

## TERTIARY STRATIGRAPHIC UNITS OF WESTERN MOJAVE DESERT, CALIFORNIA<sup>1</sup>

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### ABSTRACT

Scattered throughout the western Mojave Desert, mostly in the vicinities of Rosamond, Mojave, and Boron, are exposures of non-marine sedimentary and volcanic rocks of Tertiary age. These rocks rest on a deeply eroded surface of pre-Tertiary granitic and metamorphic rocks that form the crystalline basement complex of this region, and are overlain unconformably by alluvial sediments of Quaternary age. Where exposed the Tertiary rocks are moderately deformed and much eroded.

With the exception of exposures in the foothills northwest of Mojave, the rocks of Tertiary age are mapped as a group, named the Tropic group, with a maximum exposed thickness of about 2,800 feet. This group is divided into several lithologic units of local extent. In most sections the lower unit is a pyroclastic formation, with associated rhyolitic intrusions and flow-breccias, and the upper unit is either fanglomerate or a sequence of carbonate rocks, clays, and sandstones of lacustrine and fluvial origin. Several basalt flows occur locally in the group, mostly in the middle part. The group is non-fossiliferous except at one locality, where diatom remains in the upper unit suggest early Pliocene age. The lower unit is tentatively correlated with lithologically similar formations of known Miocene age in areas west and northwest. Formations in the Tropic group that are locally distinct are named the Gem Hill formation, Fiss fanglomerate, Bissell formation, Saddleback basalt, and Red Buttes quartz basalt.

In the foothills northwest of Mojave the granitic basement is overlain by about 1,000 feet of terrestrial sandstones and clays named the Horned Toad formation. This formation yielded a mammalian fauna indicating middle or early Pliocene age, and is either younger than or correlative with the upper part of the Tropic group.

### INTRODUCTION

The sequence of non-marine sedimentary, pyroclastic, and volcanic rocks of Tertiary age, exposed in the vicinities of Rosamond and Boron in the western Mojave Desert, has recently been mapped as a group that is locally differentiated into several formational units. In the Rosamond Hills north and northwest of Rosamond this sequence was first described and named the Rosamond series by Hershey (1902, pp. 365-72), and later mapped and described as the Rosamond formation by Simpson (1934, pp. 395-401). Since Hershey's description, the name Rosamond has been applied by later workers to Tertiary stratified rocks exposed in widely separated areas in the Mojave Desert, as far north as Ricardo and as far east as Newberry. Many of these exposed sections called Rosamond were found to be of different ages, with one as old as Paleocene and another as young as Pliocene.

Because of the indiscriminate application of the name Rosamond to so many incongruous assemblages of Tertiary strata in the Mojave Desert, the U. S. Geological Survey does not recognize the application of this name to a stratigraphic unit (Wilmarth, 1938, pp. 3 and 1843). For this reason, the sequence of non-marine sedimentary, pyroclastic, and volcanic rocks exposed in the Rosamond Hills and originally described as the Rosamond series by Hershey (1902,

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pp. 365-72), together with similar and probable correlative rocks of Tertiary age exposed in the vicinities of the Kramer borate area and in the Kramer Hills, are mapped as a major unit. This unit is here named the Tropico group, and is differentiated locally into several formational units where feasible.

#### TROPICO GROUP

The Tropico group of Miocene(?) and Pliocene age is here named after the Mojave-Tropico road that traverses the type section, and is a sequence of non-marine sedimentary, pyroclastic, and volcanic rocks of Tertiary age exposed in the vicinities of Rosamond, Mojave, Castle Butte, Kramer borate area, and Kramer Hills. All the rocks of Tertiary age exposed in the part of the western Mojave Desert included in Figure 1 and southeast of the Garlock fault, with the exception of those exposed in the Horned Toad Hills, are included in the Tropico group. This group is not certainly recognizable elsewhere. Among these exposures of the Tropico group the most complete sections are those at Antelope Buttes, Rosamond Hills, hills north of Bissell, at and near Castle Butte, and in the Kramer Hills. Incomplete sections are exposed at Soledad Mountain and vicinity, and in the Kramer borate district. The type section is designated as that exposed in the Rosamond Hills within  $\frac{1}{2}$  mile west of the Mojave-Tropico road 1-2 miles north of the Tropico mines, Rosamond Quadrangle, in the NE.  $\frac{1}{4}$  of Sec. 2, T. 9 N., R. 13 W., San Bernardino Base and Meridian.

The Tropico group lies on the deeply eroded surface of granitic basement rocks, mostly quartz monzonite, of pre-Tertiary (Mesozoic?) age, and is unconformably overlain by alluvial sediments of Quaternary age. The group is moderately deformed and the maximum exposed thickness is about 2,800 feet. Abrupt lateral changes of facies are prevalent so that correlation of isolated exposures is difficult if not impossible. In general, however, the lower part is composed mainly of tuffaceous strata of rhyolitic composition, and the upper part is made up of either coarse stream-laid or fine lacustrine sediments or both. Mafic lava flows are commonly present in some sections, mostly in the middle part of the group. Rhyolitic rocks in the form of volcanic intrusive masses or extrusive flow-breccias of limited extent are associated with the tuffaceous strata of the lower part of the group in some places. The Tropico group is non-fossiliferous, except for diatom remains in a limestone in the upper part, 2 miles west of Castle Butte, which suggest early Pliocene age. However, stratigraphic evidence suggests that the lower part of the Tropico group may be as old as middle or possibly early Miocene.

The Tropico group is divided into units recognizable only in local areas. These units are given in the following sequences of the Tropico group exposed in the local areas and shown on Figure 1. Thicknesses given are the maximum exposed. The aggregate totals for the group exposed in any area are not necessarily sum totals of units, because the maximum thickness of all the units does not necessarily occur in one section exposed in any area. The stratigraphic se-

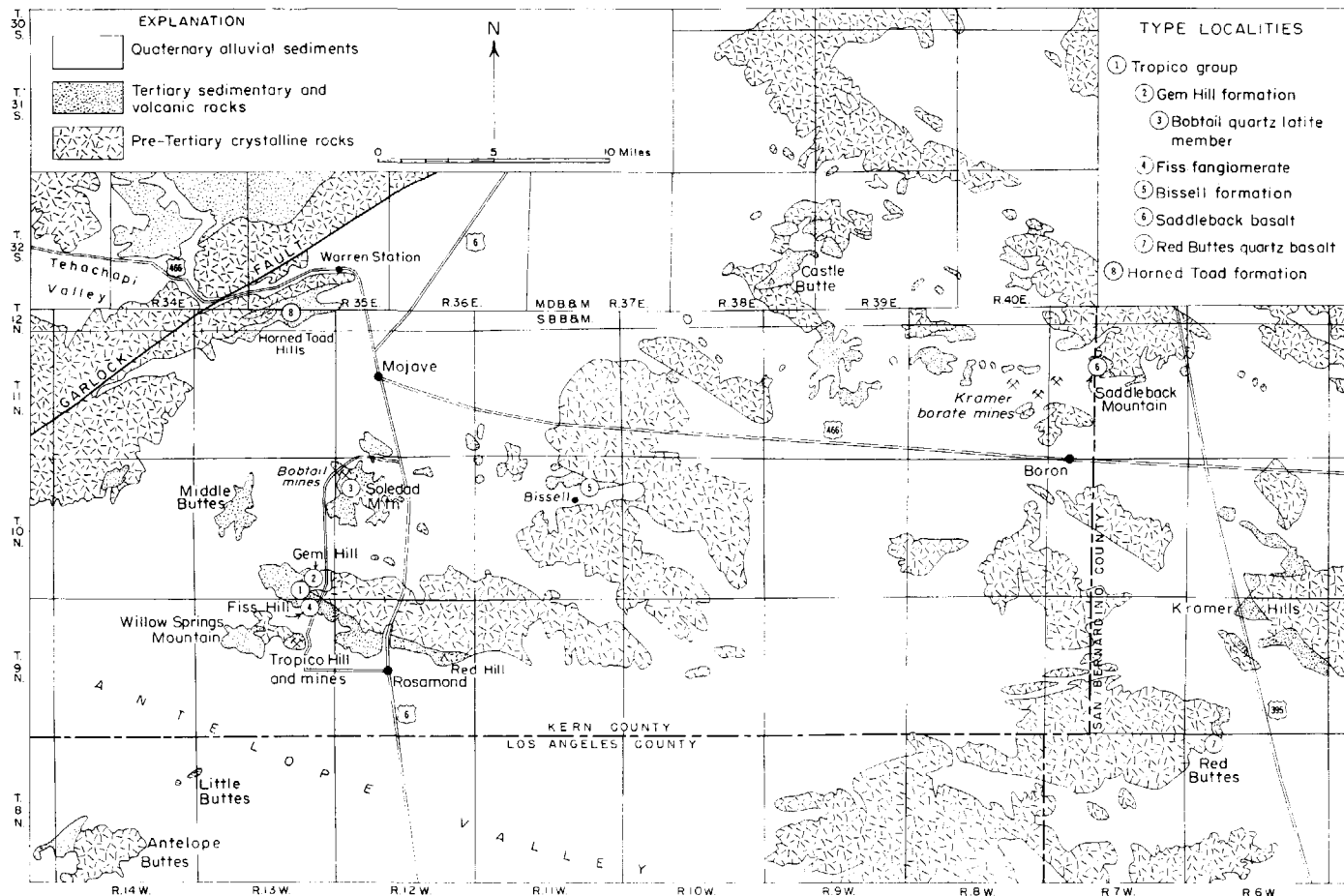


FIG. 1.—Generalized geologic map of part of western Mojave Desert, California, showing type localities of rock units of Tertiary age.

quences of these local units of the Tropico group and their possible correlations are shown graphically in Figure 2.

TROPICO GROUP IN ROSAMOND HILLS (INCLUDING TYPE SECTION), AND AT ANTELOPE BUTTES, ROSAMOND AND WILLOW SPRINGS QUADRANGLES

	<i>Feet</i>
Fiss fanglomerate	
Fanglomerate and conglomerate of volcanic and some granitic detritus.....	1,700
Gem Hill formation	
Tuff, tuff-breccia, tuffaceous sandstone, some conglomerate; local thin basic lava flows at or near top.....	1,250
Aggregate total.....	2,800*

TROPICO GROUP IN HILLS NORTH OF BISSELL, ROSAMOND QUADRANGLE

Bissell formation	
Arkosic sandstone, granitic conglomerate, and green-gray siltstone.....	450
Clay shale, some thin, soft, white magnesite layers near base.....	150
Interbedded limestone, dolomite, chert, siliceous shale, and clay shale.....	200
Gem Hill formation	
White tuff, some granitic conglomerate at base.....	150
Aggregate total.....	950

\* Not sum total because all units do not attain maximum thickness in any single exposed sequence.

Associated with the Gem Hill formation in the Rosamond and Bissell areas are rhyolitic rocks that are mostly volcanic intrusive although some are extrusives masses. These rocks are mapped separately as the Bobtail quartz latite member.

	Age	Southeast foothills of Tehachapi Mountains	Antelope Buttes	Rosamond Hills	Hills north of Bissell	Castle Butte area	Kramer borate area	Kramer Hills
QUATERNARY	Pleistocene	Fanglomerate	Sand	Sand and gravel	Fanglomerate	Fanglomerate	Fanglomerate	Fanglomerate
		Sand and silt						
	Pliocene(?)	Horned Toad formation					?	?
TERTIARY	?				?		Upper part	Upper part
						Basalt	Saddleback basalt	Red Buttes quartz basalt
	Miocene(?)		Fiss fanglomerate	Fiss fanglomerate	Bissell formation	Sandstone, shale, and limestone	Lower part	Lower part
		Quartz latite dikes	Gem Hill formation	Gem Hill formation and Bobtail quartz latite member	Gem Hill formation and Bobtail quartz latite member	Lithic tuff		
PRE-TERTIARY		Quartz monzonite	Quartz monzonite	Quartz monzonite	Quartz monzonite	Quartz monzonite	Qtz monzonite and qtz latite porph	Qtz monzonite and meta-andesite

FIG. 2.—Sequences of rocks of Cenozoic age in western Mojave Desert area. Only relative stratigraphic positions and not precise correlations intended. Unconformities indicated by wavy lines.

## TROPICO GROUP AT CASTLE BUTTE, CASTLE BUTTE QUADRANGLE

	<i>Feet</i>
Tropico group	
Basalt.....	50
Arkosic sandstone.....	200
Clay shale.....	260
Limestone, chert, and siliceous shale.....	50
Lithic tuff.....	885
Aggregate total.....	1,445

## TROPICO GROUP IN KRAMER BORATE DISTRICT, BORON AND CASTLE BUTTE QUADRANGLES

Upper part	
Granitic conglomerate.....	300
Arkosic sandstone.....	200
Clay shale, containing borates.....	250
Saddleback basalt	
One or more basalt flows.....	600

*(Local Unconformity)*

Lower part (Equivalent to beds of Tropico group exposed at Castle Butte)	
Lithic tuff, tuffaceous shale, some arkosic sandstone, and granitic conglomerate.....	1,500
Aggregate total.....	2,800*

\* Not sum total because all units do not attain maximum thickness in any exposed sequence.

In his description of the Kramer borate district, Gale (1946, p. 335) referred the Saddleback basalt and the beds above to the Ricardo formation, and the beds below to the Rosamond formation of Simpson (1934) because of the unconformity at the base of the Saddleback basalt. However, there is no faunal evidence to verify this conclusion. The lower part of the Tropico group in the Kramer borate district is tentatively correlated with all the beds exposed below the basalt at Castle Butte, as the basalt at the top of the section at Castle Butte may be equivalent to the Saddleback basalt.

## TROPICO GROUP OF KRAMER HILLS, KRAMER QUADRANGLE AND BARSTOW (30-MINUTE) QUADRANGLE

	<i>Feet</i>
Upper part	
Arkosic sandstone and clay shale, local granitic conglomerate.....	800
Red Buttes quartz basalt	
Flows of quartz-bearing black basalt.....	270

*(Local Unconformity)*

Lower part	
Arkosic sandstone, clay shale, limestone, dolomite, chert, and flows of basalt.....	1,400
Rhyolitic tuff, arkosic sandstone and conglomerate.....	630
Aggregate total.....	2,600*

\* Not sum total because all units do not attain maximum thickness in any exposed sequence.

The eastern exposures of this group were described by Bowen (1954, pp. 77, 78) as the Kramer Hills lakebeds, and the upper part of the Tropico group is shown on a sketch map (Bowen, 1954, p. 78) as upper lakebeds, and the lower part as lower lakebeds. However, these are not all of lacustrine origin as they contain a large proportion of stream-laid sandstone and some conglomerate.

## GEM HILL FORMATION

The Gem Hill formation of Miocene(?) age, the lower unit of the Tropico group in the Rosamond district, is here named from Gem Hill in the Rosamond Hills,  $5\frac{1}{2}$  miles northwest of Rosamond. This formation is exposed nearly continuously from Gem Hill southeastward 7 miles to Red Hill, 2 miles northeast of Rosamond. Other exposures occur at various places in the Elizabeth Lake Quadrangle or Willow Springs and Rosamond quadrangles, namely, Antelope Buttes and Little Buttes southwest of Rosamond, Middle Buttes, Soledad Mountain, and the ridge north of Bissell.

The Gem Hill formation consists mainly of stratified light-colored rhyolitic lithic tuff, tuff-breccia, tuffaceous sandstone, volcanic agglomerate, and some conglomerates of both volcanic and granitic clasts. At or near the top at several places are one or more thin basalt flows. At Gem Hill the thickness of this formation is 1,250 feet; and at Antelope Buttes, about 1,200 feet; it is thinner elsewhere. It rests on quartz monzonite, and is overlain by the Fiss fanglomerate, with a gradational contact at Gem Hill, but with a sharp, locally unconformable contact elsewhere.

The Gem Hill formation is non-fossiliferous so that its position in the Tertiary is uncertain. However, it is tentatively correlated on the basis of its lithologic similarity and stratigraphic position with the Miocene Kinnick formation of Buwalda and Lewis (1955, pp. 147-48) in the Tehachapi area.

*Type locality.*—Gem Hill, in S.  $\frac{1}{2}$ , Sec. 25, SE.  $\frac{1}{4}$ , Sec. 26, and NE.  $\frac{1}{4}$ , Sec. 35, T. 10 N., R. 13 W., San Bernardino Base and Meridian,  $5\frac{1}{2}$  miles northwest of Rosamond, Rosamond Quadrangle.

## BOBTAIL QUARTZ LATITE MEMBER

The rhyolitic volcanic rock extensively exposed on Soledad Mountain and vicinity, near Mojave, is here named the Bobtail quartz latite member of the Gem Hill formation, after the Bobtail mines on the west slope of Soledad Mountain as shown in the Rosamond Quadrangle. At Soledad Mountain and vicinity it makes up several large volcanic plugs, a number of small plugs, pods, and dikes intrusive through pre-Tertiary granitic rocks and into the Gem Hill formation. It also occurs as several short lentils of flow breccia in this formation. Other scattered buttes within 10 miles of Soledad Mountain are remnants of volcanic plugs made up of the Bobtail quartz latite. Among these are several small buttes on the east and north; Middle Buttes 5 miles west; Willow Springs Mountain and Tropico Hill about 7 miles southwest; and several small intrusive masses in the Rosamond Hills.

The Bobtail quartz latite member is a felsitic to porphyritic rock that is predominantly cream white in color, but in places is tan, pink, brown, or pale green. The porphyritic facies contains scattered phenocrysts that make up as much as 25 per cent of the rock mass and are composed of quartz, plagioclase (oligoclase) and orthoclase (sanadine). The felsitic facies and groundmass of the porphyritic

facies are dense massive to faintly flow-laminated, and composed of the same minerals as the phenocrysts, plus small amounts of hematite. In addition to these facies there are chilled marginal zones of gray perlite in some places.

The age of most if not all the Bobtail quartz latite member must be the same as that of the Gem Hill formation, which it intrudes and in which it occurs as extrusive masses, or probably middle Miocene. It is older than the Fiss fanglomerate, which it does not intrude, and the fanglomerate is made up largely of detritus derived from it and contains several small landslide masses of it near the base.

*Type locality.*—Soledad Mountain, Rosamond Quadrangle, Secs. 6 and 7, T. 10 N., R. 12 W., San Bernardino Base and Meridian.

#### FISS FANGLOMERATE

The Fiss fanglomerate of Miocene(?) age, the upper unit of the Tropic group in the vicinity of Rosamond, is here named after Fiss Hill, in the Rosamond Hills a mile south of Gem Hill. It crops out discontinuously about 8 miles along the southwestern margin of the Rosamond Hills from the west end 6 miles northwest of Rosamond to Red Hill 2 miles northeast of that town. The only other exposure of this fanglomerate is at Antelope Buttes, 12 miles southwest of Rosamond.

The Fiss fanglomerate is crudely bedded and is composed of ill-sorted cobbles and boulders of pinkish brown rhyolitic volcanic rocks and some of granitic rocks. The exposed thickness at the type section is about 500 feet, and a mile northwest, about 900 feet. At Antelope Buttes it is about 1,700 feet. It rests on the Gem Hill formation, in places unconformably; the top is eroded, and north of Rosamond the fanglomerate is overlain unconformably by gravel of probable Pleistocene age.

The Fiss fanglomerate is non-fossiliferous but is probably correlative with similar fanglomerate mapped and described by Wiese (1950, pp. 33-35, Pl. 1) as Miocene(?) continental deposits in west Antelope Valley, and which in part grade laterally westward into marine sediments with upper Miocene molluscan fossils. It may be correlative with the late Miocene Bopesta formation of Buwalda and Lewis (1955, p. 148) in the Tehachapi area.

*Type locality.*—Fiss Hill, a low hill in west-central part of Sec. 1, T. 9 N., R. 13 W., San Bernardino Base and Meridian,  $1\frac{1}{2}$  miles north-northeast of Tropic Mine,  $4\frac{1}{2}$  miles northwest of Rosamond, Rosamond Quadrangle.

#### BISSELL FORMATION

The Bissell formation of Miocene or Pliocene age is here named after the Bissell Hills, between Soledad Mountain and Boron. This unit is about 845 feet in thickness and the sequence is as given under the Tropic group. The Bissell formation, which crops out about 3 miles along an east-trending ridge, lies with apparent conformity on tuff of the Gem Hill formation and is overlain unconform-

ably by fanglomerate of probable Pleistocene age. The Bissell formation is non-fossiliferous so that its position within the Tertiary is uncertain. It may be in part a lacustrine facies of the Fiss fanglomerate.

*Type locality.*—An east-trending ridge in N.  $\frac{1}{2}$ , Sec. 11, T. 10 N., R. 11 W., in the Bissell Hills, in the Rosamond Quadrangle.

#### SADDLEBACK BASALT

The Saddleback basalt of Pliocene(?) age was named by Gale (1946, p. 335) as the basal part of the Ricardo formation. The Saddleback basalt is here redefined as a local formation in the Tropico group in the Kramer borate district. Saddleback Mountain is designated as the type locality, in the S.  $\frac{1}{2}$  of Sec. 9, T. 11 N., R. 7 W., San Bernardino Base and Meridian, 4 miles north of Boron, Boron Quadrangle. From this feature the Saddleback basalt crops out as scattered exposures in low isolated hills toward the northwest for 6 miles, and west about 10 miles. The exposures in the vicinity of the Kramer borate mines were mapped by Gale (1946).

The Saddleback basalt, as described in detail by Gale (1946, pp. 346–50) is a black dense to fine diabasic-textured rock whose groundmass is composed essentially of plagioclase (calcic labradorite), augite, and olivine, in which are scattered small phenocrysts of calcic labradorite. It consists of several flows that total about 200 feet in thickness at most exposures, including the type section, but in some places it is as much as 600 feet. At the type section it rests on quartz monzonite, but elsewhere it rests with a probable slight unconformity on the lower part of the Tropico group. In the Kramer borate district these underlying rocks were referred to as the Rosamond formation by Gale (1946, pp. 335, 350–57, Pl. 51). The Saddleback basalt is overlain conformably by the borate-bearing shale of the upper part of the Tropico group in the Kramer borate district in the borate mines, and unconformably by fanglomerate of probable Pleistocene age at the surface. The age of the basalt within the Tertiary is in doubt, but if it is correlative with the Ricardo formation as inferred by Gale (1946, p. 335), it would be of early Pliocene age.

#### RED BUTTES QUARTZ BASALT

The Red Buttes quartz basalt of Pliocene(?) age is here defined as a local formation within the Tropico group in the Kramer Hills area. It is named after Red Buttes, the type locality, in Sec. 5, T. 8 N., R. 6 W., Kramer Quadrangle, and is prominently exposed north and northeast about 7 miles in the Kramer Hills, Kramer Quadrangle and (30-minute) Barstow Quadrangle.

The Red Buttes quartz basalt is the same as the black quartz andesite described and mapped by Bowen (1954, pp. 78, 83–84, Pl. 1) in the eastern Kramer Hills. The rock is black basalt or mafic andesite and according to Bowen (1954, pp. 8–84) has a dense groundmass of plagioclase and augite-diopside with some hypersthene, hornblende, and magnetite, and contains scattered small



phenocrysts of quartz and labradorite. It consists of several flows totaling about 360 feet in maximum thickness. At Red Buttes it rests on pre-Tertiary quartz monzonite, and is overlain unconformably by fanglomerate of probable Pleistocene age. However, in the Kramer Hills the Red Buttes quartz basalt overlies, probably unconformably, the lower part of the Tropico group and is overlain conformably by the upper part. The age of the Red Buttes quartz basalt is unknown, although Bowen (1954, pp. 77, 81) regards it as Miocene. The probable unconformity at its base and its apparently similar stratigraphic position suggest that it may be correlative with the Saddleback basalt of supposed Pliocene(?) age, of the Kramer borate district.

#### HORNED TOAD FORMATION

The Horned Toad formation of early or middle Pliocene age is a sequence of stream-laid and lacustrine sediments here named after the Horned Toad Hills which are about 4 miles northwest of Mojave, Mojave (15-minute) Quadrangle. It crops out in these low southeast foothills of the Tehachapi Mountains from Warren Station southwestward about 3 miles. The formation, which is moderately deformed, overlies quartz monzonite of pre-Tertiary age and intrusive quartz latite of Tertiary age. It is overlain unconformably by light reddish sand, siltstone, and fanglomerate of probable Pleistocene age that is also deformed. The Horned Toad formation is composed of the following members.

	<i>Feet</i>
Upper member	
Gray gypsiferous clay.....	80
Middle member	
Indurated green muddy sandstone and several layers of white caliche.....	75
Lower member	
Gray-white arkosic sands and interbedded light reddish sandy siltstone; basal granitic conglomerate.....	900
	1,055

The Horned Toad formation has yielded mammalian fossils indicating early or middle Pliocene age. It may be correlative in part with the Ricardo formation (Merriam, 1914, pp. 275-81, and Dibblee, 1952, pp. 25-30, Pl. 1) exposed in Redrock Canyon. It is either younger than, or possibly equivalent to, the upper part of the Tropico group in the Kramer borate district and in the Kramer Hills.

*Type locality.*—Horned Toad Hills, 4 miles northwest of Mojave, 15-minute Mojave Quadrangle; 30-minute Mojave Quadrangle (E.  $\frac{1}{2}$  of Sec. 33, T. 32 S., R. 33 E., Mount Diablo Base and Meridian, NE.  $\frac{1}{4}$  of Sec. 35 and NW.  $\frac{1}{4}$  of Sec. 36, T. 12 N., R. 13 W., San Bernardino Base and Meridian).

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