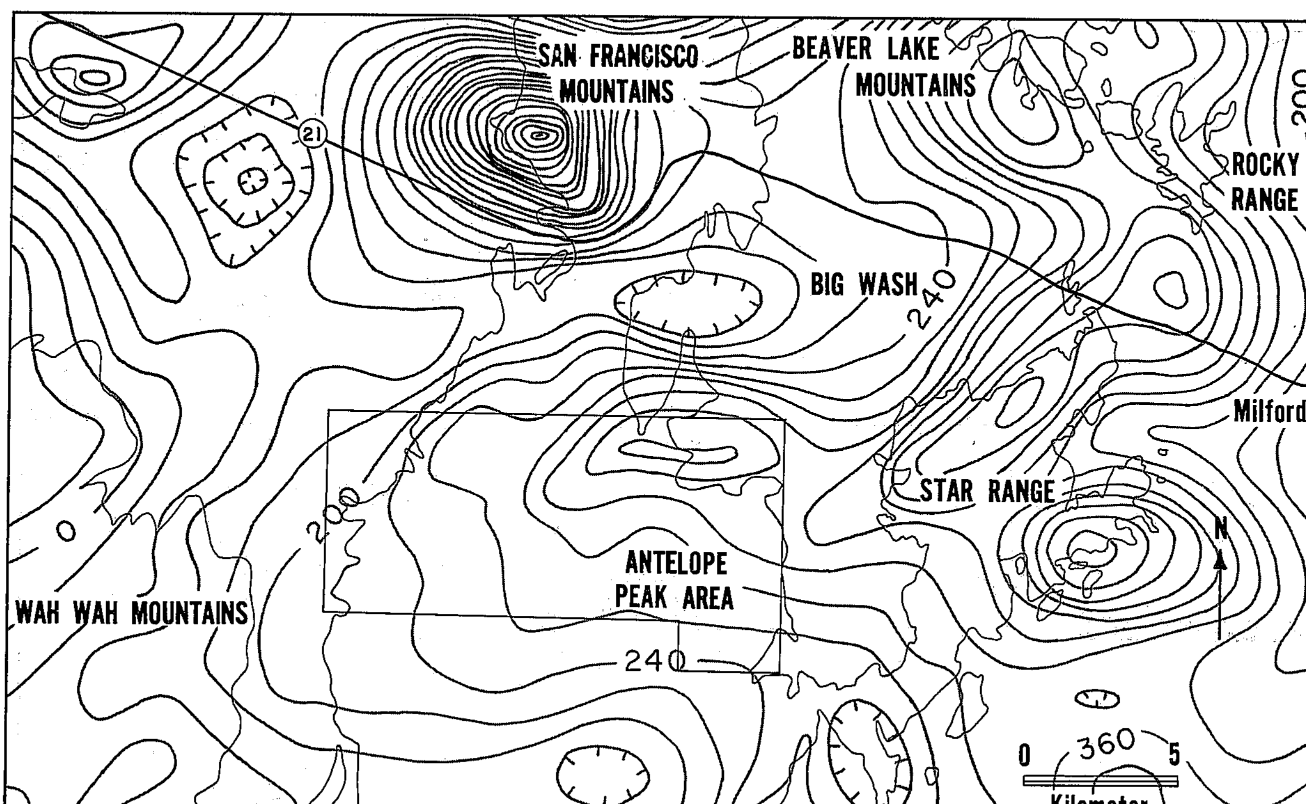

FIGURE 14.—Magnetic map (taken from Schmoker 1972). Contour interval = 40 gammas.

sional or depositional response to doming caused by a shallow intrusion to the north.

3. Temporal and spatial relationships suggest the possibility that the 28 m.y. granodiorite stocks of the San Francisco and Beaver Lake Mountains may be genetically related to dacitic flows of the Wallaces Peak Tuff.

4. During the Miocene, the Antelope Peak area was part of a northeast-trending belt of tectonomagmatic activity in which thick deposits of locally derived silicic to intermediate tuffs and lava flows were deposited. These Miocene-age volcanic rocks are collectively called the Formation of Blawn Wash after equivalent rocks exposed in the southern Wah Wah Mountains.

5. From the late Oligocene to early Miocene a northeast-trending, high-angle fault system is thought to have originated with the development of the northeast-trending tectonomagmatic belt. This fault system was overprinted in mid-Miocene by high-angle northwest- and east-trending fault systems. All of these fault systems were apparently reactivated during basin-and-range faulting, leaving many of the volcanic rocks dipping to the east.

6. During Miocene time an elliptical depression developed in the southern San Francisco Mountains and was subsequently filled with thick accumulations of Miocene volcanic rocks. This depression is thought to be a graben associated with the Miocene northeast-trending tectonomagmatic belt.

7. Hydrothermal solutions were introduced into the Antelope Peak area with the Miocene magmatic activity. Silicification, argillization, and hematitic-limonitic staining are the primary products of this hydrothermal alteration. The Needles Range Formation experienced the greatest degree of alteration, possibly acting as the host rock.

In conclusion, I suggest a few additional geologic studies that could be done in the area. Because there are several hydrothermally altered areas, it would be well to carefully sample them and do a geochemical study for trace elements, as well as economic elements. A regional stratigraphic and petrographic study of the Isom Formation would help in the understanding of this unit's extent and origin. Also, since this unit has unusually high counts on the scintillometer, a correlative petrographic study may show the origin of this high count. Mapping of the volcanic rock units to the north and west could depict the nature of the depression and perhaps show that it is a caldera.

REFERENCES

Abbott, J. T., Best, M. G., and Morris, H. T., Preliminary map and cross sections of the Pine Grove–Blawn Mountain area, Beaver County, Utah: U.S. Geological Survey Open-File Report 81-525.

Baer, J. L., 1962, Geology of the Star Range, Beaver County, Utah: Brigham Young University Geology Studies, v. 9, pt. 2, p. 29–53.

Best, M. G., and Keith, J. D., 1979, Volcanic geology of the Observation Knoll and the Tetons Quadrangles, Beaver and Iron Counties, Utah: U.S. Geological Survey Open-File Report 79-1611.

Best, M. G., Shuey, R. T., Caskey, C. F., and Grant, S. K., 1973, Stratigraphic relations of members of the Needles Range Formation at type localities in southwestern Utah: Geological Society of America Bulletin, v. 84, p. 3269–78.

Brooke, J. P., 1964, Alteration and trace elements in the San Francisco Mountains, Utah: Ph.D. dissertation, University of Utah, Salt Lake City, 122p.

Butler, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts: U.S. Geological Survey Professional Paper 80.

Campbell, D. R., 1978, Stratigraphy of pre-Needles Range Formation ash-flow tuffs in the northern Needle Range and southern Wah Wah Mountains, Beaver County, Utah: Brigham Young University Geology Studies, v. 25, pt. 3, p. 31–46.

East, E. H., 1966, Structure and stratigraphy of the San Francisco Mountains, western Utah: American Association of Petroleum Geologists Bulletin, v. 50, h. 5, p. 901–20.

Erickson, M. P., 1961, Reconnaissance geologic map of the southern San Francisco Mountains, Utah: Utah State Mapping Project unpublished map.

Fleck, R. J., Anderson, J. J., and Rowley, P. D., 1975, Chronology of mid-Tertiary volcanism in the High Plateaus region of Utah: Geological Society of America Special Paper 160, p. 53–61.

Hintze, L. F., 1963, Geologic map of southwestern Utah: Utah Geological and Mineralogical Survey.

Lemmon, D. M., and Morris, H. T., 1979a, Preliminary geologic map of the Frisco Quadrangle, Beaver County, Utah: U.S. Geological Survey Open-File Report 79-724.

———, 1979b, Preliminary geologic map of the Milford Quadrangle, Beaver County, Utah: U.S. Geological Survey Open-File Report 79-1471.

Lemmon, D. M., Silberman, M. L., and Kistler, R. W., 1973, Some K-Ar ages of extrusive and intrusive rocks of the San Francisco and Wah Wah Mountains, Utah: In Geology of the Milford area: Utah Geological Association Publication 3, p. 23–36.

Rowley, P. D., Lipman, P. W., Mehnert, H. H., Lindsey, D. A., and Anderson, J. J., 1978, Blue Ribbon lineament, an east-trending structural zone within the Pioche mineral belt of southwestern Utah and eastern Nevada: U.S. Geological Survey Journal of Research, v. 6, no. 2, p. 175–92.

Schmoker, J. W., 1972, Analysis of gravity and aeromagnetic data, San Francisco Mountains and vicinity, southwestern Utah: Utah Geological and Mineralogical Survey, Bulletin 98.

Shaw, D. R., and Stewart, J. H., 1976, Ore deposits as related to tectonics and magmatism, Nevada and Utah: Society of Mining Engineers, AIME, Transactions, v. 260, p. 225–31.

Smith, R. L., and Bailey, R. A., 1968, Resurgent cauldrons: Studies in volcanology: Geological Society of America Memoir 116, p. 613–62.

Stewart, J. H., 1978, Basin-range structure in western North America: Geological Society of America Memoir 152.

Stringham, B. F., 1963a, Hydrothermal alteration south of the Horn Silver Mine, Beaver County, Utah: Utah Geological and Mineralogical Survey Special Studies 16, 35p.

———, 1963b, Hydrothermal alteration in the southeast part of the Frisco Quadrangle, Beaver County, Utah: Utah Geological and Mineralogical Survey Special Studies 4, 26p.

———, 1967, Hydrothermal alteration near the Horn Silver Mine, Beaver County, Utah: Utah Geological and Mineralogical Survey Special Studies 16, 35p.

Weaver, C. L., 1979, Geology of the Blue Mountain Quadrangle, Beaver and Iron Counties, Utah: Brigham Young University Geology Studies, v. 27, pt. 3, p. 116–32.

Wheeler, R. F., 1980, Geology of the Sewing Machine Pass Quadrangle, Beaver County, Utah: Brigham Young University Geology Studies, v. 27, pt. 2, 175–91.