Geology of the Sycamore Flat and Paraiso Springs Quadrangles, Monterey County, California

GEOLOGICAL SURVEY BULLETIN 1285

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Geology of the Sycamore Flat and Paraiso Springs Quadrangles, Monterey County, California

By DAVID L. DURHAM

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A study of stratigraphy and structure of Cenozoic sedimentary rocks in part of the Salinas Valley

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By David L. Durham

ABSTRACT

The Sycamore Flat and Paraiso Springs quadrangles are on the west side of the Salinas Valley and contain the south end of the Sierra de Salinas and the lower reaches of the Arroyo Seco, a major tributary to the Salinas River from the west.

Plutonic and metamorphic rocks of the pre-Tertiary basement complex crop out in the northern and western parts of the map area. A conformable stratigraphic sequence that overlies the basement complex comprises four major units: the Tierra Redonda Formation, Monterey Shale, Pancho Rico Formation, and Paso Robles Formation. The Tierra Redonda is chiefly sandstone and contains marine fossils of middle Miocene age. The Monterey is mainly calcareous mudstone in the lower part and porcelanite and porcelaneous mudstone in the upper part. The lower part constitutes the Sandholdt Member and contains foraminifers of the upper middle Miocene Luisian Stage of Kleinpell; the upper part is probably mostly of late Miocene age. The Pancho Rico is sandstone that locally contains marine fossils; it is of Pliocene age. The Paso Robles is chiefly fluviatile conglomerate and sandstone and is of Pliocene and Pleistocene(?) age.

The map area lies in a re-entrant that disrupts the generally northwest-trending structural grain of the Coast Ranges with more nearly east- and west-trending structural features. The steep northeast-facing scarp of the Sierra de Salinas is generally attributed to uplift of the mountain block along a concealed fault, commonly called the King City fault. The Reliz fault, which is exposed in the map area, is probably either a continuation or a branch of the King City fault.

At least 19 wells were drilled for oil in the map area before July 1968. The small Monroe Swell oil field, on the east border of the Paraiso Springs quadrangle, produced about 70,000 barrels of oil from 1959 to 1966.

INTRODUCTION

PURPOSE AND SCOPE

The southern Salinas Valley area contains Cenozoic strata that hold economically important accumulations of oil and gas. The area also contains sand and gravel, diatomite, gypsum, bituminous sandstone, and placer gold deposits that have been worked commercially, and phosphate deposits that are potentially commercial. U.S. Geological

Survey investigations in the area are concerned chiefly with the character, distribution, structure, and economic geology of sedimentary rocks exposed there. The work involves the preparation of reports limited to description of selected quadrangles, followed by the preparation of a more general paper on the regional geology of the southern Salinas Valley area. This report on the Sycamore Flat and Paraiso Springs quadrangles includes a geologic map of each quadrangle (pls. 1, 2) and structure sections across the quadrangles (pl. 3). Previously published reports describe the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles (Durham, 1963), the Cosio Knob and Espinosa Canyon quadrangles (Durham, 1964), the Jolon and Williams Hill quadrangles (Durham, 1965), the Hames Valley, Wunpost, and Valleton quadrangles (Durham 1966), the Tierra Redonda Mountain and Bradley quadrangles (Durham, 1968a), and the Adelaida quadrangle (Durham, 1968b). These reports on selected quadrangles are of limited scope in that discussion of regional relations is left for the more general paper on the southern Salinas Valley area. They are preliminary in that some of the conclusions presented may be modified after work in adjacent areas is complete.

LOCATION OF AREA

The Sycamore Flat and Paraiso Springs quadrangles (fig. 1) are in Monterey County on the west side of the Salinas Valley at the latitude of Greenfield. They lie at the south end of the Sierra de Salinas, a mountain range that extends along the west side of the Salinas Valley for about 30 miles, and they include the lower reaches of the Arroyo Seco, a major tributary to the Salinas River from the west. One of the few roads from the Salinas Valley across the mountains to the coast traverses the map area westward along the Arroyo Seco and northward up Paloma Creek toward Carmel Valley. Part of the small Monroe Swell oil field is in the southeastern part of the Paraiso Springs quadrangle.

PREVIOUS WORK

Whitney (1865, p. 155–157) gave geologic details observed on a trip from Carmel Valley to the Arroyo Seco and described and illustrated folds in "bituminous slate" exposed along the Arroyo Seco. Peale (1886, p. 207) listed Paraiso Springs and gave (p. 214) an analysis of the water. Dall and Harris (1892, p. 209–210) repeated some of Whitney's data. Fairbanks (1894, p. 519) noted that Miocene rocks along the Arroyo Seco "are folded together and contorted into every conceivable position." Hamlin (1904, p. 53) described the channel of the Arroyo Seco and stream terraces along it that "mark successive periods of uplift." He discussed (p. 56–57, 59–69) dam sites along the Arroyo Seco and (p. 79) irrigation canals supplied by water from the stream. He also included (pls. 7–10) photographs taken in the area. Aubury (1906, p. 292) mentioned "a belt of infusorial earth" that he believed extends to the Arroyo Seco from the southeast. Lawson and others (1908, p. 409) noted that after the great San Francisco earthquake of 1906 the flow of water at Paraiso Springs increased and the temperature of the hot water, which had been diminishing for some time, returned to normal. Waring (1915, p. 60–62) described Paraiso Springs, gave chemical analyses of the water, and

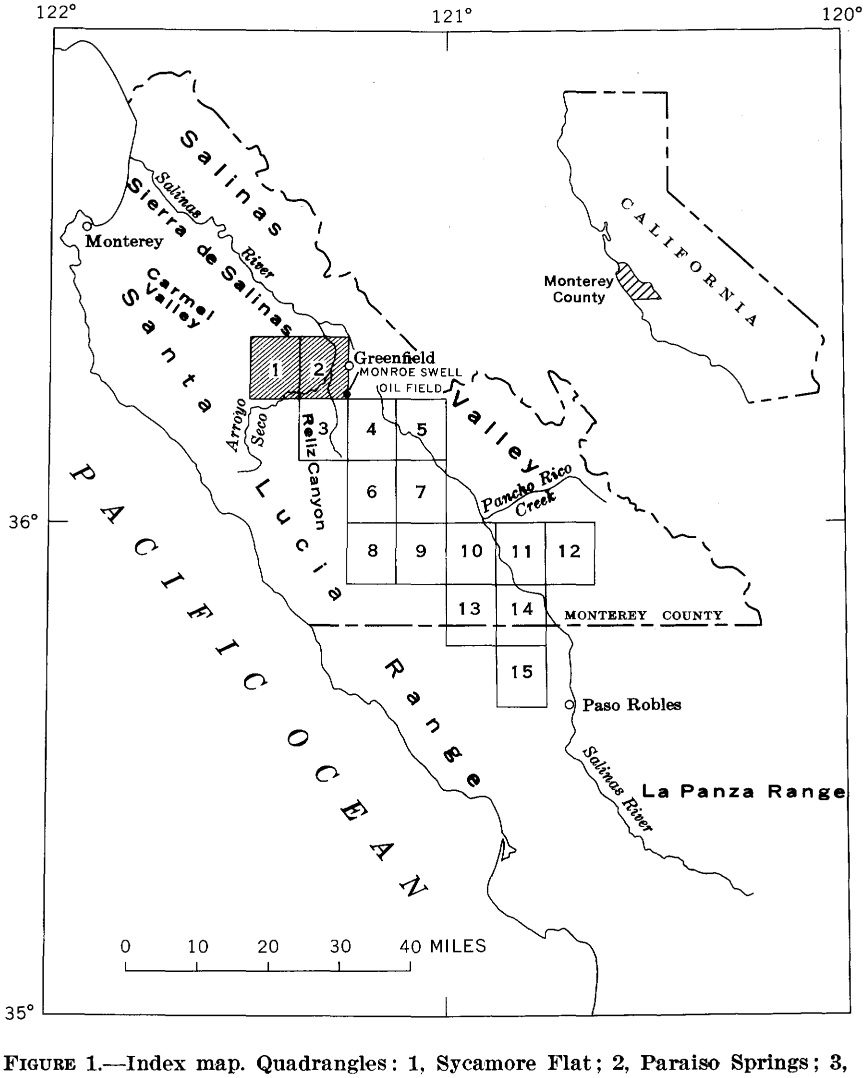

FIGURE 1.—Index map. Quadrangles: 1, Sycamore Flat; 2, Paraiso Springs; 3, Reliz Canyon; 4, Thompson Canyon; 5, San Lucas; 6, Cosio Knob; 7, Espinosa Canyon; 8, Jolon; 9, Williams Hill; 10, Hames Valley; 11, Wunpost 12, Valleton; 13, Tierra Redonda Mountain; 14, Bradley; 15, Adelaida.

included (pl. 4) a photograph of the resort developed around the springs. Waring's information was repeated by Waring and Bradley (1917, p. 607–609) and by Laizure (1925, p. 45–47).

Vander Leck (1921, p. 85) described "a body of coarse white and yellow sandstone about 2,000 feet thick, containing near the base conglomerate beds made up of fragments of Monterey shale," exposed south of the mouth of the Arroyo Seco and noted folded Monterey Shale farther west. He gave reported "seepages of black asphaltic oil" on the north bank of Paloma Creek about the center of sec. 21, T. 19 S., R. 5 E., and at a fork in Piney Creek near the W¼ cor. sec. 12, T. 19 S., R. 4 E., and evaluated the oil potential of the area. He also mentioned (p. 87) large alluvial fans on the flank of the Sierra de Salinas and concluded that "a fault of considerable magnitude probably parallels the west side of the Salinas River." Willis and Wood (1922) showed faults in the Sierra de Salinas and Arroyo Seco areas on a fault map of California. Reed (1925, p. 593) described the conformable contact between the Monterey Shale and overlying sandstone beds at three localities along and south of the Arroyo Seco and showed (fig. 1) the King City fault along the northeast margin of the "Palo Escrito Range" (Sierra de Salinas). Clark (1930, p. 767) mentioned that beds "equivalent to" the "Jacalitos" horizon occur in the Arroyo Seco district. Nickell (1931) summarized the geology of the Soledad 15-minute quadrangle, the south half of which coincides with the Sycamore Flat and Paraiso Springs 7½-minute quadrangles. Reed (1933, p. 44) stated that evidence of faulting along the east flank of the Sierra de Salinas (King City fault) is chiefly physiographic. Taliaferro (1935, p. 453) listed the properties of a chert sample from the Monterey Shale in the Arroyo Seco area.

Schombel (1943) presented an uncolored geologic map (scale about 1:125,000) of the Soledad 15-minute quadrangle, the south half of which covers the Sycamore Flat and Paraiso Springs quadrangles. He included structure sections, a composite columnar section, and a brief discussion of general geology and petroleum exploration. Taliaferro (1943, p. 121, 158–159) mentioned Miocene paleogeography of the Sierra de Salinas and discussed the King City fault, Reliz fault, and the anomalous east and west trend of structural features near the Arroyo Seco. Bramlette and Daviess (1944) showed the distribution of the basement complex and Vaqueros Sandstone in the Salinas Valley area. The beds that they assigned to the Vaqueros in their report are here assigned to the Tierra Redonda Formation. They also gave columnar sections for Tash Creek and the area west of Paraiso Springs and tabulated information on wells drilled for oil in the area. Fiedler (1944, p. 234–238) described faults that extended southeastward into the Sycamore Flat quadrangle. Kilkenny (1948, p. 2266, fig. 1) placed the King City fault along the margin of the Sierra de Salinas and gave (p. 2258) the age and stratigraphic position of his Sandholdt Formation (the Sandholdt Member of the Monterey Shale of this report) in the Paraiso Springs area.

Hill and Dibblee (1953, p. 455) mentioned the Reliz (Canyon) fault and included it and the King City fault on a map of lateral faults in California (pl. 1).

Schwade, Carlson, and O'Flynn (1958, fig. 4) showed "lower Miocene nonmarine" strata overlying basement complex at the south end of the Sierra de Salinas. Gribi (1963a, p. 16) mentioned alluvial fans west of Greenfield and (p. 23) evidence of right-lateral movement along the Reliz fault. He described (p. 19) sandstone in the subsurface in the Monroe Swell oil field area and (p. 24) the structure there. In another paper Gribi (1963b, p. 76–77) presented data on the Monroe Swell oil field, including a structure section and structure contour map. A California Department of Water Resources report (1964) shows the pattern of faults at the south end of the Sierra de Salinas and the epicenters of earthquakes there of 4.0 or greater magnitude. Goldman (1964, p. 22) tabulated data on sand and gravel deposits of the Arroyo Seco. Gower and Madsen (1964, p. D81) listed an occurrence of pellet phosphate beds in roadcuts along the Arroyo Seco. Christensen (1965, p. 1113) cited work by K. G. Snetsinger reporting stream terrace deposits as high as 1,600 feet above the bed of the Arroyo Seco. Compton (1966b, pl. 1, fig. 4) included the southernmost part of the Sycamore Flat and Paraiso Springs quadrangles on horizontal sections of the area to the south and cited (p. 1367) E. A. Gribi, Jr., for information on folds in alluvial fans near Paraiso Springs. Dickert (1966, p. 295–296) mentioned phosphate localities in the Arroyo Seco and Paloma Creek areas. Hart (1966, p. 76–77) gave information on the Monroe Swell oil field, on sand and gravel deposits of the Arroyo Seco area (p. 99, 101, 104–105, 106, 135, 136, 138), and on Paraiso Springs (p. 74). Gribi (1967, p. 91) and Rogers, Gribi, Thorup, and Nason (1967, p. 23–24) mentioned the northerly extension of the Reliz fault along the east side of the Sierra de Salinas.

FIELDWORK AND ACKNOWLEDGMENTS

The Sycamore Flat and Paraiso Springs quadrangles were mapped during the years 1966–1968 on aerial photographs of about 1:20,000 scale, and the field data were compiled on topographic maps of 1:24,000 scale. R. L. Bendixon assisted with the mapping along and south of the Arroyo Seco in 1966; R. J. McLaughlin, with the mapping near Piney Creek in 1967.

Many landowners and U.S. Forest Service personnel at the Arroyo Seco Guard Station were helpful in providing access to parts of the area. R. R. Thorup, consulting geologist, Pebble Beach, Calif., provided the location of USGS fossil localities M3707 and M3708.

Patsy B. Smith, of the U.S. Geological Survey, identified foraminifers from the Monterey Shale; W. O. Addicott, also of the Geological Survey, collections of larger fossils.

STRATIGRAPHY

GENERAL FEATURES

Marine strata of middle and late Miocene and Pliocene age, and nonmarine beds of Pliocene and Pleistocene(?) age overlie the pre-Tertiary basement complex at the south end of the Sierra de Salinas. These strata constitute a conformable stratigraphic sequence comprising four major units: the Tierra Redonda Formation, Monterey Shale, Pancho Rico Formation, and Paso Robles Formation. Quaternary fluviatile sediments unconformably overlie the older units. Plate 4 shows stratigraphic relations, lithologic character, and thickness of stratigraphic units in the map area. Table 4 contains some subsurface data from wells.

Table 6, under the section "Fossil localities," gives the location of fossil localities in the area; table 1 and the list on page 31 give fossils of the Tierra Redonda Formation; tables 2 and 3, fossils of the Sandholt Member of the Monterey Shale and Pancho Rico Formation, respectively. All fossil localities given in tables and referred to in text are U.S. Geological Survey localities.

PRE-TERTIARY BASEMENT COMPLEX

Plutonic and metamorphic rocks of the basement complex are undifferentiated on the accompanying geologic maps (pls. 1, 2). The plutonic rocks are generally correlated with those in the Santa Lucia Range named the Santa Lucia Granite by Lawson (1893, p. 6) and more commonly called the Santa Lucia Granodiorite. The associated metamorphic rocks are ordinarily assigned to the Sur Series of Trask (1926, p. 127). The basement complex crops out across the northern part of the map area, along the southwest border of the Sycamore Flat quadrangle, and in structurally elevated patches across the middle of that quadrangle. At least three wells drilled for oil in the map area reportedly reached the basement complex (table 4, Nos. 6, 11, 16).

The basement complex includes a wide variety of rocks; pelitic mica schist is probably the most common type in the metamorphic terrane, and granodiorite or adamellite appears to form most of the plutonic terrane. Aplite dikes are abundant in the basement complex, and pegmatite dikes cut the plutonic rocks at some localities. Pink orthoclase phenocrysts are conspicuous at places in the plutonic rocks, most noticeably along Basin Creek and upper Sand Creek. Marble crops out by the dam on Piney Creek near the W¼ cor. sec. 12, T. 19 S., R. 4 E.

The plutonic rocks of the map area are part of the Coast Range granitic basement, which has been radiometrically dated as Cretaceous at a number of places (Compton, 1966a, p. 277). They intrude metamorphic rocks that formed mainly from Mesozoic or older strata (Compton, 1966a, p. 286).

TERTIARY SYSTEM

MIOCENE SERIES

TIERRA REDONDA FORMATION

Sandy marine strata that overlie the basement complex in the map area are assigned to the Tierra Redonda Formation. The type locality of the formation (Durham, 1968a) is about 40 miles southeast of the Arroyo Seco in the Tierra Redonda Mountain quadrangle (fig. 1, No. 13), where the unit conformably overlies the lower Miocene Vaqueros Formation and intertongues with and underlies the lower and middle Miocene Sandholdt Member of the Monterey Shale. Farther southeast, the Tierra Redonda lies unconformably on undifferentiated Paleocene and Cretaceous beds in the Adelaida quadrangle (Durham, 1968b) and disconformably on the basement complex at the north end of the La Panza Range. Use of the name Tierra Redonda Formation is here extended from the type locality to sandy beds in the southern Salinas Valley area that overlie either the Vaqueros Formation or older rocks and that underlie and locally intertongue with the Sandholdt Member of the Monterey Shale. Thus, the Tierra Redonda Formation is a middle Miocene counterpart of the upper Miocene Santa Margarita Formation, a sandstone unit that overlies and intertongues with the upper part of the Monterey Shale in the southern Salinas Valley area (Durham and Addicott, 1964, p. E3–E4). The term Tierra Redonda Formation for the sandstone at the base of the stratigraphic sequence in the map area seems preferable to names applied previously to the unit, such as "Temblor sandstone" (Nickell, 1931, p. 314), "Monterey sandstone" (Schombel, 1943, p. 467), "Vaqueros sandstone" (Bramlette and Daviess, 1944), and "Vaqueros-Temblor sandstone" (Fiedler, 1944, p. 194).

The Tierra Redonda Formation crops out in a narrow belt at the margin of the basement complex, in structurally elevated patches farther south, and near Paraiso Springs. The Tierra Redonda disconformably overlies the basement complex. The contact is obscure at most places, but is well exposed along a dirt road about 2,000 feet west of Big Sand Creek, near fossil locality M3244 (sec. 30, T. 18 S., R. 5 E.). There massive friable sandstone fills irregularities in the underlying basement rocks, and granitic boulders and cobbles are scattered in sandstone near a horizon about 10 feet above the base of the unit.

Sandstone and conglomerate beds that crop out in a fault block at the head of Basin Creek (secs. 27, 34, 35, T. 18 S., R. 5 E.; pl. 1) are only questionably assigned to the Tierra Redonda because they include red beds and are lithologically dissimilar to much of the Tierra Redonda nearby. Similar rocks near Paraiso Springs are included in the Tierra Redonda, although Jennings and Strand (1959) considered them nonmarine beds of Oligocene age.

LITHOLOGY

The Tierra Redonda Formation is chiefly arkosic sandstone, but conglomerate is common in the unit and minor amounts of mudstone occur in it also. The sandstone is mainly massive or poorly bedded and ranges from fine to coarse grained. The rock generally is poorly sorted and locally contains granules and pebbles from the basement complex. The sand grains are commonly angular or subangular and are chiefly feldspar and quartz, although mica flakes and basement-rock fragments are conspicuous in the rock at some places. The color of the weathered sandstone ranges from very light gray through very pale orange and yellowish gray to pinkish gray and grayish red. The sandstone is friable to well indurated, and some has a calcite matrix. It commonly forms bold outcrops.

Conglomerate that contains pebbles and cobbles of rocks like those in the nearby basement complex is interbedded with sandstone of the Tierra Redonda Formation. The larger clasts range from angular to well rounded, and those clasts that are more angular are the most common. Clasts as large as boulders are scarce. Beds of conglomerate are less common than are sandstone beds that contain conglomerate lenses or scattered pebbles and cobbles.

THICKNESS

The Tierra Redonda Formation is about 500 feet thick near Tash Creek (measured on structure section *D–E*, pl. 3). The thickness appears greater farther east near Basin Creek and Paraiso Springs, but because the structural relations there are obscure, the thickness is uncertain. The formation probably thins and pinches out to the south, for it is unrecognized in exploratory wells drilled in the southern part of the map area. Contemporaneous beds that crop out just south of the map area are shaly rather than sandy and belong to the Sandholdt Member of the Monterey Shale.

AGE AND CONDITIONS OF DEPOSITION

Fossil mollusks from the Tierra Redonda Formation in the map area are listed in table 1. According to W. O. Addicott (written commun., 1967, 1968), the faunas at USGS localities M3247, M3705, M3707, and M3708 indicate either the early Miocene "Vaqueros Stage" or the middle Miocene "Temblor Stage" of the Pacific coast megafaunal sequence of Weaver and others (1944); the faunas at localities M3248 and M3706 indicate the middle Miocene "Temblor Stage"; the fauna at locality M3244 is Miocene in age; and the fauna at locality M3245 could be either Miocene or Pliocene. He pointed out that *Amussiopecten lompocensis* of locality M3706 is restricted to strata of middle Miocene age and that *Turritella ocoyana* found at the same locality "may be suggestive of middle Miocene age here because it has never been found associated with early Miocene assemblages north of the

TABLE 1.—*Fossil mollusks from the Tierra Redonda Formation*

[Identified by W. O. Addicott. ×, present as identified; ?, doubtful identification; cf., similar form, specimen(s) incomplete or too poorly preserved for definite identification; aff., comparable but apparently different form; sp., species not determinable; n. sp., new species]

	USGS locality							
	M3244	M3245	M3247	M3248	M3705	M3706	M3707	M3708
Gastropods:								
Calyptraea sp.						×		
Conus sp.			×			×	×	
Diodora? cf. *D. rixfordi* (Hertlein)			×					
Neverita sp.						×		
?*Oliva* sp.			×					
Turritella ocoyana Conrad						×	×	×
Pelecypods:								
Aequipecten andersoni (Arnold)				×		?		
andersoni forma *subandersoni* (Loel and Corey)					×			
Amussiopecten lompocensis (Arnold)						×		
sp.		×						
Chione sp.						×		×
Diplodonta sp.			×					
Dosinia sp.			×				×	
Florimetis aff. *F. hiangulata* (Carpenter)			×					
Glycymeris branneri Arnold			×					
Isognomon aff. *I. panzana* (Loel and Corey)			×					
Lima (*Limaria*) n. sp.			×					
Lucina excavata Carpenter			×					
Lucinoma sp.			×					
Lyropecten miguelensis Arnold							×	
Macoma? cf. *M. secta* (Conrad)	×							
Miltha cf. *M. sanctaecrucis* (Arnold)			×			×		
Mytilus expansus Arnold			×					
cf. *M. schencki* Hanna and Hertlein	×							
sp.		×						
Ostrea sp.	×		×				×	
Pitar n. sp.			×					
Tellina cf. *T. idae* Dall								×
Trachycardium vaquerosensis (Arnold)			×					
?*Trachycardium* sp.							×	

southeasternmost part of San Luis Obispo County." He added, "biostratigraphic studies by J. G. Vedder in the eastern part of the Caliente Range, San Luis Obispo County, suggest that *Lyropecten miguelensis* (loc. M3707) ranges from 'Vaqueros Stage' into the lowest part of the 'Temblor Stage'."

Fossil foraminifers (identified by Patsy B. Smith) from the Tierra Redonda Formation at locality Mf1015 (Sec. 29, T. 18 S., R. 5 E.), which is in a thin mudstone unit that is a few feet stratigraphically below megafossil locality M3706 and that is just above the base of the formation, are as follows:

Bolivina advena striatella Cushman
guadeloupae Parker
tumida Cushman
Buliminella subfusiformis Cushman
Cassidulina cf. *C. crassa* d'Orbigny
Dentalina obliqua (Linné)
Nonionella incisa (Cushman)
Nonion costiferum (Cushman)
Robulus smileyi Kleinpell
Saracenaria beali (Cushman)
Uvigerinella obesa Cushman
Valvulineria californica Cushman
miocenica Cushman
Virgulina californiensis Cushman

According to Patsy B. Smith (written commun., 1968), the foraminiferal fauna indicates the middle Miocene lower(?) Luisian Stage of Kleinpell (1938).

Fossil localities M3248, M3706, and Mf1015, which have faunas assigned to a middle Miocene age in terms of common usage in the California Coast Ranges, are all near the base of the Tierra Rodonda Formation, and thus in the map area the Tierra Redonda probably is no older than middle Miocene. Furthermore, the overlying Sandholdt Member of the Monterey Shale, where exposed in the map area, contains foraminiferal faunas of the middle Miocene Luisian Stage of Kleinpell (1938) that thus restrict the Tierra Redonda to an age no younger than middle Miocene. Thus, the middle Miocene age of the Tierra Redonda in the map area seems well established.

The marine fossils in the Tierra Redonda Formation indicate a marine origin for at least part of the unit. According to W. O. Addicott (written commun., 1968), the molluscan faunas from the Tierra Redonda in the map area "represent a shallow water nearshore environment. Genera such as *Miltha*, *Lyropecten*, and *Dosinia* suggest a warm-temperate to subtropical shallow-water temperature regime comparable to that of the Gulf of California and southwestern coast of Baja California." The fossil foraminifers from locality Mf1015, however, suggest bathyal depth (Patsy B. Smith, oral commun., 1968).

MONTEREY SHALE

Blake (1855) named the Monterey Shale, rather unintentionally, in his description of strata exposed near the town of Monterey, about 25 miles northwest of the map area. Outcrops of the Monterey are nearly continuous from the type locality through Carmel Valley into the Sycamore Flat quadrangle. The Monterey crops out over most of the southern part of the Sycamore Flat quadrangle and of the southwestern part of the Paraiso Springs quadrangle. It is especially well seen in roadcuts and streambanks near Arroyo Seco (fig. 2) and Paloma Creek.

The contact between the Sandholdt Member of the Monterey Shale and the underlying and locally intertonguing Tierra Redonda Formation is poorly exposed in the map area, but the two units are apparently conformable (pl. 4). The contact is at the top of the stratigraphically highest sandstone unit beneath calcareous mudstone of the Sandholdt. Sandstone interbeds in calcareous mudstone of the Sandholdt, for example in roadcuts in sec. 25, T. 18 S., R. 4 E., suggest

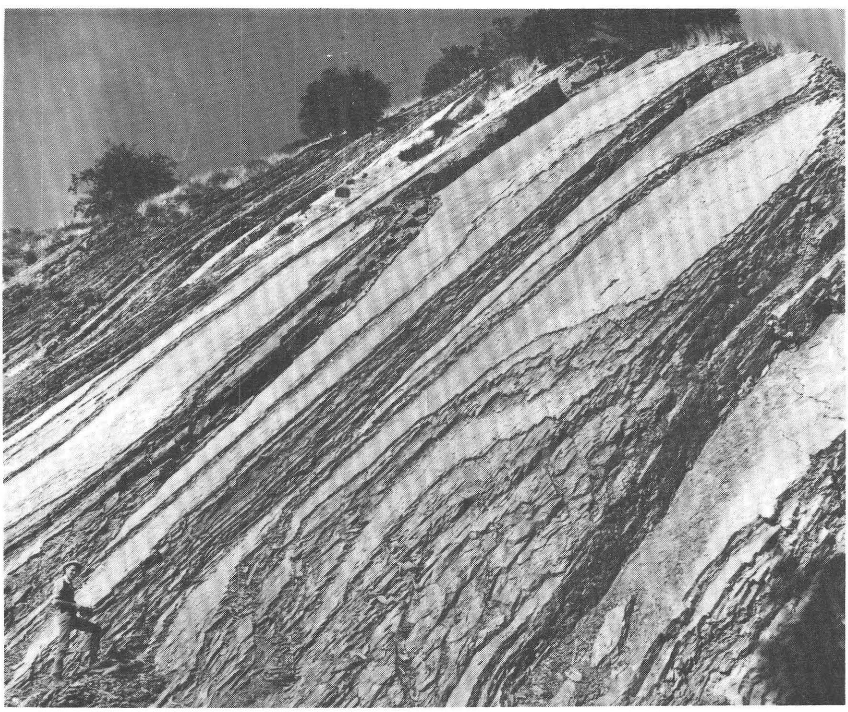

FIGURE 2.—Porcelaneous rocks of the Monterey Shale that form dip slopes by the Arroyo Seco in sec. 28, T. 19 S., R. 5 E.

intertonguing or gradation of the Tierra Redonda and Monterey. The absence of the Tierra Redonda from the middle Miocene stratigraphic sequence exposed just south of the map area indicates that the Tierra Redonda and Sandholdt intertongue southward in the subsurface.

SANDHOLDT MEMBER

The type locality of the Sandholdt Member of the Monterey Shale is in Reliz Canyon about 4 miles south of the Paraiso Springs quadrangle (Durham, 1963, p. 15). The unit corresponds approximately to the Sandholdt Formation of Thorup (1941, p. 1958) and the Sandholdt Shale of Bramlette and Daviess (1944), but includes beds stratigraphically higher than those originally assigned to the Sandholdt in the type area by Thorup.

The Sandholdt Member crops out mainly in the northern part of the Monterey Shale outcrop area, near exposures of basement complex and Tierra Redonda Formation. It consists chiefly of calcareous mudstone and shale, in contrast to the upper part of the Monterey, which lacks calcareous mudstone and is predominantly porcelaneous and cherty rock. The contact between the Sandholdt and upper part of the Monterey is poorly exposed in the map area, but it appears to be conformable and also gradational in that some porcelaneous rocks are interbedded with calcareous mudstone near the top of the Sandholdt. The contact is at the top of the stratigraphically highest calcareous mudstone beds.

LITHOLOGY

Porcelaneous Rocks

Porcelanite is a silica-cemented rock that is less hard, dense, and vitreous than chert and has the dull luster of unglazed porcelain (Bramlette, 1946, p. 15). According to X-ray analysis, it consists largely of cristobalite, quartz, and opal (R. A. Gulbrandsen, oral commun., 1962). Porcelanite grades through porcelaneous mudstone into clastic mudstone as the ratio of clastic material to silica matrix in the rock increases.

Porcelanite and porcelaneous mudstone are by far the most common rocks in the upper part of the Monterey Shale; more rarely they occur in the Sandholdt Member. The porcelaneous rocks range from thin bedded (fig. 2) to thick bedded or massive, but generally the thickness of the beds is 3–18 inches; the bedding surfaces are uneven. The rocks have a wide color range, but most commonly are yellowish gray, very pale orange, pinkish gray, or light olive gray. Some porcelaneous rocks contain conspicuous streaks and bands of brownish-black chert, which thin sections show is mainly fibrous chalcedony.

The porcelaneous rocks are hard and brittle and generally break into hackly pieces along joints spaced a fraction of an inch to several inches apart. The porcelaneous mudstone commonly contains some mica flakes, and thin sections of the rock generally show scattered angular very fine sand grains. Some porcelanite and porcelaneous mudstone beds contain molds of clam shells, molds of foraminifers, fish scales, and diatom remains. At some places the porcelaneous rocks include thin interbeds of bentonitic clay and at a few places they contain phosphatic pellets and nodules. Gypsum is common along some bedding or joint surfaces.

Mudstone

The Monterey Shale contains both calcareous and noncalcareous mudstone. Calcareous mudstone is restricted to the Sandholdt Member, and noncalcareous mudstone is most common in the upper part of the formation.

Noncalcareous mudstone is composed largely of clay, silt, and scattered very fine or fine sand grains, cemented by silica. It is similar to the porcelaneous rocks in color, bedding, and jointing. The rock commonly contains fish scales, molds of foraminifers, and small black charcoallike chips.

Calcareous mudstone of the Sandholdt Member ranges from laminated or platy to massive (fig. 3) and has a hackly fracture. It is generally very pale orange and contains clay, silt, scattered fine sand grains, and silica. Remains of foraminiferal tests are abundant, and fish scales and molds of clam shells are common. The calcareous nature of the rock is probably due entirely to the foraminiferal tests that it contains, for K. J. Murata (written commun., April 1967; cited in full in Durham, 1968a) found this to be the sole source of calcite in calcareous mudstone of the Sandholdt Member from other places in the southern Salinas Valley area. A thin section of calcareous mudstone associated with banded cherty rock of the Sandholdt in sec. 30, T. 18 S., R. 5 E., has abundant foraminiferal tests and a few angular fine sand grains, as well as numerous areas filled with fibrous chalcedony. The calcareous mudstone contains phosphatic pellets at fossile locality Mf971 in sec. 12, T. 19 S., R. 4 E. (Patsy B. Smith, written commun., 1968).

Sandstone

Arkosic sandstone in beds as thick as 2 feet is interbedded with calcareous mudstone of the Sandholdt Member at a few places, generally near the base of the unit. Calcite cements the sandstone and forms veins in it. A thin section of medium-grained sandstone from near fossil locality Mf964 in sec. 25, T. 18 S., R. 4 E., contains angular feldspar and quartz grains, as well as some biotite flakes, all separated by coarsely crystalline calcite.

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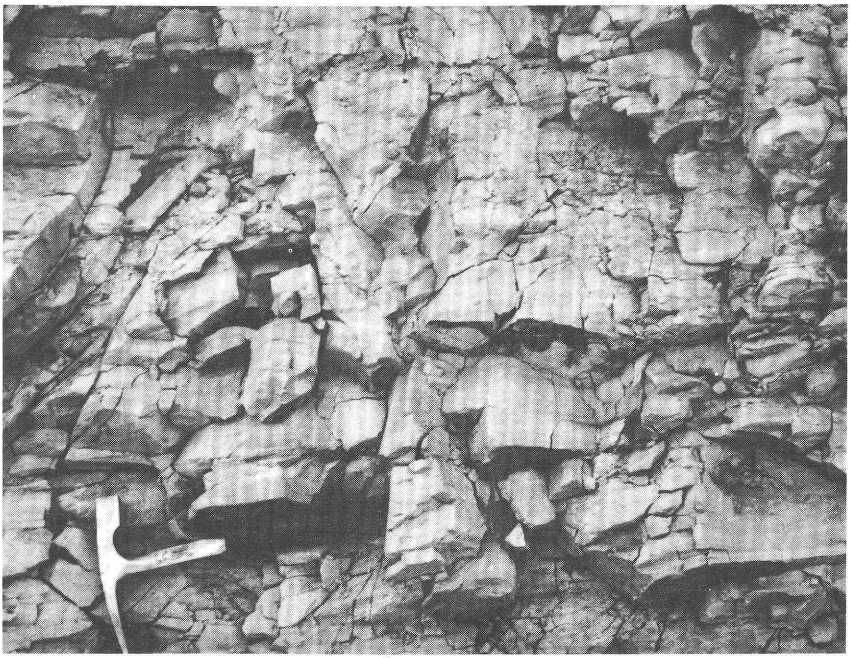

FIGURE 3.—Massive hackly calcareous mudstone of the Sandholdt Member of the Monterey Shale exposed in bank of Paloma Creek in sec. 7, T. 19 S., R. 5 E.

Sandstone units in the subsurface in the eastern part of the Paraiso Springs quadrangle (structure sections *B–C* and *F–G*, pl. 3) intertongue with the upper part of the Monterey Shale and also lie on the basement complex beneath the Monterey. These units include the Beedy sand, Doud sand, and 44 sand, all oil zones in the Monroe Swell oil field area (Gribi, 1963b). Because these sandy units intertongue with the upper part of the Monterey, they might properly be called Santa Margarita Formation, but on the structure sections they are shown simply as sandstone units within the Monterey.

Carbonate Beds and Concretions

Dolomitic carbonate rock forms beds and ellipsoidal concretions in both the Sandholdt Member and the upper part of the Monterey Shale. The thickness of the beds is generally 1–2 feet; the thickness of the concretions is also 1–2 feet, and their length is 2–4 feet. The concretions lie with their longest axes parallel to the bedding surfaces. The rock is hard, dense, and resistant to weathering, so at many places it forms bold outcrops. Calcite commonly forms veins and cavity fillings in the beds and concretions. The exposed rock is ordinarily dark yellowish orange or moderate yellowish brown. Concretions are especially well seen in cuts along the trail by Piney Creek about 1,000 feet northwest of the center of sec. 18, T. 19 S., R. 5 E.

THICKNESS

Determination of the thickness of the Monterey Shale in the map area is hampered by the severe deformation of the unit and by the lack of marker beds in it. The thickness of the Sandholdt Member of the Monterey is apparently no greater than 400 feet near Tash Creek (measured on structure section *D–E*, pl. 3), but the unit thickens southward, as shown diagrammatically on structure section *D–E*. Well data suggest that the thickness of the Sandholdt is greater than 3,500 feet in The Texas Lewis 1 well (structure section *A–B*, pl. 3) and greater than 4,500 feet in the Humble Oil and Refining Thorup 1 well (structure section *B–C*, pl. 3).

The thickness of the upper part of the Monterey Shale appears to be at least as great as 4,500 feet near the Humble Oil and Refining Thorup 1 well (measured on structure section *B–C*, pl. 3), but could be much greater. The thickness of the Monterey is only about 2,000 feet in The Texas Doud (NCT–1) 1 well (measured on structure section *B–C*, pl. 3) and about 2,200 feet in the Humble Oil and Refining Capital C–1 well (measured on structure section *F–G*, pl. 3). Both wells are in the eastern part of the Paraiso Springs quadrangle, where the basement complex is structurally high and the Sandholdt Member is absent.

AGE AND CONDITIONS OF DEPOSITION

Fossil foraminifers from the Sandholdt Member of the Monterey Shale at 25 localities in the map area are listed in table 2. According to Patsy B. Smith (written commun., 1967, 1968), the faunas are indicative of middle Miocene age and are mainly characteristic of the upper middle Miocene Luisian Stage of Kleinpell (1938).

The porcelaneous and other rocks of the upper part of the Monterey Shale lack fossils of age significance, but must be mainly of late Miocene age on the basis of their stratigraphic position conformably between the Sandholdt Member, which contains fossils of middle Miocene age, and the Pancho Rico Formation, which in nearby areas contains fossils of Pliocene age.

Fossil foraminifers, fish scales, and mollusks in the Monterey Shale demonstrate the marine origin of the unit. According to Patsy B. Smith (written commun., 1967, 1968), the foraminiferal faunas generally typify bathyal or upper bathyal depth, although the fauna at locality Mf971 characterizes neritic depth, the fauna at locality Mf966 probably indicates lower neritic depth, and the fauna at locality Mf968 suggests lower neritic or upper bathyal depth. The fauna at locality Mf963 probably denotes the inner shelf.

TABLE 2.—*Fossil foraminifers from the Sandholdt Member of the Monterey Shale*

[Identified by Patsy B. Smith. X, present as identified; cf., similar form, specimen(s) incomplete or too poorly preserved for definite identification; sp., species not determinable; ?, doubtful identification]

	USGS locality																								
	Mf921	Mf922	Mf923	Mf924	Mf955	Mf956	Mf959	Mf960	Mf961	Mf962	Mf963	Mf964	Mf965	Mf966	Mf967	Mf968	Mf969	Mf970	Mf971	Mf972	Mf1012	Mf1014	Mf1016	Mf1017	Mf1018
Age or stage of Kleinpell (1938)	Middle Miocene	Luisian Stage	Luisian Stage	Lower (?) Luisian Stage	Luisian Stage	Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Lower Luisian Stage	Luisian Stage	Middle Miocene	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Upper Luisian Stage	Luisian Stage	Lower(?) Luisian Stage	Lower(?) Luisian Stage
?*Annonia beccarii* (Linné)																			X						
Anomalina salinasensis Kleinpell																				X					
Baggina californica Cushman								X	X			X	X			X		X				X	X		X
robusta Kleinpell										X										X				X	
Bolivina advena advena Cushman					X			X						cf.					X				X		
advena striatella Cushman		X		X		X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X
californica Cushman								X		X			X					X							
cf. *B. decurtata* Cushman																			X						
floridana Cushman													X					X				X			
guadaloupae Parker		X	X	X			X		X	X	X					X	X	X	X			X			X
imbricta Cushman					X		X	X			X	X					X			X	X				
rhomboidalis (Millett)								X		X			X							X					
salinasensis Kleinpell						X	X	X	X	X			X		X	X	X	X							
tumida Cushman							X	X	X	X	X		X			X	X	X	X			X			
Bulimina montereyana Kleinpell					X		X	X			?		X		X					X					

Buliminella curta Cushman				×			×			×	×	×						×	×		×	×		×	
elegantissima (d'Orbigny)											×														
subfusiformis Cushman			×			×		×		×	×	×	×	×	×	×	×	×	×						×
Cassidulina cf. *C. crassa* d'Orbigny																			×						
cf. *C. pulchella* d'Orbigny								×																	
sp												×	×												
Dentalina obliqua (Linné)									×	×			×				×	×		×		×	×		
Epistominella relizensis (Kleinpell)										×	×		×			×	×	×		×					
Globigerina cf. *G. bulloides* d'Orbigny	×			×																					
cf. *G. pachyderma* (Ehrenberg)																			×						
sp		×	×		×				×	×							×			×		×			×
Globigerinita sp				×																					
Gyroidina reliziana Kleinpell					×			×	×	×		×			×			×		×					
Hanzawaia sp											×														
Legena sp											×														
Nonion costiferum (Cushman)			×	×	×	×	×	×	×	×	×	×	×		×	×	×	×		×	×	×	×	×	×
incisum Cushman																			×						
Nonionella micocenica Cushman								×		×	×			×	×	×	×		×						
Pullenia miocenica miocenica Kleinpell							×			×					×										
miocenica globula Kleinpell								×	×								×	×			×	×	×		
Robulus miocenicus (Chapman)											×								×	×					
smileyi Kleinpell								×	×	×	×	×	×			×		×		×		×	×		
sp																					×				
Saracenaria beali (Cushman)								×	×	×	×	×	×			×	×	×			×	×			
Siphogenerina branneri Bagg																									
collomi Cushman								×	×	×		×	×			×	×			×	×				
reedi Cushman	?	×															×								
sp															×										
Uvigerinella californica californica Cushman				×									×	×				×				×			
obesa Cushman					×				×	×	×	×				×				×					
?*Uvigerinella californica gracilis* Cushman and Kleinpell												×													
Valvulineria californica californica Cushman	×		×	×	×	×	×	×	×	×	×		×	×		×	×	×	×	×	×	×	×	×	×
californica obesa Cushman												×			×		×	×	×						
depressa Cushman				×																				?	?
miocenica Cushman		×		×				×	×	×	×	×				×	×	×	×	×	×	×	×	×	
Virgulina californiensis californiensis Cushman							×	×	×	×			×	×	×	×	×	×	×	×					×

PLIOCENE SERIES

PANCHO RICO FORMATION

Reed (1925, p. 606) "grouped together as the Poncho Rico formation" certain marine beds exposed on the east side of the Salinas Valley and presumably intended that those along Pancho Rico Creek, about 30 miles southeast of the Arroyo Seco, be considered typical of the unit. Durham and Addicott (1964, p. E4) redefined the Pancho Rico Formation to include sandy marine strata and interbedded finer and coarser grained marine rocks that generally overlie the Monterey Shale and underlie the nonmarine Paso Robles Formation in the southern Salinas Valley area. The term Pancho Rico is thus appropriate for the sandy marine beds that overlie the Monterey in the Sycamore Flat and Paraiso Springs quadrangles. Nickell (1931, p. 314) assigned these beds to his Santa Margarita Sandstone, and Schombel (1943, p. 467) assigned them to his Santa Margarita Sandstone, Pancho Rico Sandstone, and Jacalitos sandstone and shale.

The Pancho Rico Formation crops out west of the Reliz fault near the south edge of the map area and east of the fault on both sides of the mouth of the Arroyo Seco. It conformably overlies the Monterey Shale; the contact is well exposed in the bank of the Arroyo Seco about 800 feet east of the highway bridge in sec. 16, T. 19 S., R. 6 E.

LITHOLOGY

The Pancho Rico Formation is chiefly arkosic sandstone, although locally it includes interbedded mudstone and porcelaneous rocks similar to rocks of the Monterey Shale. The sandstone is generally massive, fine grained, and yellowish gray (fig. 4). At some places it contains scattered granules and small pebbles, mainly of quartz. The rock ranges from friable to well indurated and is mainly noncalcareous, although some is calcite cemented. It contains ellipsoidal limy concretions as large as 3 feet, and some concretions are conspicous in bluffs along the Arroyo Seco (fig. 4), where they are localized along particular horizons. The sandstone contains fossils at only a few localities.

THICKNESS

The thickness of the Pancho Rico Formation north of the Arroyo Seco is about 1,250 feet (measured on structure section *F–G*, pl. 3). It is about 850 feet in the Humble Oil and Refining Capital C–1 well (measured on structure section *F–G*) and is apparently only 450–650 feet in the subsurface near the southeast corner of the Paraiso Springs quadrangle (measured on structure section *B–C*, pl. 3).

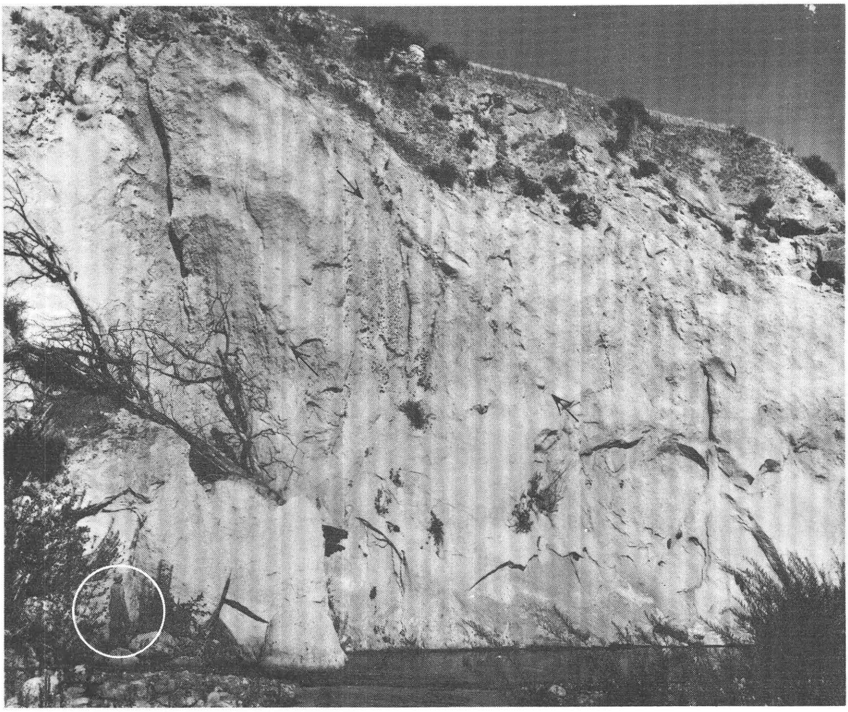

FIGURE 4.—Massive sandstone of the Pancho Rico Formation exposed in north bank of the Arroyo Seco in sec. 16, T. 19 S., R. 6 E. Limy concretions occur along particular horizons (arrows).

AGE AND CONDITIONS OF DEPOSITION

Fossils from four localities in the Pancho Rico are listed in table 3. According to W. O. Addicott (written commun., 1967), the fauna at USGS locality M2900 indicates a late Miocene or early Pliocene age; the fauna at locality M2903, a late Miocene or Pliocene age; the fauna at locality M2904, a Miocene or Pliocene age. He stated that the assemblage from locality M2900 "is similar to collections from the Pancho Rico Formation to the southeast of King City," and "the *Lyropecten* is identical, as far as I can tell, to specimens from an early Pliocene locality near San Lucas (USGS Cenozoic loc. M903)." Although the meager fossil faunas collected from the Pancho Rico in the map area indicate either Miocene or Pliocene age, the unit is considered Pliocene because it contains fossils of Pliocene age in the Reliz Canyon quadrangle at USGS localities M981 and M902, only 1,925 feet and 3,350 feet south of the map area (Durham, 1963, pl. 1).

The fossils in the Pancho Rico Formation demonstrate the marine origin of at least part, and presumably all, of the formation.

TABLE 3.—*Fossils from the Pancho Rico Formation*

[Identified by W. O. Addicott. ×, present as identified; ?, doubtful identification; cf., similar form, specimen(s) incomplete or too poorly preserved for definite identification; sp., species not determinable]

	USGS locality			
	M2900	M2902	M2903	M2904
Gastropods:				
?*Cancellaria*	×			
Pelecypods:				
?*Cyclocardia* sp	×			
Dosinia sp	×			
Florimetis cf. *F. biangulata* (Carpenter)				×
Lyropecten cf. *L. estrellanus* (Conrad)	×			
Macoma nasuta (Conrad)			×	
sp				×
Panope abrupta (Conrad)	×			
Protothaca tenerrima (Carpenter)			×	
?*Saxidomus* sp		×		
Siliqua sp	×			
Solen sp	×		×	×
Tresus cf. *T. nuttalli* (Conrad)		×		
sp				×
Barnacle:				
Balanus gregarius (Conrad)	×			

TERTIARY AND QUATERNARY(?) SYSTEMS

PLIOCENE AND PLEISTOCENE(?) SERIES

PASO ROBLES FORMATION

Fairbanks (1898, p. 565) named the Paso Robles Formation for exposures near the town of Paso Robles, about 50 miles southeast of the map area. South of the Arroyo Seco the Paso Robles Formation crops out on both sides of the Reliz fault; north of the Arroyo Seco, only east of the fault. It appears to overlie the Pancho Rico Formation conformably, but the contact is poorly exposed.

LITHOLOGY

The Paso Robles Formation is mainly pebble conglomerate, but it also contains sandstone and mudstone. The conglomerate is poorly bedded or massive, and some is cross-stratified. Conglomerate commonly fills channels in underlying beds. Pebbles in the formation are chiefly clasts of chert and porcelaneous rocks, presumably derived from the Monterey Shale; however, some are clasts of rocks from the basement complex. The pebbles are scattered in a matrix of poorly sorted sandstone that ranges from moderately friable to well cemented. The larger pebbles are generally rounded.

Sandstone interbedded with conglomerate in the Paso Robles Formation is mainly poorly bedded and poorly sorted or conglomeratic. Mudstone in the formation is generally sandy, massive, and hackly.

THICKNESS

The thickness of the Paso Robles Formation is greater than 1,400 feet (measured on structure section B–C, pl. 3) east of Reliz Canyon, where the upper part of the unit is missing. Data from the Humble Oil and Refining Capital C–1 well (No. 6, structure section F–G, pl. 3) suggests that the total thickness of the Paso Robles and overlying alluvial sediments there is about 2,500 feet; the Paso Robles probably accounts for most of the total thickness.

AGE AND CONDITIONS OF DEPOSITION

The Paso Robles Formation lacks fossils, but apparently it conformably overlies the Pliocene Pancho Rico Formation and unconformably underlies ancient alluvial sediments unrelated to present streams. Thus, by its stratigraphic position the Paso Robles is no older than Pliocene and no younger than Pleistocene. In the map area, as elsewhere in the southern Salinas Valley area, the Paso Robles is assigned a Pliocene and early Pleistocene(?) age.

Poor sorting, crude bedding, cross-stratification, and channeling in the Paso Robles Formation imply that the unit is of nonmarine origin, chiefly fluviatile.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

FANGLOMERATE

Alluvial fans that flank the Sierra de Salinas north of Paraiso Springs consist of fanglomerate that, unlike the Paso Robles Formation, contains basement-complex debris, mainly schist fragments, derived from the nearby highland. The larger clasts in the fanglomerate are generally embedded in a poorly sorted sandy matrix that contains abundant fine mica flakes. The rock is commonly moderate yellowish brown and well indurated.

The fan surfaces preserved in the map area slope 400 feet or more per mile. Valleys dissect the fans and expose fanglomerate as thick as 200 feet. The fanglomerate obviously predates the older alluvium deposited in the valleys that cut the fans; unlike the Paso Robles Formation, it appears undeformed. It is thus younger than the Pliocene and Pleistocene(?) Paso Robles, older than at least part of the Pleistocene and Holocene(?) older alluvium, and is therefore considered to be of Pleistocene age.

PLEISTOCENE AND HOLOCENE(?) SERIES

OLDER ALLUVIUM

Older alluvium covers the flatlands in the northeastern part of the Paraiso Springs quadrangle and floors the larger stream valleys. It also covers remnants of stream terraces preserved along the Arroyo Seco (fig. 5) and some of its tributaries. Small patches of older al-

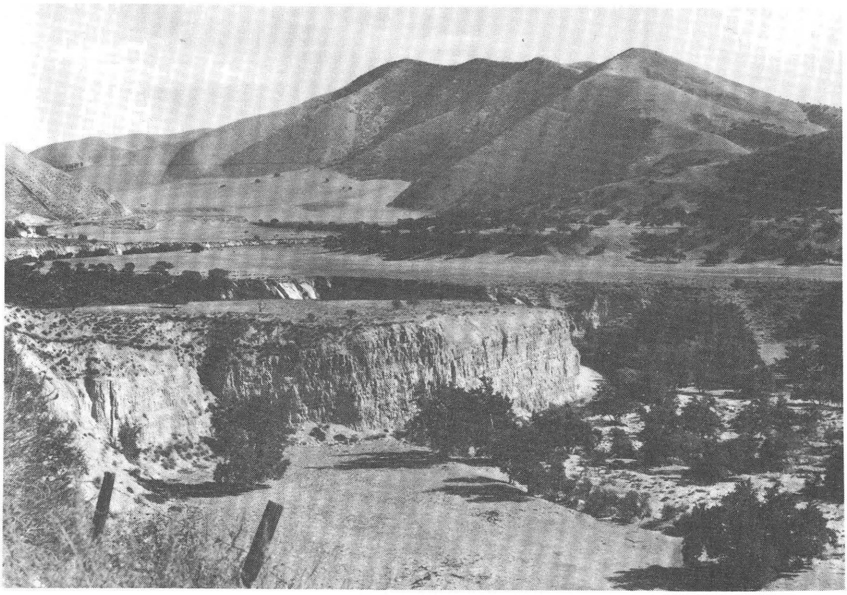

FIGURE 5.—River terraces, capped by older alluvium, 120 feet and higher above the bed of the Arroyo Seco. View eastward from just north of the center of sec. 19, T. 19 S., R. 6 E.

luvium on hills north of the Arroyo Seco in sec. 8, T. 19 S., R. 6 E., are at an elevation of about 1,900 feet, or about 1,500 feet above the modern bed of the Arroyo Seco.

The older alluvium consists of unconsolidated or semiconsolidated sandy gravel that includes cobbles and boulders. The larger clasts are mainly of basement rocks, but some are of sandstone or Monterey Shale. Older alluvium near the base of the hills just north of the mouth of the Arroyo Seco contains breccia composed of angular fragments of porcelaneous rock well cemented in an earthy calcareous matrix.

The thickness of the older alluvium exposed in the banks of the Arroyo Seco near projected sec. 10, T. 19 S., R. 6 E., is 40–50 feet and could be greater farther northeast. At most places the thickness of the older alluvium in terrace remnants is no greater than 5–10 feet, although at the gravel pit in sec. 15, T. 19 S., R. 6 E., the thickness is apparently greater than 50 feet.

Older alluvium in patches west of Tash Creek, in and west of sec. 30, T. 18 S., R. 5 E., consists almost entirely of granitic debris and apparently represents remnants of an old fanlike deposit of low relief formed along the flank of a basement highland to the north. Obviously the older alluvium in these patches predates older alluvium along streams that have dissected the fanlike deposit.

The age relations of fanglomerate and topographically high remnants of older alluvium are unclear. If, as seems likely, some topographically high patches of older alluvium predate at least part of the uplift of the Sierra de Salinas, then they should also predate at least part of the fanglomerate, which must have accumulated during or after elevation of the mountains. Older alluvium in valleys that cut the fans, however, is younger than the fanglomerate. Thus the older alluvium appears to represent a considerable time span, beginning after deposition of the Paso Robles Formation in Pliocene and Pleistocene(?) time. It is considered to be of Pleistocene and possible Holocene age.

DEBRIS-FLOW MATERIAL

Debris-flow material covers an area greater than a square mile in and around sec. 32, T. 18 S., R. 6 E., in front of the steep hills southeast of Paraiso Springs. It is poorly exposed, but seems to consist mainly of angular fragments of Monterey Shale that are embedded in an earthy matrix. The jumbled arrangement of the clasts in the material, together with physiographic evidence of an upslope scar where the material originated and a frontal lobate edge where it came to rest, indicates that the deposit represents one or more debris flows, rather than fan or stream-terrace sediments. It appears to be younger than at least part of the older alluvium.

HOLOCENE SERIES

ALLUVIUM

Alluvium forms the beds of streams in the map area, but only along the Arroyo Seco is it extensive enough to show properly at the scale of the geologic maps (pls. 1, 2). It consists of sand and gravel and contains clasts as large as cobbles and boulders. The clasts reflect the diverse basement and sedimentary terranes in the Arroyo Seco watershed. The thickness of the alluvium is no greater than 10–20 feet, except possibly in the bed of the Arroyo Seco in the northeastern part of the Paraiso Springs quadrangle.

STRUCTURE

GENERAL FEATURES

Tertiary sedimentary rocks near the Arroyo Seco occupy a reentrant that disrupts the dominant northwest structural trend of the Sierra de Salinas and Santa Lucia Range massif. Consequently, the trend of structural features is more nearly east and west in the map area than in nearby parts of the Coast Ranges.

The basement complex crops out in the northern part of the Sycamore Flat quadrangle and in fault-elevated blocks farther south. Well data show that in the area east of the Reliz fault the concealed basement complex surface is structurally high near the southeast corner of the Paraiso Springs quadrangle (structure section B–C, pl. 3).

FAULTS

The steep northeast-facing scarp of the Sierra de Salinas is generally attributed to uplift of the mountain block along a fault buried by fans on the west side of the Salinas Valley. Reed (1925, p. 590) called this buried feature the King City fault, and Nickell (1931, p. 314) believed that physiographic evidence shows about 4,000 feet of vertical displacement. The fault is presumed to be present but concealed by fanglomerate and older alluvium in the northern part of the Paraiso Springs quadrangle.

The Reliz fault is a major feature that extends southeast from near Paraiso Springs to Arroyo Seco and up Reliz Canyon (pl. 2). It separates older beds exposed on the west side from younger beds exposed to the east along most of its trace in the map area. The fault surface is well exposed in a roadcut on the north side of the Arroyo Seco, where it strikes N. 40° W. and dips 70° SW. in Monterey Shale (fig. 6). Monterey Shale beds on both sides of the fault are crushed and contorted. The fault continues for about 17 miles southeast of the map area and throughout this distance forms a linear zone of brecciated and deformed rock across which the structure of nearby beds is discontinuous.

Nickell (1931, p. 314) considered the Reliz fault, which he named Reliz Canyon fault, a branch of the King City fault. Taliaferro (1943, p. 159) also considered the Reliz fault a branch of the King City fault, or possibly the south end of the King City fault. Hill and Dibblee (1953, p. 454–455) referred to the Reliz (Canyon) and King City faults as probably "characterized by major right lateral components of displacement." Gribi (1963a, p. 23) attributed right lateral movement of "probably no more than a couple of thousand feet" to the Reliz fault and its extension to the south. Later he (1967, p. 91) applied the name Reliz fault to the buried fault along the east margin of the Sierra de Salinas and stated that there it had "at least 10,000 feet of vertical movement."

Direct evidence is lacking in the map area for the nature and magnitude of displacement on the Reliz fault. The exposure of generally older strata on the west side suggests that the feature is a reverse fault, but with considerably less than the 10,000 feet of displacement proposed for it farther north.

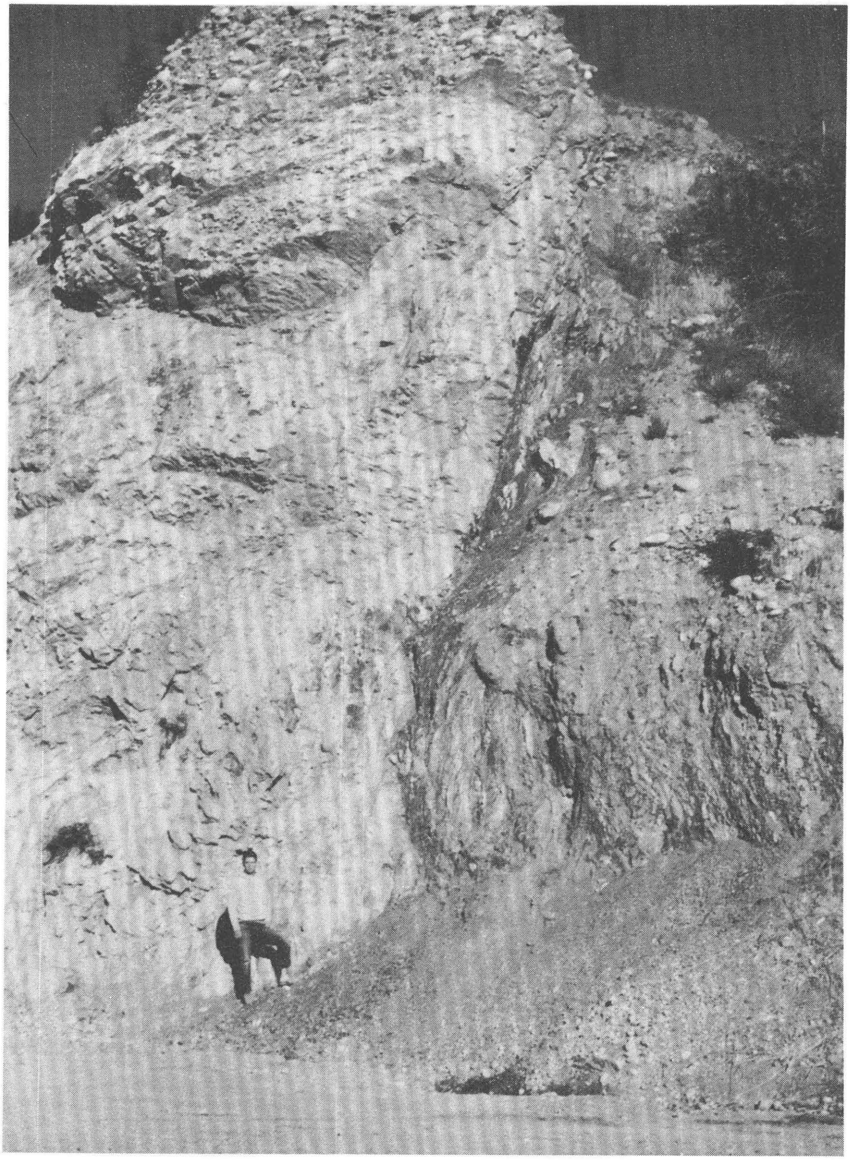

FIGURE 6.—Reliz fault exposed in a roadcut on the north side of the Arroyo Seco at the highway bridge in sec. 16, T. 19 S., R. 6 E. Beds of Monterey Shale on both sides of the fault are crushed and contorted. Stream gravels of the older alluvium at the top of the roadcut are undisturbed by the fault, but have shed debris onto the Monterey Shale below.

A complex fault system trends westward across the map area from near Paraiso Springs to beyond Paloma Creek. Near Paraiso Springs it brings basement complex of the Sierra de Salinas into fault contact with middle Miocene beds. Farther west, in the Sycamore Flat quadrangle, the fault system elevates blocks of basement complex and overlying strata on the south side against Monterey Shale to the north. Cross faults cut these blocks and form a complicated outcrop pattern. The fault system apparently extends at least 15 miles northwest of the map area to include the Paloma and Tularcitos faults of Fiedler (1944, p. 236–238).

Faults bound the basement complex exposed near the southwest corner of the Sycamore Flat quadrangle. The trace of the fault on the east side of the basement complex there suggests a normal fault that dips steeply eastward. It terminates at the north end against another fault, which Fiedler (1944, p. 235–236) called the Bruce Ranch fault and mapped for about 6 miles northwest of the Sycamore Flat quadrangle.

A fault south of the Arroyo Seco near the southeast corner of the Sycamore Flat quadrangle downdrops Pancho Rico Formation on the north side against Monterey Shale to the south. The trace of this fault extends southeast of the map area for about 9 miles (Durham, 1963, pls. 1, 2).

The Reliz fault cuts the Paso Robles Formation of Pliocene and Pleistocene(?) age, and this relationship shows that at least part of the movement on the fault occurred after deposition of that unit. Remnants of stream gravels high above or unrelated to present streambeds suggest considerable uplift of the hills after deposition of some of the older alluvium, probably in the Pleistocene along a fault or faults near the margin of the hills. Direct evidence of earlier faulting is lacking, although the basement rocks of the Sierra de Salinas must have formed a structural high during and perhaps before middle Miocene time, when sediments forming the Tierra Redonda Formation were deposited in the map area.

FOLDS

The Monterey Shale is severely deformed at many places in the map area. North of the Arroyo Seco and west of the Reliz fault, for example, the Monterey forms several large steep-limbed anticlines and synclines and numerous smaller folds, but even the large anticlines and synclines are difficult to follow as far as half a mile. Difficulty in mapping the folds is due both to lack of good exposures and to the masking of larger features by local folds; also, unrecognized faults in the Monterey may terminate or complicate some folds. At most places on the geologic maps (pls. 1, 2), fold trough and crest lines are omitted, and the structure of the Monterey is indicated, where possible, by dip and strike symbols.

ECONOMIC GEOLOGY

PETROLEUM

Nineteen wells were drilled for oil in the Sycamore Flat and Paraiso Springs quadrangles before July 1968 (table 4). Most of the wells apparently were drilled in search of oil from sandstone beds in or under the Monterey Shale.

The small Monroe Swell oil field is on the east boundary of the map area near the southeast corner of the Paraiso Springs quadrangle. According to Gribi (1963b, p. 77), oil there is in sandstone beds of late Miocene age in anticlinal and "shale edge" traps. The Texas Co. discovered the field in 1949 with its Beedy (NCT–2) 1 well (No. 15, pl. 2); however, production was suspended, and the well was finally abandoned. The Bandini Petroleum Doud 54–X well, drilled just east of the Paraiso Springs quadrangle in sec. 19, T. 19 S., R. 7 E., was completed in 1959 as a new pool discovery with an initial production of 72 barrels of 19.2° gravity oil per day from a depth of 2,995–3,174 feet (Barton, 1959, p. 92). Table 5 gives production statistics for the field, which has two productive wells and 20 proven acres.

SAND AND GRAVEL

Alluvium in the bed of the Arroyo Seco and older alluvium west of the mouth of Reliz Canyon have been the source of sand and gravel produced in the map area. According to Hart (1966, p. 135), a pit in projected sec. 23, T. 18 S., R. 6 E., furnished sand and gravel used in 1956–58 "as base and concrete-treated base materials and as aggregate in asphalt concrete" for highway construction. Another deposit in the bed of the Arroyo Seco in projected sec. 35, T. 18 S., R. 6 E., was developed in 1959–60 (Hart, 1966, p. 138). The larger clasts in the alluvium are mainly granitic and metamorphic rocks, but some are sandstone, and some are sedimentary rocks from the Monterey Shale. They are embedded in a matrix of sand and rock fragments that generally forms 25–50 percent of the volume of the alluvium. Hart (1966, p. 101) described the Arroyo Seco alluvium as of marginal quality for portland cement concrete.

Older alluvium in the gravel pit in sec. 15, T. 19 S., R. 6 E., just west of the mouth of Reliz Canyon, is similar in composition to alluvium of the Arroyo Seco. It was used for fill in road construction (Hart, 1966, p. 106).

TABLE 4.—*Wells drilled for oil in the Sycamore Flat and Paraiso Springs quadrangles before July 1968*

[Locations were supplied by the operator or taken from published reports and verified in the field where possible. Stratigraphic nomenclature used in the remarks column is that of the operator or of the authority cited and is not necessarily the same as that used elsewhere in this report. Elevation: from topographic map, t; kelly bushing, kb; ground, gr]

Map No. (pls. 1, 2)	Operator	Well	Location			Year(s) drilled	Elevation (ft)	Total depth (ft)	Remarks (depths in feet)
			Sec.	T. (S.)	R. (E.)				
1	Bandini Petroleum Co	Doud 43-19	19	19	7	1959	988 gr	3,807	Top of Monterey Shale, 1,785; bottom in Miocene (California Oil Fields, 1959, v. 45, no. 2, p. 118); reported formation test, 3,285-3,381, ¼-inch and ½-inch bean, open 1 hr, medium steady blow throughout, recovered 540 ft mud with oil spots, 10 ft 19.2° gravity oil and 90 ft mud with slightly gassy oil spots; top of Doud sand, at 3,550. On structure section *B-C*, pl. 3.
2	Ferguson and Bosworth	Kin-Ark-Pura 1	19	18	6	1965	700 kb	4,035	
3	W. W. Holmes	C.C.W.C. 1	[1]9	19	6	1965	362 kb	5,800	
4	do	Doud 1-13	13	19	6	1967	1,318 kb	3,809	
5	do	Doud 1-14	14	19	6	1965	410 gr	3,725	
6	Humble Oil and Refining Co	Capital Co. C-1	[1]27	18	6	1953	379 kb	6,103	"Santa Margarita, 2,410; Miocene shale, 3,252; bottom in schist" (California Oil Fields, 1953 v. 39, no. 2, p. 101). On structure section *F-G*, pl. 3.
7	do	C. N. Thorup 1	21	19	6	1950	418 gr	7,651	Top of Luisian, 3,040; top of Relizian, 4,600 (Oakeshott and others, 1952, p. 62); reported no oil shows. On structure section *B-C*, pl. 3.
8	do	A. J. Zabala 1	[1]34	18	6	1954	370 t	5,955	"Santa Margarita, 2,765; Monterey Shale, 3,790; bottom in nonmarine Miocene" (California Oil Fields, 1954, v. 40, no. 2, p. 117).
9	Jones Oil Co	Harriman 1	20	19	6	1923-25	630 t	4,608	Monterey Shale, 0-3,000?; Sandholdt shale, 3,000?-4,608; oil and gas shows, 3,897-3,917, 4,132 (Bramlette and Daviess, 1944); a little gas produced (Schombel, 1943, p. 467); reported, flowed 26° gravity oil for short time (Kilkenny, 1948, p. 2267); also called Harriman Jones Oil Co. No. 1.
10	do	Harriman 2	21	19	6	1925-26	525	2,631	Monterey Shale, 0-2,631 (Bramlette and Daviess, 1944).

11	Luard Corp.	Marini 1	[1] 18	19	7	1961	397 kb	5,010	Monterey Shale, 2,900; basement complex, 4,980 (California Oil Fields, 1961, v. 47, no. 2, p. 147); bottom in basement complex (Popenoe, 1962, p. 1008).
12	Mayo, Luther T.	Deliamore 1	21	19	5	1963	790 gr	3,310	
13	Santa Fe Drilling Co.	Suter 1	[1] 11	19	6	1962	390 gr	4,021	"Base Santa Margarita, 2,690; bottom in Miocene" (California Oil Fields, 1962, v. 48, no. 2, p. 171).
14	The Texas Co.	Arroyo Seco 1	11	19	5	1939	2,324	4,265	Monterey Shale, 0–2527?; Sandholdt Formation, 2,527?–4,265; 30°–70° dips (Bramlette and Daviess, 1944); bottom in "silty shale (upper Relizian) that dips 45°"; "cored only thin sandstone beds" (Schombel, 1943, p. 467). On structure section *A–B*, pl. 3.
15	do.	Beedy (NCT-2) 1	19	19	7	1949	946 kb	3,300	Beedy zone, upper Miocene, 2,220–2,435 (Jennings and Hart, 1956, p. 54); reported on pump 6–29–49, 75 bbl per day rate, 50 percent cut; 6–30–49, 13 bbl per day, 14.0° gravity, 5 percent cut; 7–6–49, 14 bbl per day, 17.8° gravity, 7 percent cut; 7–14–49, 11 bbl per day, 16 percent cut.
16	do.	Doud (NCT-1) 1	24	19	6	1950	1,534 gr	4,120	Base of Paso Robles Formation, 945; top of basal sand, 3,640; top of continental beds, 3,714; bottom in continental beds (Oakeshott and others, 1952, p. 62); bottom in granite (Moody, 1951, p. 1154). On structure section *B–C*, pl. 3.
17	do.	Gould 1	9	19	6	1951	966 gr	6,997	Bottom in middle Miocene (Jennings and Hart, 1956, p. 54), reported tested intervals: 2,103–2,174, 3,300–3,500, 4,102–5,342, 3,500–3,800.
18	do.	E. T. Lewis 1	13	19	5	1938	1,224	4,537	Monterey Shale, 0–1,400?; Sandholdt shale, 1,400?–4,537; oil shows, 3,500–4,537; 20°–65° dips, 85° at bottom (Bramlette and Daviess, 1944); bottom in upper Relizian (Oakeshott and others, 1952, p. 27); bottom in "silty shale (upper Relizian) with 90° dips" (Schombel, 1943, p. 467). On structure section *A–B*, pl. 3.
19	Westates Petroleum Corp.	Doud 44	19	19	7	1960	820 kb	3,045	Reported top of Monterey Shale, 1,200; top of 44 sand, 2,007; top of Doud sand, 2,748; base of Doud sand, 2,954; pumped 20–23 bbl per day, 85 percent cut.

[1] Projected section.

TABLE 5.—*Production from Monroe Swell oil field*

[Data taken from California Oil Fields: 1959, v. 45, no. 2, p. 56; 1960, v. 46, no. 2, p. 112; 1961, v. 47, no. 2, p. 87; 1962, v. 48, no. 2, p. 110; 1963, v. 49, no. 2, p. 72; 1964, v. 50, no. 2, p. 100; 1965, v. 51, no. 2, p. 95; 1966, v. 52, no. 2, p. 21]

Year	Oil (bbl)	Water, including water in emulsion (bbl)	Year	Oil (bbl)	Water including water in emulsion (bbl)
1959	10, 541	2, 102	1964	7, 944	5, 249
1960	8, 705	3, 365	1965	6, 856	5, 970
1961	10, 160	6, 518	1966	7, 470	4, 302
1962	9, 254	6, 318			
1963	8, 327	6, 310	Total	69, 257	40, 134

PHOSPHATE

A few thin beds of pellet phosphate crop out in porcelaneous rocks of the Monterey Shale on a ridgetop about 1,400 feet west of the SE. cor. sec. 8, T. 19 S., R. 5 E., and thin phosphate pellet and nodule beds crop out in a roadcut about 700 feet N. 70° W. of the SE. cor. sec. 21, T. 19 S., R. 5 E. Patsy B. Smith (written commun., 1967) reported pellet phosphate in the Sandholdt Member of the Monterey Shale at fossil locality Mf971, in sec 12, T. 19 E., R. 4 E.

MINERAL WATER

Paraiso Springs was an active hot springs resort for many years following its development late in the nineteenth century. Although the popularity of such resorts eventually declined, the hot springs property was still active in 1967 as a recreational area.

Early Spanish settlers at Soledad Mission, located about 5 miles to the north, used the waters of Paraiso Springs for bathing. Peale (1886, p. 207) listed the springs as a resort in 1886 and included (p. 214) a chemical analysis of the water. Waring (1915, p. 60), who also gave (p. 61) chemical analyses of the water, stated that at least five springs rise in the area and attributed to the largest a discharge of about 8 gallons of water per minute at a temperature of 111°F. The hot mineralized water was used for bathing and drinking.

FOSSIL LOCALITIES

The location of fossil localities in the map area is given in table 6.

TABLE 6.—*Fossil localities*

USGS loc.	Location: Quadrangle	Sec.	T.(S.)	R.(E.)	Stratigraphic unit	Type of fossils: Foraminifers	Gastropods	Pelecypods	Barnacles
Mf921	Paraiso Springs	6	19	6	Sandholdt Member of Monterey Shale.	X			
Mf922	do	6	19	6	do	X			
Mf923	do	6	19	6	do	X			
Mf924	do	6	19	6	do	X			
Mf955	Sycamore Flat	36	18	5	do	X			
Mf956	do	2	19	5	do	X			
Mf959	do	17	19	5	do	X			
Mf960	do	7	19	5	do	X			
Mf961	do	7	19	5	do	X			
Mf962	do	6	19	5	do	X			
Mf963	do	1	19	4	do	X			
Mf964	do	25	18	4	do	X			
Mf965	do	1	19	4	do	X			
Mf966	do	25	18	4	do	X			
Mf967	do	30	18	5	do	X			
Mf968	do	30	18	5	do	X			
Mf969	do	1	19	4	do	X			
Mf970	do	1	19	4	do	X			
Mf971	do	12	19	4	do	X			
Mf972	do	2	19	4	do	X			
Mf1012	do	33	18	5	do	X			
Mf1014	do	9	19	5	do	X			
Mf1015	do	29	18	5	Tierra Redonda Formation	X			
Mf1016	do	29	18	5	Sandholdt Member of Monterey Shale.	X			
Mf1017	do	3	19	5	do	X			
Mf1018	do	9	19	5	do	X			
M2900	Paraiso Springs	5	19	6	Pancho Rico Formation		X	X	X
M2902	do	8	19	6	do			X	
M2903	do	25	19	5	do			X	
M2904	do	25	19	5	do			X	
M3244	Sycamore Flat	30	18	5	Tierra Redonda Formation			X	
M3245	do	30	18	5	do			X	
M3247	do	30	18	5	do		X	X	
M3248	do	31	18	5	do			X	
M3705	do	32	18	5	do			X	
M3706	do	29	18	5	do		X	X	
M3707	Paraiso Springs	31	18	6	do		X	X	
M3708	do	31	18	6	do		X	X	

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