Geology of the Tierra Redonda Mountain and Bradley Quadrangles Monterey and San Luis Obispo Counties California

GEOLOGICAL SURVEY BULLETIN 1255

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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 Tierra Redonda Mountain and Bradley quadrangles are on the west side of the southern Salinas Valley. They include the lower reaches of the San Antonio and Nacimiento Rivers, which join the Salinas River near Bradley.

The following strikingly different, but largely contemporaneous, stratigraphic sections are juxtaposed in the map area across the Jolon fault:

Southwest of Jolon fault

Paso Robles Formation:
Pliocene and Pleistocene(?), nonmarine.
Santa Margarita Formation:
Upper Miocene, marine.
Monterey Shale:
Miocene, marine (includes the lower and middle Miocene Sanholdt Member).
Tierra Redonda Formation:
Lower and middle Miocene, probably marine.
Vaqueros Formation:
Lower Miocene, marine.
Unnamed formation:
Upper Cretaceous and lower Tertiary, at least partly marine.

Northeast of Jolon fault

Paso Robles Formation:
Pliocene and Pleistocene(?), nonmarine.
Pancho Rico Formation:
Lower Pliocene, marine.
Monterey Shale:
Miocene, marine (includes the upper Miocene Buttle Member and—in the subsurface—the Sandholdt Member).
Vaqueros Formation:
Lower Miocene, marine (subsurface only).
Granitic basement complex:
(subsurface only).

The Vaqueros Formation unconformably overlies older strata southwest of the Jolon fault, but overlies the granitic basement complex in the subsurface northeast of the fault. The Tierra Redonda Formation underlies and intertongues with the Sandholdt Member of the Monterey Shale southwest of the Jolon fault, but apparently is absent northeast of the fault. The Paso Robles Formation southwest of the Jolon fault conformably overlies the Santa Margarita Formation and unconformably overlies older units, whereas the Paso Robles northeast of the fault conformably overlies the Pancho Rico Formation and generally is only slightly discordant to the Monterey Shale.

The Jolon fault trends northwest across the map area. Regional relations indicate right-lateral displacement of at least 11 miles along the fault. The rocks were probably faulted and deformed mainly during and after deposition of the Pliocene and Pleistocene (?) Paso Robles Formation.

Diatomite, sand, gravel, and rock have been produced commercially in the map area. At least 24 unsuccessful exploratory oil wells were drilled in the area before 1966.

INTRODUCTION

PURPOSE AND SCOPE

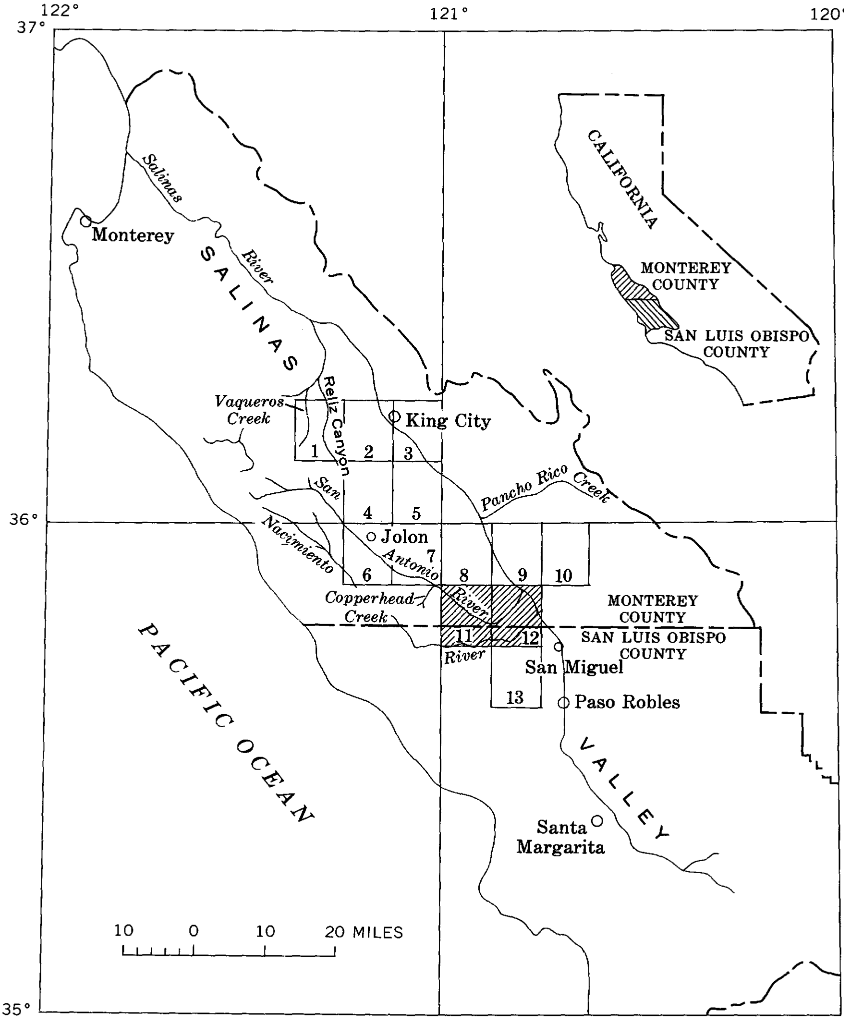
Cenozoic strata cover more than 2,250 square miles in the southern Salinas Valley area. These rocks are important both locally for their mineral resources and more generally for the clues that they contribute toward an understanding of the geologic history of the California Coast Ranges. U.S. Geological Survey investigation in the valley is concerned chiefly with the character, distribution, and structure of these rocks. The work involves preparation of reports that describe the geology of selected quadrangles and of a more general paper on the regional geology of the southern Salinas Valley area. This report covers the Tierra Redonda Mountain and Bradley quadrangles; it includes a geologic map of each quadrangle (pls. 1 and 2), structure sections across them (pl. 3), and a list of fossil localities in the map area (table 8). 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, 1965a), and the Hames Valley, Wunpost, and Valleton quadrangles (Durham, 1966).

LOCATION OF AREA

The Tierra Redonda Mountain and Bradley quadrangles are on the west side of the Salinas Valley, in southern Monterey and northern San Luis Obispo Counties, Calif. (fig. 1). The quadrangles include the lower reaches of San Antonio and Nacimiento Rivers, which join the Salinas River in the Bradley quadrangle. The Tierra Redonda Mountain quadrangle covers the easternmost part of Hunter Liggett Military Reservation and contains the Nacimiento and San Antonio Dams. The Bradley quadrangle covers the northern part of Camp Roberts Military Reservation.

PREVIOUS WORK

Some of the earliest geological investigators in California inspected and wrote about places in the Tierra Redonda Mountain and Bradley quadrangles, and many later workers also reported geological data



1. Reliz Canyon
2. Thompson Canyon
3. San Lucas
4. Cosio Knob
5. Espinosa Canyon
6. Jolon
7. Williams Hill
8. Hames Valley
9. Wunpost
10. Valleton
11. Tierra Redonda Mountain
12. Bradley
13. Adelaida

FIGURE 1.—Location of quadrangles mapped in southern Salinas Valley.

from parts of the area. Whitney (1865, p. 145–147) described beds exposed along the lower course of the Nacimiento River, between the Nacimiento and San Antonio Rivers, and on bluffs east of the Salinas River. He also mentioned (p. 147–148) terraces along the Nacimiento River and a "flow" of bitumin near the San Antonio River. Goodyear (1888, p. 85–86) discussed bituminous sandstone and associated beds near the San Antonio and Nacimiento Rivers and referred to a cold sulphur spring near the San Antonio River. Dall and Harris (1892, p. 210) summarized the stratigraphic section exposed along the Nacimiento River 6–8 miles from its mouth. Fairbanks (1900, p. 144) reported outcrops of tar sand near the San Antonio River and a well drilled there for oil. Eldridge (1901, p. 411; 1903, p. 303) also recorded outcrops of bituminous rocks along the San Antonio River and gave a brief description of the strata exposed nearby (p. 411). Hamlin (1904, p. 19) mentioned bituminous sandstone beds exposed along the San Antonio River, discussed the rocks there, and listed nearby oil wells. He (1904, p. 16) remarked that the Paso Robles Formation covers a large area near Bradley. In addition, he reported (p. 33) an artesian water well half a mile southeast of Pleyto and suggested a dam site (p. 51) on the San Antonio River. Anderson (1905, p. 189) reported that the Santa Margarita Formation crops out along the Nacimiento River.

Arnold (1906, p. 18) mentioned that the Vaqueros Formation is present at Lynchs (Tierra Redonda) Mountain, and he stated (p. 70) that Lynchs Mountain is the type locality of *Pecten* (*Chlamys*) *sespeensis* var. *hydei*. Aubury (1906, p. 292–293) recorded outcrops of infusorial earth (diatomite) in a belt through secs. 4, 9, and 10, T. 24 S., R. 10 E. Arnold and Anderson (1907, pl. 15, fig. 1) figured *Purpura vaquerosensis* from the Vaqueros at Lynchs (Tierra Redonda) Mountain. Eakle (1914, p. 69) noted that diatomaceous earth near Bradley grades into the Monterey Shale. Waring (1914, p. 435–436) listed wells drilled near outcrops of tar-impregnated sandstone along the San Antonio River. Nomland (1917, p. 304) stated that the Santa Margarita Formation is exposed extensively along the Nacimiento and San Antonio Rivers. He asserted that the Santa Margarita there lies unconformably on the Monterey Shale and listed the fossil fauna from the Santa Margarita near the Nacimiento River. Waring and Bradley (1917, p. 596) wrote that oil-impregnated sandstone exposed near the Nacimiento River had been quarried for use on roads and bridges. English (1918, p. 229) mentioned the Santa Margarita Formation west of the Salinas River and discussed (p. 240–243) the geology and petroleum possibilities of the "Pleyto oil district," an early name for the area near outcrops of tar-impregnated sandstone along the San Antonio River. He concluded (p. 227) that oil and tar in the sandstone originated in the Salinas (Monterey) Shale. His report included a geologic map of the district (fig. 36) and a list of the wells drilled for oil (p. 242–243). He also summarized (p. 234, 236–240) the geology and petroleum possibilities of the area near Bradley and mentioned (p. 240) oil sands along the Nacimiento River.

Vander Leck (1921, p. 87) stated that a fault along the edge of the hills northeast of the San Antonio River trends across the river into San Luis Obispo County in sec. 34, T. 24 S., R. 10 E. He indicated that the Paso Robles Formation crops out along the axis of a small syncline farther east at the bend in the San Antonio River and reported a tar seep near there. He also mentioned (p. 89) an anticline near Bradley. Laizure (1925, p. 32–33, 36) gave an account of diatomite mining and prospecting in secs. 4, 14, and 15, T. 24 S., R. 10 E. Reed (1925, p. 593) described the upper contact of the Monterey Shale along the San Antonio River (secs. 26, 29, and 34, T. 24 S., R. 10 E.) and in Sulphur Canyon (sec. 3, T. 25 S., R. 10 E.). He reported (p. 595) a fault along the east side of the exposures of the Santa Margarita Formation near the Nacimiento River, overturned beds of the Santa Margarita in Sulphur Canyon, and (p. 606) folds that involve the Pancho Rico Formation and older units to the same degree. Wilson (1931, p. 102) listed fossil diatoms from diatomaceous rocks at the top of the Monterey Shale in the Bradley quadrangle (SW¼ sec. 26, T. 24 S., R. 10 E.) and noted that in addition to diatoms the rock contains fossil fish remains, sponge spicules, radiolarians, and silicoflagellates. He correlated (p. 104) the diatomaceous strata with part of the Monterey Shale in Reliz Canyon and at its type area near Monterey. Clark (1932, p. 394) assigned a pre-Miocene age to a fault (presumably the Jolon fault) that trends across the Tierra Redonda Mountain and Bradley quadrangles and pointed out the contrast in the stratigraphic sections juxtaposed across the feature. Loel and Corey (1932, p. 117–120) listed the fossil fauna from the Vaqueros Formation at a locality near Tierra Redonda Mountain (sec. 3, T. 25 S., R. 9 E.) and at another locality south of Bee Rock (sec. 7, T. 25 S., R. 10 E.).

Kleinpell (1938, p. 131, 133) mentioned a possible structural discordance between strata of his Mohnian and Delmontian Stages along the lower Nacimiento River. Taliaferro (1943a, p. 140) noted that the upper contact of the Monterey Shale along the Nacimiento River is gradational and mentioned (p. 153–154, 158) the San Marcos fault. He described in another paper (Taliaferro, 1943b) the geology of the Bradley 15-minute quadrangle, the south half of which covers the Tierra Redonda Mountain and Bradley 7½-minute quadrangles. Bramlette and Daviess (1944) gave information on wells drilled for oil in the area and mentioned Pliocene tar sands and an unconformity at the base of the Santa Margarita Formation near the San Antonio River. Taliaferro (1944, p. 487) stated that lateral variation of Upper Cretaceous strata is especially abrupt in the southern part of the Bradley 15-minute (Tierra Redonda 7½-minute) quadrangle and asserted

(p. 501) that "fossils occur rather abundantly" there in Upper Cretaceous beds. Kilkenny (1948, p. 2258, 2267) presented information on wells drilled for oil in the area, mentioned (p. 2260–2261) tar sand along the San Antonio River, and discussed (p. 2264) the San Marcos fault. Kilkenny and others (1952) included the Shell Oil Branch 1 and 2 wells on a structure section across the Salinas Valley. Forrest and Gribi (1963, p. 129–130) mentioned an anticline in Sulphur Canyon, tar sands exposed along the San Antonio River, and the old Pleyto well, which oozes heavy oil in warm weather. Kilkenny (1963, p. 55) also mentioned the oozing of heavy oil from the old Pleyto well. Mandra (1963a, p. 99) reported at least 11 species of silicoflagellates from diatomaceous beds near Buttle Canyon. He (1960a, b; 1963b) described the diatomaceous unit and proposed that it be named the Buttle Diatomite, and defined it as a member of the Monterey Formation. Manning (1963, p. 109) explained the purpose of the Nacimiento Dam.

FIELDWORK AND ACKNOWLEDGMENTS

The Tierra Redonda Mountain quadrangle was mapped at intervals from 1962 to 1966; D. C. Wiese assisted with the mapping in 1962, and T. L. Winder, in 1965. The Bradley quadrangle was mapped in 1964, with the assistance of R. J. McLaughlin. Mapping was done on aerial photographs of about 1:20,000 scale, and the field data were compiled on topographic maps of 1:24,000 scale.

The lake behind the Nacimiento Dam filled for the first time early in 1958 and part of the Nacimiento River valley flooded before fieldwork for this report began. The extent of alluvium and older alluvium shown on the geologic map of the Tierra Redonda Mountain quadrangle (pl. 1) in that part of the valley, however, was taken from aerial photographs made in 1956. The geologic mapping in the San Antonio River valley was completed before the San Antonio Dam was finished in 1965.

Many landowners in the map area were helpful in providing access to their property, as were U.S. Army authorities at Camp Roberts. W. S. Harris, of Texaco, Inc., and E. A. Gribi, Jr., geologist, King City, Calif., kindly provided information on some of the wells drilled for oil in the area.

W. O. Addicott identified collections of larger fossils and visited the field several times to collect at some localities. J. Wyatt Durham identified an echinoid from the Santa Margarita Formation. Patsy J. Smith identified foraminifers from the area.

STRATIGRAPHY

GENERAL FEATURES

Strata exposed in the map area range in age from Late Cretaceous to Recent. The oldest beds crop out in the southern part of the Tierra Redonda Mountain quadrangle, and in general the exposed beds are progessively younger northeastward. This pattern is complicated by a striking difference in the succession of formations and thickness of units on opposite sides of the Jolon fault. Table 1 summarizes the contrasts in stratigraphic section across the Jolon and nearby San Marcos faults, and plate 4 gives a pair of composite generalized stratigraphic sections for the mapped area. Granitic basement complex is reported to have been reached in the Shell Oil Branch 1 well.

TABLE 1.—*Contrasts in the Miocene to Pleistocene(?) stratigraphic sections across the Jolon and San Marcos faults*

System	Series		Southwest of Jolon and San Marcos faults	Between Jolon and San Marcos faults	Northeast of Jolon fault
Tertiary and Quaternary(?)	Pliocene and Pleistocene(?)		Paso Robles Formation: (Uncomformably overlies Monterey Shale and Tierra Redonda Formation).	Paso Robles Formation: (Conformably overlies Santa Margarita Formation).	Paso Robles Formation: (Conformably overlies Pancho Rico Formation; overlaps onto and locally unconformably overlies Monterey Shale).
Tertiary	Pliocene		(Beyond limits of deposition of Pancho Rico Formation.)	(Beyond limits of deposition of Pancho Rico Formation.)	Pancho Rico Formation: (Conformably overlies and intertongues with Buttle Member of Monterey Shale.)
	Miocene	Upper	Monterey Shale: (Santa Margarita Formation and most of upper part of Monterey Shale absent, presumably removed by erosion).	Santa Margarita Formation and Monterey Shale (Contact gradational).	Monterey Shale, including Buttle Member: (Beyond limits of deposition of Santa Margarita Formation).
		Lower and middle	Sandholdt Member of Monterey Shale and Tierra Redonda Formation: (Sandholdt conformably overlies and intertongues with Tierra Redonda; Tierra Redonda conformably overlies Vaqueros Formation).	Sandholdt Member of Monterey Shale: (Tierra Redonda Formation probably present in subsurface).	Sandholdt Member of Monterey Shale: (In subsurface only; Tierra Redonda Formation unrecognized and probably absent in subsurface).
		Lower	Vaqueros Formation: (Unconformably overlies Upper Cretaceous or lower Tertiary strata).	(Vaqueros Formation probably present in subsurface, but difficult to distinguish from Tierra Redonda Formation.)	Vaqueros Formation: (Subsurface only; reportedly overlies granitic basement complex in Shell Oil Branch 1 well).

CRETACEOUS AND TERTIARY SYSTEMS

UNNAMED FORMATION

Strata that underlie the Vaqueros Formation in the southern part of the Tierra Redonda Mountain quadrangle are grouped together and assigned to an unnamed formation of Late Cretaceous and early Tertiary age. The unit apparently occurs only southwest of the Jolon fault, for the Shell Oil Branch 1 well, which was drilled just northeast of the fault, reached the granitic basement complex after penetrating the Vaqueros Formation. The base of the unnamed formation is concealed in the map area.

LITHOLOGY

The unnamed formation is mainly sandstone and conglomerate, but locally mudstone is abundant. The coarser gained sandstone and the conglomerate beds crop out in conspicuous cliffs and ledges at many places, but finer grained sandstone and the mudstone commonly underlie rounded hills that have few exposures. The stratigraphic and areal distribution of rock types in the formation is unsystematic.

Sandstone ranges from fine to coarse grained, and much of it is conglomeratic. The coarse-grained sandstone is most commonly poorly sorted and is found in massive beds several feet thick; some fine-grained sandstone is well sorted and is found in thin beds or laminae. The sandstone is generally noncalcareous, but at a few places contains calcite cement and veins of calcite. It is generally well cemented. Sand grains are chiefly subangular or subrounded and are mainly quartz and feldspar. Biotite is abundant in much of the sandstone, and rock fragments are common locally. Chips of black charcoal-like material are conspicuous in some beds of fine-grained sandstone. The rock is mainly yellowish gray, olive gray, or grayish orange.

Conglomerate occurs both in massive beds as thick as several feet and in lenses or poorly defined layers in sandstone beds. Pebbles, cobbles, and small boulders in the conglomerate are generally well rounded and are chiefly granitic rock, porphyry, and quartzite. The matrix of the conglomerate is sandstone similar to that in adjacent sandstone beds.

Mudstone in the unnamed formation is massive and has a hackly or conchoidal fracture. The rock is generally noncalcareous, or only slightly calcareous, and well cemented. It contains scattered sand grains and abundant small mica flakes and is most commonly olive gray. Limestone beds and concretions are associated with mudstone at some places.

THICKNESS

The total thickness of the unnamed formation is unknown because the base of the unit is concealed in and near the map area. A thickness of at least 2,500 feet for the exposed part of the unit is suggested on structure section *C–D–E* (pl. 3), but the total thickness of the formation is probably much greater.

AGE AND CONDITIONS OF DEPOSITION

Fossils collected from the unnamed formation at fossil locality M2672 (sec. 18, T. 25 S., R. 10 E.) include the following, identified by W. O. Addicott:

Gastropods:
- Naticid
- *Pugnellus* sp.
- *Tessarolax* sp.
- *Turritella* cf. *T. chicoensis perrini* Merriam
- *Turritella peninsularis* Anderson and Hanna (*T. chaneyi* of Merriam, in part)

Pelecypods:
- Arcid
- ?*Glycymeris*
- *Septifer* cf. *S. susanaensis* Nelson
- ?*Solen*

Scaphopod:
- *Dentalium* sp.

Cephalopod:
- *Baculites* sp. (reworked)

According to W. O. Addicott (written commun., 1966), the fauna indicates a Late Cretaceous age. The fossils show a marine origin for at least part of the unnamed formation.

Taliaferro (1944, p. 505) reported foraminifers of Late Cretaceous age from along the Nacimiento River (SW¼SE¼ sec. 18, T. 25 S., R. 10 E.) at the south edge of the Tierra Redonda Mountain quadrangle and from about a quarter of a mile south of the quadrangle (NE¼NE¼ sec. 19, T. 25 S., R. 10 E.). These localities are now probably covered by the water behind the Nacimiento Dam, but they undoubtedly are in strata here assigned to the unnamed formation. Taliaferro also reported (p. 516) mollusks of Paleocene age from 1 to 2 miles south of the Tierra Redonda quadrangle (sec. 30, T. 25 S., R. 10 E.).

TERTIARY SYSTEM

MIOCENE SERIES

VAQUEROS FORMATION

Hamlin (1904) gave the name Vaquero Sandstone to beds that crop out along Vaqueros Creek, 25–30 miles northwest of the map area. The modified term Vaqueros Formation is applied in the Tierra Redonda Mountain and Bradley quadrangles to strata similar in general lithologic character and equivalent in age to part of the sequence of beds named by Hamlin. Modification of "Vaquero" to "Vaqueros" reflects a geographic name change, and use of the term "formation" rather than "sandstone" recognizes the variety of rocks in the unit, both at the type area and in the map area.

The Vaqueros Formation crops out in the southern part of the Tierra Redonda Mountain quadrangle and was reported in several wells drilled for oil in the map area (table 7). It is chiefly fine- to coarse-grained sandstone that is locally conglomeratic. The Vaqueros unconformably overlies older strata in the southern Tierra Redonda Mountain quadrangle, but the basal contact is poorly exposed. The Vaqueros reportedly lies directly on granitic basement complex in the Shell Oil Branch 1 well drilled northeast of the Jolon fault near the San Antonio River (Kilkenny and others, 1952). Fossils are common in the formation; in fact, the most obvious distinction of the Vaqueros from the underlying unnamed formation is the abundance of fossils in the Vaqueros at most places. The Vaqueros also has fewer clasts of larger-than-pebble size and less biotite than the unnamed formation.

LITHOLOGY

Most of the Vaqueros Formation is fine- to coarse-grained sandstone that in places is conglomeratic. The sand grains are mainly quartz and feldspar, and the coarser grains are subangular or subrounded. Pebbles in conglomeratic beds or scattered in the sandstone are well rounded and are mainly granitic rock and porphyry. The rock is generally calcareous, but some of it lacks calcite in the matrix. It ranges from well cemented to friable and from thin bedded to massive. The finer grained sandstone has a hackly fracture. The rock is most commonly grayish orange or yellowish gray. Fossil mollusk shells, shell fragments, or impressions of fossils are common throughout the formation. Some beds several feet thick, for example at fossil localities M2688 and M2692, are composed almost entirely of fossil Turritellas in a sandy matrix. Other beds are composed almost entirely of oyster-shell fragments, and some contain fragments of fossil bone in addition to mollusk shells.

Mudstone in units as thick as several feet is interbedded with sandstone in the Vaqueros Formation at some places. It is massive and has a hackly or conchoidal fracture. The mudstone is noncalcareous, well cemented, and generally yellowish gray or pale olive. It commonly contains imprints of clam shells.

THICKNESS

The thickness of the Vaqueros Formation is about 1,300 feet on the southwest side of Tierra Redonda Mountain (measured on structure sections *C–B* and *C–D–E*, pl. 3). The unit presumably thins southward, for south of the map area in the Adelaida quadrangle, the Tierra Redonda Formation lies directly on strata older than the Vaqueros. This presumed pinching out is shown diagrammatically on structure sections *F–G–H* and *F–I–E* (pl. 3). The thickness of the Vaqueros is apparently about 1,650 feet in the subsurface near the San Antonio River where the formation was penetrated by the Shell Oil Branch 1 well.

AGE AND CONDITIONS OF DEPOSITION

Fossils collected from the Vaqueros Formation in the Tierra Redonda Mountain quadrangle are listed in table 2. According to W. O. Addicott, who identified the fossils (written commun., 1966), *Turritella inezana pervulgata* indicates an early Miocene age ("Vaqueros Stage" of Weaver and others, 1944), and *Bruclarkia barkeriana* indicates either an early or a middle Miocene age. The Vaqueros is considered to be of early Miocene age in the map area.

TABLE 2.—*Fossils from the Vaqueros Formation*

Identified by W. O. Addicott. ×, present as identified; cf., similar form; ?, doubtful identification]

	USGS locality							
	M2670	M2688	M2689	M2691	M2692	M3242	M3249	M3250
Gastropods:								
Bruclarkia barkeriana (Cooper)			×					
Turritella inezana pervulgata Merriam	×	×		×	×		×	×
Pelecypods:								
Anomia vaquerosensis Loel and Corey					×	×		×
Clementia sp.					×			
Lyropecten miguelensis Loel and Corey							cf.	?
Lyropecten sp. (immature specimens)					×			
Small pectinid	×							

TIERRA REDONDA FORMATION

The unit of sandstone and conglomerate that conformably overlies the Vaqueros Formation and underlies and intertongues with the Sandholdt Member of the Monterey Shale is here named the Tierra Redonda Formation. It is named for Tierra Redonda Mountain, its type locality (sec. 10, T. 25 S., R 9 E.), where the base is exposed; the area including Tierra Redonda Mountain, the hamlet of Bee Rock, and upper Harris Creek is considered the type area. The top of the formation is exposed near the southeast corner of the Tierra Redonda Mountain quadrangle; this area is designated as a reference locality. The formation also crops out along the San Antonio River near the center of the quadrangle. Northwestward the Tierra Redonda Formation intertongues abruptly with the Sandholdt Member; as a result, the Tierra Redonda is absent 2 miles west of the map area along Copperhead Creek, and the Sandholdt, which at the base contains foraminifers of the early Miocene Saucesian Stage (Patsy J. Smith, written commun., 1966), directly overlies the Vaqueros Formation. The Tierra Redonda is apparently restricted to the region southwest of the Jolon fault, for wells drilled northeast of the fault reached the Vaqueros Formation without penetrating strata recognized as Tierra Redonda (structure section *F–D–H*, pl. 3). Taliaferro (1943b, fig. 189) included as part of the Vaqueros Formation beds here assigned to the Tierra Redonda Formation, but the Tierra Redonda is a distinct unit that overlies the typically fossiliferous Vaqueros and is partly contemporaneous with the Sandholdt Member of the Monterey Shale.

The Tierra Redonda Formation conformably overlies the Vaqueros Formation. The lower contact of the Tierra Redonda on the south side of Tierra Redonda Mountain is at the base of an unfossiliferous unit of massive friable white medium- to coarse-grained conglomeratic sandstone about 50 feet thick that overlies fossiliferous well-cemented grayish-orange fine-grained sandstone of the Vaqueros. The basal unit of the Tierra Redonda is succeeded by unfossiliferous very pale orange fine-grained calcareous sandstone, which in turn is overlain by massive calcite-cemented sandstone that forms the precipitous upper slope of the mountain. The distinction of the Tierra Redonda Formation from the Vaqueros is based mainly on the absence from the Tierra Redonda of abundantly fossiliferous hackly fine-grained sandstone and mudstone characteristic of the Vaqueros. In addition, sandstone of the Tierra Redonda is commonly white or light gray, whereas that of the Vaqueros is generally darker. Also, boulders are common in the Tierra Redonda but are absent from the Vaqueros.

LITHOLOGY

Sandstone forms the bulk of the Tierra Redonda Formation and is most commonly in beds several feet thick. The rock is fine to coarse grained and is locally conglomeratic. Grains of quartz and feldspar, generally angular or subangular, are about equally abundant in the sandstone. Mica flakes occur in most of the sandstone and are especially conspicuous in some beds. The exposed rock shows a wide range of color but is generally yellowish gray, light gray, or white. Calcareous sandstone is common in the lower part of the formation, and both calcareous and noncalcareous sandstone occur higher in the unit. The calcareous sandstone contains calcite in veins and cavity fillings as well as in the matrix. Thin sections of noncalcareous sandstone generally have some fibrous chalcedony in the matrix. Both the calcareous and noncalcareous rocks range from friable to well cemented. Where the Tierra Redonda Formation and Sandholdt Member of the Monterey Shale intertongue near the San Antonio River, the typically sandy Tierra Redonda includes some interbeds of rocks identical to those in the Sandholdt.

Pebbles and cobbles in the Tierra Redonda Formation are well rounded and are mainly granitic rock and porphyry. Rounded boulders of granitic rock 1–8 feet in greatest dimension occur in the formation in and near Harris Valley, particularly in secs. 26, 27, and 34, T. 24 S., R. 9 E. (fig. 2). The boulder-bearing part of the formation appears to be at least 300 feet thick at the W¼ cor. sec. 26; there the hills on both sides of Harris Creek are covered with large boulders. Boulders in the Tierra Redonda are well exposed in the NE¼ sec. 34 in cuts along a road built in 1966 (not shown on pl. 1); the boulders are scattered along particular horizons in massive fine- and medium-grained sandstone (fig. 3). Boulders of granitic rock also occur in the Tierra Redonda northeast of the San Antonio River (near the center of projected sec. 24 T. 24 S., R. 9 E.) and near the Nacimiento River (NW¼ sec. 9, T. 25 S., R. 10 E.). The source of the huge clasts is unknown.

FIGURE 2.—Boulder conglomerate in the Tierra Redonda Formation exposed near Harris Creek (sec. 27, T. 24 S., R. 9 E.). The larger clasts are of granitic rock.

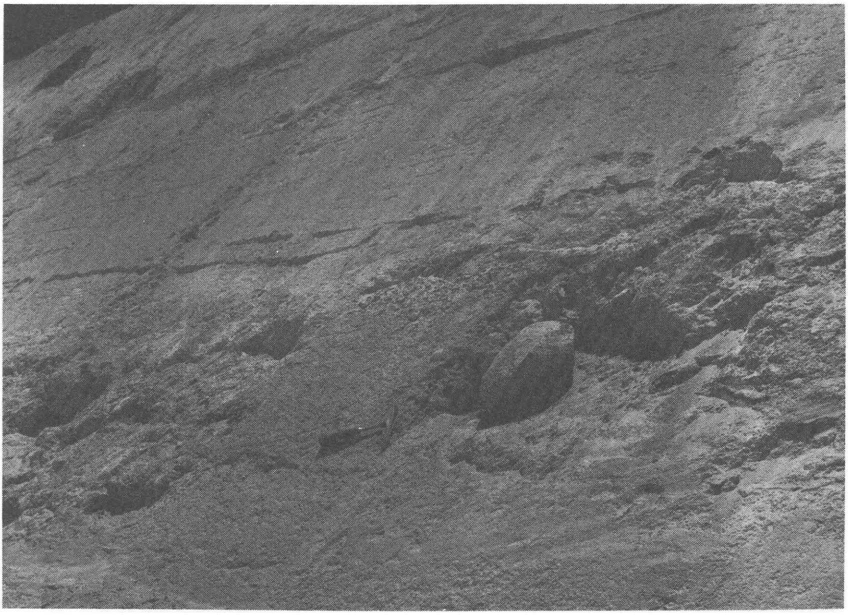


FIGURE 3.—Boulders of granite rock scattered at a particular horizon in massive sandstone of the Tierra Redonda Formation near the center of the NE¼ sec. 34, T. 24 S., R. 9 E.

THICKNESS

The thickness of the Tierra Redonda Formation is probably about 1,650 feet in the type area (estimated from structure section *C–D–E*, pl. 3), but the exact thickness is unknown because exposures of the formation are incomplete in the map area.

AGE AND CONDITIONS OF DEPOSITION

The Tierra Redonda Formation lacks diagnostic fossils. The only fossil found in the unit is an imprint of a pecten shell from sandstone exposed in the east bank of the San Antonio River, east of the center of projected sec. 24, T. 24 S., R. 9 E.; the fossil is too poorly preserved for specific identification (W. O. Addicott, oral commun., 1966). The age of the formation is based upon its stratigraphic relations: its position above the Vaqueros Formation, which locally contains mollusks of early Miocene age near the top; its intertonguing along the San Antonio River with beds of the Sandholdt Member of the Monterey Shale that contain foraminifers of the middle Miocene Luisian Stage (for example, at locality Mf785, projected sec. 24, T. 24 S., R. 9 E.), and its position beneath the lower and middle Miocene

Sandholdt Member of the Monterey Shale elsewhere. The Tierra Redonda Formation is, therefore, assigned an early and middle Miocene age.

The Tierra Redonda Formation is probably marine in origin. Although the unit generally lacks fossils, it also lacks the poor sorting, channelling, and cross-stratification of many nonmarine rocks. The intertonguing of the formation with the Sandholdt Member of the Monterey Shale also is supporting evidence for the marine origin of at least part of the Tierra Redonda.

MONTEREY SHALE

Blake (1855) informally gave the name Monterey to shaly beds exposed at the town of Monterey, about 70 miles northwest of the Tierra Redonda Mountain quadrangle. The Monterey Shale crops out in a structurally complex northwest-trending belt 2–5 miles wide that lies across the central part of the map area. It is present in the subsurface northeast of the outcrop belt, for it has been identified in the cores from several exploratory wells (table 7). The upper part of the Monterey is chiefly porcelaneous and cherty rocks, and the lower part, the Sandholdt Member, is mainly calcareous shale. The Buttle Member, which is present locally at the top of the formation, is mainly diatomite or diatomaceous mudstone.

SANDHOLDT MEMBER

The type locality of the Sandholdt Member of the Monterey Shale is in Reliz Canyon (Durham, 1963, p. 15), about 27 miles northwest of the map area. The unit corresponds approximately to the Sandholdt Shale of Thorup (1941) and of Bramlette and Daviess (1944). The Sandholdt crops out in a belt 1½–2½ miles wide that trends northwest across the map area; several wells drilled to the northeast reached it in the subsurface (table 7).

The Sandholdt Member conformably overlies the Tierra Redonda Formation at most places and intertongues with the Tierra Redonda near the San Antonio River. The Sandholdt is mainly calcareous shale, but includes porcelaneous rocks, chert, dolomitic carbonate rock, limestone, tuff, and sandstone. The lower contact of the Sandholdt is exposed on the north side of the Nacimiento River by the Nacimiento Dam. There it is distinct and marks the base of a thick sequence of shaly beds. Calcareous shale of the Sandholdt is interbedded with sandstone typical of the Tierra Redonda Formation along the San Antonio River in and northwest of sec. 29, T. 24 S., R. 10 E. The predominantly calcareous shale units there are designated as Sandholdt (pl. 1), and the predominantly sandstone units, as Tierra Redonda; at some places, the distinction between the two units is arbitrary.

Information from wells drilled through the Sandholdt Member northeast of the Jolon fault indicates that the Sandholdt overlies the Vaqueros Formation there in the subsurface. The two units presumably are conformable.

The abundance of calcareous shale in the Sandholdt Member distinguishes the unit from the upper part of the Monterey Shale, but siliceous rocks occur in the Sandholdt as well as in the overlying part of the Monterey. The upper contact of the Sandholdt is concealed in the map area, but where it is exposed 7 miles to the west in the Jolon quadrangle, the Sandholdt and overlying part of the Monterey are conformable (Durham, 1965a, p. 11).

BUTTLE MEMBER

Mandra (1960a, p. 4370; 1960b, p. 78–81, 88; 1963b, p. 104) proposed the name Buttle Diatomite for a member at the top of the Monterey Shale composed of diatomaceous beds and gave Buttle Canyon in the NE¼ sec. 15, T. 24 S., R. 10 E., as the type locality. The modified name, Buttle Member of the Monterey Shale, is used here to avoid the implication that the unit is everywhere as richly diatomaceous as it is near the type locality.

The Buttle Member forms a fringe of outcrops along the northeast edge of the belt of Monterey Shale exposed in the map area and crops out just north of the San Antonio River in the heart of a small anticline (sec. 26, T. 24 S., R. 10 E.). The unit is thin south of the river, and its exposures there are discontinuous. Diatomaceous mudstone is interbedded with porcelanite and chert near the top of the Monterey beyond the southeasternmost outcrops of the Buttle shown on plate 2 near the Nacimiento River (unit 20 and below, measured section 2). The Buttle Member is restricted to the part of the map area northeast of the Jolon fault. It occurs north of the map area in the Hames Valley, Wunpost, and Valleton quadrangles, where it was called a diatomaceous mudstone member of the Monterey Shale (Durham, 1966, p. 6).

The Buttle Member is characterized by conspicuously diatomaceous strata. Its lower contact, which is not necessarily at the same stratigraphic horizon throughout the map area, is at the base of the stratigraphically lowest mappable unit of diatomite or diatomaceous mudstone and above porcelaneous rocks of the main body of the Monterey Shale (measured section 1). The following sequence of beds overlies porcelanite of the Monterey Shale north of the Nacimiento

River near the center of the NW¼ sec. 12, T. 25 S., R. 10 E., about one-half mile northwest of measured section 2:

	Feet	Inches
Paso Robles Formation:		
Conglomerate, contains cobbles and boulders, mainly of basement rocks	10+	0
Pancho Rico(?) Formation:		
Sandstone; locally tar impregnated	4	0
Monterey Shale, Buttle Member:		
Porcelanite	1	0
Diatomite	16	0
Porcelanite		4
Diatomite		1
Monterey Shale:		
Porcelanite	20+	0

LITHOLOGY

Porcelaneous rocks

Porcelanite is a silica-cemented rock that is less hard, dense, and vitreous than chert; it has the dull luster of unglazed porcelain (Bramlette, 1946, p. 15). According to X-ray analysis, it consists largely of opal, crystobalite, and quartz. Porcelanite grades into porcelaneous mudstone by an increase in the amount of clay, silt, and sand in the rock, and porcelaneous mudstone grades into ordinary mudstone as the proportion of clastic material to porcelaneous matrix increases. Porcelanite also grades into a dense cherty rock, possibly by a decrease in porosity and a corresponding increase in silica content.

Porcelanite and porcelaneous mudstone form the bulk of the Monterey Shale, exclusive of the Sandholdt and Buttle Members. These rocks occur locally in the Sandholdt Member in association with calcareous shale or sandstone; in the Buttle Member they occur as beds or units 1–24 inches thick intercalated in diatomite. The porcelaneous rocks range from well bedded to poorly bedded or massive. Beds are generally as thick as 1–6 inches, but some are thicker than 2 feet. The rocks are mainly very light gray, white, pinkish gray, and very pale orange, but they have a wide color range that may be largely an effect of weathering. The rocks are brittle and have a hackly or conchoidal fracture; concentric ridges are common on some fracture surfaces. At some localities the rocks are sheared and form crush-breccia. Small mica flakes are commonly scattered in the porcelaneous rocks, especially in porcelaneous mudstone. Thin sections of porcelanite and porcelaneous mudstone generally contain a few scattered angular very fine sand grains. Sandy procelaneous mudstone occurs in the Sandholdt Member, especially near the San Antonio River. It contains fine and medium sand grains, both disseminated in a porcelaneous matrix and concentrated in discrete layers. Fish scales, diatom frustules, and chalcedony-filled molds of foraminifers and fish bones occur in porcelaneous mudstone, and more sparingly, in porcelanite. At many places porcelaneous rocks contain interbeds of mudstone, chert, clay, and dolomitic carbonate rock.

Chalcedony and opal are conspicuous in the porcelaneous rocks. They occur as veins, cavity fillings, bands parallel to bedding, and as irregular poorly defined masses. They form much of a type of rock that is intermediate in character between porcelanite and chert and that is conveniently termed cherty porcelanite. Brecciated porcelaneous rocks are commonly recemented by chalcedony and opal. At some places, veins of chalcedony and opal that cut the brecciated rocks include fragments of porcelanite. Generally the chalcedony in veins and cavities is clear and the opal is white, but the opal in bands and irregular masses ranges from white through many shades of brown to black. A few veins are entirely opal and a few are entirely chalcedony, but most veins are lined with opal and filled with chalcedony. Offset and crisscrossing veins demonstrate more than one time of vein formation. Some bands of opal that are parallel to bedding have distinct boundaries with the enclosing porcelaneous rock, but others grade both upward and downward into porcelanite that includes streaks of opal parallel to the bedding. A few bands are made up of dark-and light-colored silica in alternating layers, some of which are wavy or contorted. These bands are commonly broken and recemented by chalcedony and opal, although at one place where a broken band of silica occurs in porcelanite, the spaces between the pieces are filled with porcelanite.

Concentrically banded ellipsoids like those described at length by Taliaferro (1934) are conspicuous locally in the upper part of the Monterey Shale. Ellipsoids from the upper part of the Monterey on the ridge south of the San Antonio River (sec. 29, T. 24 S., R. 10 W.) are mainly 5–10 cm in their greatest dimension and are made up of concentric shells generally 1–2 mm thick, but in places as much as 5 mm thick. Each shell contains a layer of clear silica that has an irregular but distinct contact with the next inner layer. In some shells the layer of clear silica grades outward into light-brownish-gray silty porcelanite. The clear layers contain floccules of clay or silt, and the outward gradation of clear silica into porcelanite is effected simply by an outward increase in the concentration of floccules until finally they coalesce to form typical porcelanite.

In other shells the inner layer of clear silica is succeeded outward by white opal; the contact between the two is distinct, but irregular. Veinlets of clear silica project into the white opal, and in some places the clear silica layer encloses angular fragments of white opal. Irregular veinlets of clear silica also project into the porcelanite layers. The concentric structure of the ellipsoids commonly is disrupted near the center into a complicated mixture of porcelanite and clear silica. Upon weathering, the porcelanite becomes white and appears lighter than the clear silica; this contrast on the weathered surfaces of broken ellipsoids gives a strikingly banded appearance. In thin sections, the clear areas appear to be mainly cryptocrystalline silica and fibrous chalcedony. Larger areas of fibrous chalcedony are generally near the inner margins of shells or in the center of veins.

Mudstone and shale

Mudstone and shale are chiefly composed of silt and clay, but they generally contain scattered grains of sand as well. The term "mudstone" is used here for fine-grained clastic rocks that are generally thick bedded or massive, and the term "shale" for rocks of similar composition that are fissile. Noncalcareous mudstone and shaly mudstone are interbedded with porcelaneous rocks in the upper part of the Monterey Shale; calcareous shale is the most common and characteristic kind of rock in the Sandholdt Member. Just as porcelanite grades imperceptibly through porcelaneous mudstone into mudstone by an increase in the proportion of clastic material to opaline matrix, so the mudstone grades through diatomaceous mudstone into diatomite by an increase in the proportion of diatomaceous debris to other clastic material in the rock.

Noncalcareous mudstone in the upper part of the Monterey Shale resembles in general appearance the porcelaneous rocks with which it is associated. It ranges from shaly to massive, and where bedding is apparent, the beds are generally 1–12 inches thick. Noncalcareous mudstone is commonly pale yellowish brown or very pale orange, but like the porcelaneous rocks, it has a broad color range. It is generally more friable and more porous than porcelaneous mudstone. Most of it is interbedded with porcelaneous rocks, but at some places it is interbedded with chert, dolomitic carbonate rock, or diatomite. Fish scales and diatom frustules are conspicuous in the rock at many places. Noncalcareous mudstone is uncommon in the Sandholdt Member, but it is associated with calcareous mudstone along the north side of the San Antonio River (sec. 29, T. 24 S., R. 10 E.) There it is pale yellowish brown, occurs in beds 1–2 inches thick, and includes layers or lenses of chert. It contains sand grains, mica flakes, molds of foraminifers, and pieces of black plant debris.

Calcareous shale in the Sandholdt Member commonly is laminated. It is chiefly very pale orange, but has a wide range of color, including pale yellowish brown, yellowish gray, and white. The rock ranges from lightweight, porous, and friable to dense and well indurated. Foraminifers are abundant and well preserved in the calcareous shale, which also contains fish scales and bones, echinoid spines, sponge spicules, and more rarely diatom frustules. Small mica flakes are conspicuous in much of the rock. The calcareous shale is sandy locally and at a few places grades into sandstone. It commonly contains interbeds of sandstone, porcelaneous rocks, dolomitic carbonate rock, chert, or tuff. Thin sections of calcareous shale generally contain scattered angular grains of very fine grained and fine-grained sand in a matrix of silt and clay. A nearly parallel orientation of silt particles or a concentration of foraminifers in certain laminae causes conspicuous banding in some thin sections.

Diatomite

Diatomite in the Monterey Shale consists largely of diatoms and fragments of diatoms with some intermixed clay and silt. It occurs mainly near the top of the Monterey, either in the Buttle Member or as interbeds in porcelaneous rocks that are below or laterally equivalent to the member. Diatomaceous calcareous shale in the Sandholdt Member crops out on the ridge south of the San Antonio River near Harris Creek.

The diatomite is white, poorly bedded or massive, lightweight, porous, and friable. It contains conspicuous discoidal diatom frustules ¼–½ mm in diameter, and locally it includes scattered very fine sand grains, mica flakes, sponge spicules, fish scales, and fish bones. The diatomite commonly has interbeds of porcelaneous rocks, chert, or dolomitic carbonate rock.

Chert

Chert of the Monterey Shale is denser and more vitreous than the porcelanite. It consists largely of opal and chalcedony and generally lacks clay and silt. Ordinarily the chert is massive or poorly bedded; beds, where present, commonly are 1–2 inches thick, and the bedding surfaces are irregular or wavy, rather than planar. The chert ranges in color from olive black or dark reddish brown to nearly white. Even the darkest colored chert is translucent on thin edges. The rock is hard and brittle and breaks like glass. Chert is interbedded with porcelaneous rocks in the upper part of the Monterey and is associated with calcareous shale, porcelaneous rocks, sandstone, and dolomitic carbonate rock in the Sandholdt Member.

In a common association of chert and porcelaneous rock in the upper part of the Monterey Shale, a band of olive-black chert about 4 cm thick grades both upward and downward into bands of olive-gray porcelanite about 1 cm thick that in turn grade outward into white porcelanite. The chert includes angular pieces of olive-gray porcelanite and in places projects into the enclosing porcelanite. Veins of clear chalcedony cut both chert and porcelanite; some of these veins include small angular fragments of porcelanite and white opal. Both the chert and porcelanite contain lenselike bodies of chalcedony, and the porcelanite contains similar poorly defined bodies of dark-colored chert. Chalcedony fills molds of foraminifers in both chert and porcelanite.

Carbonate beds and concretions

Dolomitic carbonate rock in the Monterey Shale occurs both in beds and in concretions. Beds are most commonly 1–3 feet thick and are separated by much thicker sequences of either siliceous or calcareous beds. Ellipsoidal concretions, as much as 18 inches thick and 8 feet long, are found in particular beds rather than scattered at random; they are oriented with the two longer axes parallel to the bedding. These concretions are especially well exposed near the top of the Monterey north of the Nacimiento River and near the center of the NW¼ sec. 12, T. 25 S., R. 10 E. The dolomitic carbonate rock is generally yellowish gray. It is hard and dense, and because it is more resistant to weathering than many of the associated rocks, it commonly forms bold outcrops on hillsides that otherwise lack exposures. The rock contains calcite, both in conspicuous veins and in cavities; the latter may be molds of foraminifers or diatoms. Silica fills similar cavities at some places. Imprints of fish scales and diatoms are preserved locally in the rock. Thin sections of dolomitic carbonate rock contain scattered angular grains of quartz and feldspar 0.05–0.1 mm long in a finely crystalline calcareous matrix. Dolomitic carbonate rock is interbedded with diatomite in the Buttle Member, with calcareous shale and sandstone in the Sandholdt Member, and with chert, porcelaneous rocks, and noncalcareous mudstone throughout the Monterey.

K. J. Murata (written commun., April 1967) provided the following statement concerning calcareous shale and carbonate beds of the Monterey Shale:

Carbon and oxygen isotopes in the carbonate of foraminiferal shales and of associated dolomite beds in the Sandholdt Member were investigated by Murata, Friedman, and Madsen as an extension of their recent study (1967) of carbonates in the marine Tertiary of the west coast. Samples from both the region of Nacimiento Dam and from Reliz Canyon were included in their study.

X-ray diffraction examinations showed calcite to be the only carbonate in the shales, and staining with alizarine red sulfonate (Friedman, 1959) indicated that this calcite was localized in tests of foraminifers. Dolomite containing a slight excess of calcium in solid solution (Goldsmith and Graf, 1958) makes up the dolomite beds and is free of calcite.

The isotopic composition of foraminiferal calcite and of dolomite are given below:

Material and number of samples	*δC^{13} per mil* [1]	*δO^{18} per mil* [2]
Foraminiferal calcite (4)	−0.7 to −4.7	27.4 to 28.5
Dolomite (7)	+5.8 to +13.2	28.9 to 31.5

[1] Relative to Peedee Belemnite (PDB) standard.
[2] Relative to Standard Mean Ocean Water.

Carbon and oxygen isotopic composition of foraminiferal calcite deviate only slightly from that of normal marine carbonate. This implies that the original composition attained through equilibrium with seawater is largely retained. The carbon isotopic composition of the dolomites points to their derivation from solutions very different from normal seawater. Postdepositional isotopic equilibration between carbonate and methane of natural gas must be invoked to explain such large positive value of δC^{13}.

In the Sandholdt Member, therefore, foraminiferal shales still retaining the isotopic imprint of their marine origin are interlarded with beds of diagenetic dolomite with very different isotopic composition. The relatively sharp boundaries between dolomite and shale indicate that the dolomite-depositing solutions were restricted to certain permeable horizons and emphasize how localized the dolomitization process can be.

Impure limestone is associated at some places with calcareous shale of the Sandholdt Member. It is generally well indurated, white or very pale orange, and in beds ¼–1 inch thick. Calcite is common in the rock, both as veins and as casts of foraminifers. A thin section of the limestone contains scattered angular sand grains about 0.15 mm long in a matrix of calcite, silt, and clay. A crude banding in the thin section is caused by concentration of sand grains and foraminifers in certain layers. Veins of calcite 1–2 mm wide are more coarsely crystalline near the center than they are at the margins.

Sandstone

Sandstone is interbedded with calcareous shale, chert, or dolomitic carbonate rock at some places in the Sandholdt Member. The thickness of sandstone beds ranges from less than 1 inch to several feet. Sandstone is especially abundant in the Sandholdt Member near the San Antonio River north of the mouth of Harris Creek and along Harris Creek west of the fault in the NE¼ sec. 36, T. 24 S., R. 9 E. Sandstone in the Sandholdt is generally similar to that in the Tierra Redonda Formation. An unusual sandstone exposed in the Sandholdt west of Sulphur Canyon (sec. 3, T. 25 S., R. 10 E.) has a matrix of porcelanite; at some places in the member, sandstone contains well-rounded grains of porcelaneous rock.

Sandstone dikes cut beds of calcareous shale and are folded with them in the Sandholdt along Harris Creek (NE¼ sec. 36, T. 24 S., R. 9 E.). Sandstone in the dikes is similar to that in nearby sandstone beds.

Beds or lenses of tar-impregnated sandstone are intercalated with porcelaneous rocks near the top of the Monterey Shale on both sides of the Nacimiento River (secs. 12 and 13, T. 25 S., R. 10 E.). This sandstone is generally fine grained, well sorted, and massive.

A sandy grit that contains subangular to well-rounded clasts 3–10 mm in diameter overlies calcareous mudstone of the Sandholdt Member at the base of the bluff on the north bank of the San Antonio River in sec. 19, T. 24 S., R. 10 E. The larger clasts are quartz, feldspar, chert, and calcareous foraminiferal mudstone. The rock is noncalcareous and well indurated. A thin section of the grit has fibrous chalcedony in the mudstone matrix.

Tuff

Beds of vitric tuff crop out in the Monterey Shale at several places in the map area. They are most common in the Sandholdt Member, but a tuff bed about 18 inches thick crops out in the upper part of the Monterey just below the Buttle Member on the ridge north of the Nacimiento River at the west edge of sec. 12, T. 25 S., R. 10 E. Tuff beds in the Sandholdt are especially well exposed along a road (not shown on pl. 1) between the Nacimiento and San Antonio Rivers in secs. 3 and 10, T. 25 S., R. 10 E., and near the center of the SE¼ projected sec. 15, T. 24 S., R. 9 E.

The tuff is massive, moderately friable, porous, and medium light gray, very light gray, or white. It occurs in beds 1 inch to 8 feet thick that are interbedded with both porcelaneous rocks and calcareous shale. It also contains scattered fine sand grains at some places.

Thin sections of tuff are composed largely of shards 0.1–0.6 mm long that are alined to give the rock a crudely laminated appearance. Calcite occurs between the shards in one thin section, and clay is conspicuous in another. Angular fine sand grains scattered among the shards are mainly quartz and feldspar, but mica flakes are abundant in one thin section. A thin section of sandy tuff from a roadcut just north of the Nacimiento River, at the south edge of sec. 10, T. 25 S., R. 10 E., contains rounded clasts of calcareous mudstone as large as 0.25 mm. Some of these clasts have an angular sand grain in the center.

Bentonitic clay is common as thin beds and laminae interspersed in the porcelaneous rocks of the Monterey Shale. It most likely was derived from alteration of volcanic ash or tuff.

THICKNESS

The Sandholdt Member is about 4,000 feet thick northeast of the Jolon fault (structure section *F–G–H*, pl. 3), and about 2,800 feet thick between the Jolon and San Marcos faults (structure section

C–D–E, pl. 3). The thickness of the Sandholdt is uncertain southwest of the Jolon and San Marcos faults because the upper part of the unit is absent and the rest is severely deformed.

The upper part of the Monterey Shale, exclusive of the Buttle Member, is about 9,000 feet thick northeast of the Jolon fault (structure sections *A–B* and *F–G–H*, pl. 3) and about 2,000 feet thick between the Jolon and San Marcos faults (structure section *C–D–E*, pl. 3). The thickness of the Buttle Member varies. The member is 585 feet thick where it was measured southwest of Hames Valley (measured section 1) and could be greater nearby. The member is thin or absent near and south of the San Antonio River. This thinning may result at least partly from lateral lithologic change of diatomaceous to porcelaneous rocks and partly from the erosion of the member prior to deposition of the sediments of the Paso Robles Formation.

These figures indicate a cumulative total thickness greater than 13,000 feet for the Monterey Shale in the map area. This total is consistent with information from The Texas Shell 1 well (structure section *A–B*, pl. 3), which was begun in strata well below the top of the Monterey Shale and was drilled to a depth of nearly 12,000 feet, apparently without reaching the base of the Sandholdt.

AGE AND CONDITIONS OF DEPOSITION

Fossils are plentiful in parts of the Monterey Shale and are scarce in other parts. Foraminifers are abundant in calcareous shale of the Sandholdt Member. Most of the foraminiferal faunas are indicative of the middle Miocene Relizian and Luisian Stages of Kleinpell (1938), although faunas from near the base of the Sandholdt where it overlies the Vaqueros Formation are indicative of the lower Miocene Saucesian Stage (Patsy J. Smith, written commun, 1962–66). Table 3 lists foraminifers collected from the Sandholdt Member at 30 localities in the mapped area and shows the stage of Kleinpell indicated by each fauna. Table 4 lists foraminifers from a sequence of beds 75 feet thick in the Sandholdt at fossil locality Mf901 (sec. 9, T. 25 S., R. 10 E.) and shows the small variation found in the faunas from closely spaced samples. The fauna at the base of this sequence of beds indicates the upper Relizian or lower Luisian Stage, and the faunas as high as 50 feet and at 60 feet above the base indicate the lower Luisian Stage; the other faunas indicate simply middle Miocene age (Patsy J. Smith, written commun., 1966). According to W. O. Addicott (written commun., 1964), *Delectopecten* cf. *D. peckhami* (Gabb), collected from the Sandholdt at locality M1938 (projected sec. 22, T. 24 S., R. 9 E.), suggests a Miocene age.

TABLE 3.—*Fossil foraminifers from the Sandholdt Member of the Monterey Shale*

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

	Stage of Kleinpell (1938)																													
	Saucesian		Upper Relizian			Relizian or lower Luisian		Lower Luisian					Luisian undifferentiated									Upper Luisian								
	USGS locality																													
	Mf893	Mf899	Mf825	Mf826	Mf829	Mf827	Mf828	Mf785	Mf830	Mf831	Mf832	Mf853	Mf854	Mf639	Mf641	Mf779	Mf780	Mf782	Mf783	Mf784	Mf786	Mf640	Mf642	Mf643	Mf644	Mf778	Mf781	Mf787	Mf788	Mf820
Angulogerina sp.																										×				
Anomalina salinasensis Kleinpell			×	×	×	×		×		×		×	cf.	×	×					×	×	×	×	×	×	×	×		×	×
Baggina californica Cushman					×				×		×			×								×								
cancriformis Kleinpell	×																													
robusta Kleinpell													×		×		×						×		×	×	×	×	×	
Bolivina advena Cushman				×				×																						
adena striatella Cushman		×	×	×	×	×		×	×	×	×		×	×		×	×	×	×	×	×	×	×		×	×	×			×
californica Cushman	×	×	×	×	×	×		×				×	×				×				×	×		×	×	×		×	×	
conica Cushman												×																		
cuneiformis Kleinpell								×																						
floridana Cushman																					×							×	×	
guadaloupae Parker									×									×								×				×
imbricata Cushman				×	×		×		×													×						×		
marginata Cushman	×							×				×	×	×	×					×	×			×	×	×	×	×	×	
marginata adelaidana Cushman and Kleinpell	×																													
cf. *B. marginata adelaidana* Cushman and Kleinpell				×		×				×																				
cf. *B. marginata multicostata* Cushman			×																											
cf. *B. plicatella* Cushman				×	×	×																								
pseudospissa Kleinpell																				×										
cf. *B. rhomboidalis* (Millett)								×																						
salinasensis Kleinpell	×			×					×								×	cf.												
tongi Cushman														×								×								
tumida Cushman				×	×										×						×		×	×	×					×

TABLE 3.—*Fossil foraminifers from the Sandholdt Member of the Monterey Shale*—Continued

	Stage of Kleinpell (1938)																													
	Saucesian		Upper Relizian			Relizian or lower Luisian		Lower Luisian					Luisian undifferentiated									Upper Luisian								
	USGS locality																													
	Mf893	Mf899	Mf825	Mf826	Mf829	Mf827	Mf828	Mf785	Mf830	Mf831	Mf832	Mf853	Mf854	Mf639	Mf641	Mf779	Mf780	Mf782	Mf783	Mf784	Mf786	Mf640	Mf642	Mf643	Mf644	Mf778	Mf781	Mf787	Mf788	Mf820
Bulimina affinis d'Orbigny																X										X		X	X	
inflata alligata Cushman and Laiming		X																												
ovata d'Orbigny																	X													
pseudotorta Cushman															X								X		X					
subacuminata Cushman and R. E. Stewart																				X										
Buliminella curta Cushman			X	X			X								X		X				X			X		X	X		X	X
elegantissima (d'Orbigny)																		X												
subfusiformis Cushman	X		X		X			X	X	X	X	X	X	X		X	X	X	X	X			X		X			X		
Cancris sagra d'Orbigny									X								cf.				cf.						cf.			
Cassidulina crassa d'Orbigny					cf.	cf.	cf.	X			cf.	cf.	X			X	X			X	X					X			X	X
cf. *C. pulchella* d'Orbigny															X									X						
Cassidulinoides? sp.							X																							
Cibicides cf. *C. lobatulus* (Walker and Jacob)																										X				
Dentalina obliqua (Linné)																	cf.										X			
spp.									X	X															X	X				
Epistominella relizensis (Kleinpell)			X	X	X	X				X	X				X	X	X			X	X			X	X			X	X	
smithi (R. E. and K. C. Stewart)											X																			
subperuviana (Cushman)												X																		
Eponides rosaformis Cushman and Kleinpell				X				cf.	X							X		cf.					cf.	cf.		cf.		cf.		X
Globigerina bulloides d'Orbigny									X					X	X	cf.		cf.	cf.			X	X	X	X	cf.		cf.	cf.	
dubia Egger					X	X			X	X																				
quinqueloba Natland																	X	X		X						X			X	
spp.	X											X	X																	
Globigerinita sp.																				X										
Globoquadrina hexagona (Natland)														X	X					X		X	X	X	X					
sp.																														X
Globorotalia cf. *G. tumida* (Brady)																				X										

Gyroidina rotundimargo Stewart and Stewart											X		X	X			X				X									
Hanzawaia sp.															X									X	X					
Hemicristellaria beali (Cushman)			X								X			X			X				X			X	X		X			
Lenticulina cf. *L. relizensis* Kleinpell													X																	
sp.																					X					X				
Nodogenerina advena Cushman		X																												
Nonion costiferum (Cushman)				X			X		X		X			X			X													
Nonionella cf. *N. basispinata* Cushman and Moyer									X																					
miocenica Cushman																		X						X						
Planularia dubia Kleinpell													X																	
luciana Kleinpell																								X	X				X	
Planulina baggi Kleinpell	X	X																												
ornata (d'Orbigny)																					X							X		
sp.				X																										
Plectofrondicularia sp.	X	X				X																								
cf. *P. miocenica directa* Cushman and Laiming	X																													
Pullenia cf. *P. elegans* (d'Orbigny)													X																	
miocenica Kleinpell			X	X	X		X	X		X				X		X				X									X	X
miocenica globula Kleinpell									X			X										X			X	X	X	X		
Robulus cf. *R. hughesi* Kleinpell																					X								X	
cf. *R. miocenicus* (Chapman)		X										X	X																	
simplex (d'Orbigny)	X	X																												
smileyi Kleinpell													X				X													
sp.			X			X								X																
Siphogenerina branneri Bagg		X	X	X	X	X	X	X	X	X		X	X																	
collomi Cushman														X	X							X	X	X	X	X	X	X	X	X
cf. *S. hughesi* Cushman																					X									
reedi Cushman										X					X					X		X					X	X	X	
transversa Cushman	X	X																												
sp.																X														
Stilostomella sp.						X				X																				
Suggrunda sp.		X																												
Uvigerina hootsi Rankin				cf.																		X	X			cf.		X		
subperegrina Cushman and Kleinpell														X							X	X		X						
Uvigerinella californica Cushman				X	X	X				X		X	X	X	X	X				X	X	X	X		X			X		X
obesa Cushman	X	X	X	X			X	X	X	X		X																		
Valvulineria californica Cushman									X					X	X	X		X	X	X		X	X	X	X	X	X			X
californica appressa Cushman			X	X		X			X	X																		X		
californica obesa Cushman							X	X	X		X			X			X													
californica var.																					X									
cancriformis Kleinpell		X																												
cf. *V. casitasensis* Cushman and Laiming	X																													
depressa Cushman			X				X	X			X	X	X							?	cf.									
miocenica Cushman											X							X		cf.	X						X		X	
Virgulina californiensis Cushman				X					X			X					X	X		X			X							

TABLE 4.—*Fossil foraminifers from a sequence of beds in the Sandholdt Member of the Monterey Shale at fossil locality Mf901*

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

	Distance above base of sequence of beds (feet)														
	0	5	15	20	25	30	35	40	45	50	55	60	65	70	75
Anomalina salinasensis Kleinpell	×	×	×	×	×	×	×	×	×	×		×	×	×	
Baggina californica Cushman	×	×	×	×	×	×	×	×				×	×	×	
robusta Kleinpell	×														
Bolivina advena Cushman	×	×													
advena striatella Cushman	×	×	×	×	×	×	×		×	×			×		
californica Cushman	×	×	×	×	×	×	×					×			×
cuneiformis Kleinpell							×	×		×					
guadaloupae Parker		×			×	×						×			
imbricata Cushman	×	×	×	×	×	×		×	×	×		×			
tumida Cushman			×	×	×	×				×		×			
Buliminella subfusiformis Cushman							×			×					
Cassidulina cf. *C. crassa* d'Orbigny		×	×			×	×			×		×			
Dentalina obliqua (Linné)	×		×	×		×				×			×	×	
Epistominella relizensis (Kleinpell)					×		×								
cf. *E. subperuviana* (Cushman)			×												
Eponides rosaformis Cushman and Kleinpell							×								
Globigerina cf. *G. bulloides* d'Orbigny	×	×	×	×	×	×		×	×	×	×	×	×	×	×
Globorotalia sp										×					
Gyroidina sp					×										
Hemicristellaria beali (Cushman)												×			
Planulina baggi Kleinpell	×														
sp			×									×			
Plectofrondicularia sp										×					
Pullenia miocenica Kleinpell	×	×	×				×								
miocenica globula Kleinpell					×					×		×			
Robulus miocenicus (Chapman)							×								
smileyi Kleinpell			×	×	×		×					×			
Siphogenerina branneri (Bagg)	×	×	×	×	×	×	×	×			×	×	×		
reedi Cushman		×		×	×	×	×	×		×		×	×	×	×
Uvigerinella californica Cushman	×	×	×	×	×	×	×	×	×	×	×	×			
obesa Cushman			×									×			
Valvulineria californica Cushman												×	×		
californica appressa Cushman				×			×								
californica obesa Cushman	×	×	×		×	×		×							
depressa Cushman				×	×		×	×		×		×			
Virgulina californiensis Cushman					×	×									

Fossils of age significance were not found in the porcelaneous and cherty rocks of the upper part of the Monterey, but at some places these rocks conformably underlie beds of the Santa Margarita Formation that contain fossils of late Miocene age. Northeast of the Jolon fault, where the Santa Margarita is absent from the sequence of Miocene and Pliocene formations, the diatomaceous Buttle Member generally overlies the porcelaneous and cherty rocks of the upper part of the Monterey. According to Mandra (1963b, p. 104), the Buttle Member should, on the basis of its stratigraphic position, be assigned to the upper Miocene Delmontian Stage of Kleinpell. At some places the Buttle Member conformably underlies the Pancho Rico Formation, which in nearby areas contains fossils of early Pliocene age (Durham and Addicott, 1965) but which in the mapped area contains only poorly preserved fossils that are suggestive of either Miocene or Pliocene age (W. O. Addicott, written commun., 1964). In sec. 12, T. 24 S., R 10 E., the Buttle Member apparently intertongues with sandstone beds assigned to the Pancho Rico.

Southwest of the Jolon fault the age range of the Monterey Shale is limited by the Tierra Redonda Formation of early and middle Miocene age and the Santa Margarita Formation of late Miocene age. Northeast of the fault the age range of the Monterey is limited at the base by the Vaqueros Formation of early Miocene age and at the top by Pancho Rico Formation of early Pliocene age. Presumably, then, southwest of the Jolon fault the Monterey represents part of early, all of middle, and part of late Miocene time, and northeast of the fault it probably represents middle and late Miocene time.

The fossils in the Monterey Shale indicate that the unit is marine. According to Patsy J. Smith (written commun., 1962–66), foraminifers in the Sandholdt Member suggest bathyal depths at localities Mf778, Mf779, Mf780, Mf784, Mf786, Mf787, Mf788, Mf853, and Mf854, a shelf environment at locality Mf782, and questionably lower neritic depths at localities Mf641, Mf643, and Mf644.

SANTA MARGARITA FORMATION

Fairbanks (1904, p. 4) gave the name Santa Margarita Formation to the predominantly sandy fossiliferous strata exposed near the town of Santa Margarita, which is about 25 miles south of the Bradley quadrangle. The unit crops out in the map area between the Jolon and San Marcos faults in a structurally complex belt that trends southeastward from near the center of the Tierra Redonda Mountain quadrangle into the southwestern part of the Bradley quadrangle. The Santa Margarita is absent from the sequence of Miocene strata northeast of the Jolon fault, where chronologically equivalent beds belong to the Monterey. Presumably the Santa Margarita has been striped away southwest of the San Marcos fault, where upper Miocene rocks are generally absent.

The Santa Margarita Formation is chiefly massive medium- and coarse-grained fossiliferous sandstone, in contrast to the underlying finer grained Monterey Shale. The lower contact of the Santa Margarita is well exposed in a roadcut on the east side of the Nacimiento River (sec. 13, T. 25 S., R. 10 E.) and in another roadcut (fig. 4) about 750 feet south of the spillway of the San Antonio Dam (sec. 34, T. 24 S., R. 10 E.). The contact is conformable and also gradational at places where porcelaneous rocks like those in the Monterey are interbedded with sandstone near the base of the Santa Margarita.

LITHOLOGY

The Santa Margarita Formation is chiefly sandstone. It is commonly massive, but in places is bedded; where beds are present, they are usually several feet thick (fig. 5), although at some places they are only 3–12 inches thick. The sandstone ordinarily is medium or coarse grained, but it ranges from very fine to coarse grained and locally is

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FIGURE 4.—Contact between the Santa Margarita Formation and underlying Monterey Shale south of the San Antonio River (sec. 34, T. 24 S., R. 10 E.). The man stands on a sandstone bed about 1 foot thick that marks the base of the Santa Margarita. The basal bed is overlain by a unit about 5 feet thick of shaly porcelaneous rocks like those in the Monterey. Massive fossiliferous sandstone above the shaly unit is typical of the Santa Margarita. Small faults dip to the left (north).

granulitic or pebbly. Sand grains are chiefly quartz and feldspar, but grains of chert and porcelanite are common. Larger grains are rounded or subrounded, and many are polished. The rock is medium light gray to white, and much of the coarser grained rock has a speckled appearance caused by scattered grains of dark chert. It is calcareous and ranges from friable to well cemented. Thin sections of well-cemented sandstone contain sand grains in a matrix of coarsely crystalline calcite. Well-cemented rock forms bold outcrops. Fossils or fragments of fossils are abundant in much of the sandstone and at places make up most of the rock.

THICKNESS

The Santa Margarita Formation is about 500 feet thick near the Nacimiento River (measured on structure section *F–I–E*, pl. 3) and

FIGURE 5.—Massive fossiliferous sandstone of the Santa Margarita Formation that forms bold outcrops on a ridge by the San Antonio River (projected sec. 29, T. 24 S., R. 10 E.).

515 feet thick where the unit is well exposed 0.6 mile south of the map area in the Adelaida quadrangle (sec. 19, T. 25 S., R. 11 E.). It is about 475 feet thick in the subsurface in the M.J.M. and M. Oil Konekamp–Union 1–3 well and Union Oil Union–Texaco–Connell 1 well (structure section *C–D–E*, pl. 3). The formation thins to the northwest, where its thickness is only about 150 feet along the line of structure section *F–G–H* (pl. 3).

AGE AND CONDITIONS OF DEPOSITION

Fossils, or fragments of fossils, are common in the Santa Margarita Formation in the map area. Fossiliferous beds in the unit ordinarily contain large numbers of individuals of only a few taxa. Table 5 lists fossils from the Santa Margarita at five localities; the fauna at each locality indicates a late Miocene age (W. O. Addicott, written commun., 1964, 1965).

The abundance of marine fossils throughout the Santa Margarita Formation is evidence for the marine origin of the unit.

TABLE 5.—*Fossils from the Santa Margarita Formation*

[Identified by W. O. Addicott, except where otherwise noted. ×, present as identified; ?, doubtful identification; aff., comparable but apparently different form; sp., species not determinable]

	USGS locality				
	M1936	M1940	M2046	M2304	M2308
Echinoids:					
Astrodapsis margaritanus Kew? [1]		×			
?*Astrodapsis* sp					×
Brachiopod:					
Terebratalia arnoldi quaylei Hertlein and Grant			×	×	
Gastropods:					
Forreria sp		?		×	
Pelecypods:					
Chlamys n. sp.? aff. *C. hericia* (Gould)				×	
Crassostrea titan (Conrad)	×		×		×
Lyropecten estrellanus (Conrad)	×	×	×	×	×
estrellanus (Conrad) forma *catalinae* Arnold	×				
Mytilus sp. (very large, incomplete)		×			

[1] Identified by J. Wyatt Durham.

PLIOCENE SERIES

PANCHO RICO FORMATION

Reed (1925, p. 606) "grouped together as the Poncho Rico Formation" certain strata on the east side of the Salinas Valley and presumably intended that beds exposed about 10 miles north of the Bradley quadrangle along Pancho Rico Creek should be considered typical of the unit. Durham and Addicott (1964, p. 4) redefined the Pancho Rico Formation as comprising 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 Pancho Rico Formation crops out in the map area in a narrow belt near Buttle Canyon and in two areas just north of the San Antonio River. Friable white sandstone that overlies the Monterey Shale near the Nacimiento River is questionably assigned to the Pancho Rico (measured section 2, unit 63), although it lacks the fossils characteristic of the unit elsewhere. The Pancho Rico occurs in the map area only northeast of the Jolon fault, which forms the northeastern boundary of the Santa Margarita Formation. Consequently, the Pancho Rico and Santa Margarita in the map area do not occur together in the same stratigraphic sequence. The Pancho Rico is much thinner and generally finer grained, less calcareous, and much less fossiliferous than the Santa Margarita, with which it is easily confused.

The Pancho Rico Formation conformably overlies the Buttle Member of the Monterey Shale near Buttle Canyon and apparently intertongues with that member near the San Antonio River (sec. 26, T. 24 S., R. 10 E.). The base of the Pancho Rico near Buttle Canyon is marked by beds of well-cemented pebbly fossiliferous sandstone that are overlain by massive friable apparently unfossiliferous sandstone. The Pancho Rico conformably overlies porcelaneous rocks of the Monterey farther west on the north side of the San Antonio River (secs. 20 and 29, T. 24 S., R. 10 E.). Rocks questionably assigned to the Pancho Rico conformably overlie the Buttle Member north of the Nacimineto River (sec. 12, T. 25 S., R. 10 E.), but farther southeast, where the Buttle Member is absent, they conformably overlie porcelaneous rocks of the Monterey (measured section 2). The lower contact of the Pancho Rico is at the base of the stratigraphically lowest continuous sandstone unit above the Monterey Shale. By this definition, some beds or lenses of unfossiliferous tar-impregnated sandstone intercalated in porcelaneous strata near the Nacimiento River (secs. 12 and 13, T. 25 S., R. 10 E.) are included in the Monterey rather than in the Pancho Rico because they are within, rather than above, the sequence of porcelaneous beds.

LITHOLOGY

The Pancho Rico Formation is chiefly fossiliferous sandstone. Locally near the base it includes interbeds of fine-grained rocks similar to those in the underlying Monterey Shale, and at places it is pebbly like the overlying Paso Robles Formation. North of the San Antonio River at fossil locality M1937 (sec. 20, T. 24 S., R. 10 E.), the Pancho Rico consists of pebbly sandstone that fills channels several inches deep in the underlying porcelaneous rocks of the Monterey Shale. Where fossils are lacking, distinguishing the Pancho Rico from the Paso Robles is difficult, if not impossible. For this reason, some unfossiliferous sandstone beds are only questionably assigned to the Pancho Rico on plate 2.

Sandstone in the Pancho Rico Formation is generally massive or poorly bedded. It ranges from fine to coarse grained and from friable to well cemented. Well-cemented rock commonly is calcareous and forms bold outcrops. The sandstone is white or light gray. Sand grains are mainly quartz and feldspar, but grains of chert and porcelaneous rock are common. A thin section of sandstone from the Pancho Rico on the ridge west of Buttle Canyon (sec. 15, T. 24 S., R. 10 E.) contains angular to subrounded grains of quartz and feldspar 0.2–0.5 mm in diameter and rounded granules of porcelaneous rock, all in a calcite matrix. Fragments of oyster and pecten shells are abundant in the rock. A single shark's tooth about 5½ cm long was found in the formation near the San Antonio River (0.2 mile north of the S¼ cor. sec. 26, T. 24 S., R. 10 E.).

THICKNESS

The thickness of the Pancho Rico Formation is no greater than 50–100 feet in the map area, but the exact thickness is uncertain because the formation is generally poorly exposed. The thickness of the sandstone unit near the Nacimiento River questionably assigned to the Pancho Rico is only 25 feet (unit 63, measured section 2). North of the San Antonio River at fossil locality M1937 (sec. 20, T. 24 S., R. 10 E.), the Pancho Rico is about 20 feet thick.

AGE AND CONDITIONS OF DEPOSITION

Fossils in the Pancho Rico Formation in the map area are generally fragmentary or poorly preserved. Table 6 lists fossils from the unit at five localities. According to W. O. Addicott (written commun., 1964, 1965), the fauna at locality M2302 questionably suggests an early Pliocene age, but the meager faunas at localities M1937, M2301, and M2307 could be of either Miocene or Pliocene age. The barnacle at locality M2300 is of indeterminant age. The Pancho Rico in nearby areas contains fossils that indicate an early Pliocene age (Durham and Addicott, 1965), and this age may reasonably be assigned to the unit in the Tierra Redonda Mountain and Bradley quadrangles as well.

Fossils in the Pancho Rico Formation show a marine origin for the unit. However, the thin sandstone unit along the north side of the Nacimiento River that is questionably assigned to the Pancho Rico lacks fossils and may be nonmarine.

TERTIARY AND QUATERNARY(?) SYSTEMS

PLIOCENE AND PLEISTOCENE(?) SERIES

PASO ROBLES FORMATION

Fairbanks (1898, p. 565) named the Paso Robles Formation for its characteristic exposures near the town of Paso Robles, about 10 miles southwest of the map area. The formation crops out in the Tierra Redonda Mountain and Bradley quadrangles over a broad area that includes both sides of the Salinas River, Hames Valley, and the lower reaches of the San Antonio and Nacimiento Rivers. It also crops out on both sides of the San Antonio River in the northwestern part of the Tierra Redonda Mountain quadrangle and in patches between the San Marcos and Jolon faults.

The Paso Robles Formation overlies various units both conformably and with varying degrees of unconformity from one place to another (table 1); obviously the base represents different stratigraphic horizons. The Paso Robles northeast of the Jolon fault overlies either the

TABLE 6.—*Fossils from the Pancho Rico Formation*

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

	USGS locality				
	M1937	M2300	M2301	M2302	M2307
Gastropods:					
Calyptraea sp				×	
?*Forreria* sp (fragment)	×				
Naticid				×	
?*Olivella* sp				×	
Sinum sp				×	
Pelecypods:					
Anadara sp				×	×
Cardid			×		
Chione? aff. *C. fernandoensis* English					×
Chlamys n. sp.? aff. *C. hericia* (Gould)					×
?*Clinocardium* sp					×
Cryptomya cf. *C. californica* Conrad					×
?*Diplodonta* sp			×		
Florimetis biangulata (Carpenter)?					×
Lima sp				×	
Lucina excavata Carpenter					×
?*Lucinisca* sp				×	
Lyropecten cerrosensis (Gabb)?				×	
estrellanus (Conrad)	×				×
sp			×		
Macoma nasuta (Conrad)				×	×
?*Miltha* sp					×
?*Nuculana* sp			×		
Panope sp				×	
Saxidomus sp					×
Solen cf. *S. perrini* Clark					×
sp			×		
Tellinid					×
Venerid				×	
Barnacle:					
Balanus sp		×	?		

Pancho Rico Formation or the Monterey Shale. Where it overlies the Pancho Rico near Buttle Canyon, the contact is poorly exposed, but the two units are apparently conformable. There the lower contact of the Paso Robles is at the base of the stratigraphically lowest unit of unfossiliferous conglomerate above fossil-bearing sandstone beds of the Pancho Rico. The Pancho Rico is absent from about half a mile northwest of Buttle Canyon to the north edge of the mapped area, and the Paso Robles there lies directly on the Buttle Member of the Monterey Shale. Whether the disappearance of the Pancho Rico results from lateral change in lithologic character or from erosion prior to the deposition of the Paso Robles is uncertain, but the Paso Robles and Buttle Member apparently are structurally concordant. The lower contact of the Paso Robles near the north edge of the mapped area is at the base of the stratigraphically lowest conglomerate unit above diatomaceous beds of the Buttle Member.

Farther south near the San Antonio River, but still northeast of the Jolon fault, the Pancho Rico Formation and the Buttle Member are absent and the Paso Robles Formation lies directly on porcelaneous rocks of the Monterey Shale. The lower contact of the Paso Robles is well exposed in the roadcut on the south side of the San Antonio River, where the Paso Robles overlies the Monterey with only slight angular discordance on an irregular eroded surface. The contact there is at the base of the stratigraphically lowest unit of conglomerate and sandstone above porcelaneous and cherty rocks of the Monterey. Debris from the Monterey is incorporated in the conglomerate, which is also impregnated with tar.

North of the San Antonio River near the center of the Tierra Redonda Mountain quadrangle (secs. 19, 20, 29, 30, T. 24 S., R. 10 E.), the Paso Robles overlies porcelaneous rocks of the Monterey Shale and fossiliferous sandstone of the Pancho Rico Formation with little or no angular discordance. Apparently all but local patches of the Pancho Rico were stripped away before deposition of the Paso Robles.

North of the San Antonio River farther west, the Paso Robles lies directly on porcelaneous rocks of the Monterey Shale. There the Paso Robles and Monterey are both folded and faulted, although not to the same extent.

Between the Jolon and San Marcos faults, the Paso Robles conformably overlies the Santa Margarita Formation. The lower contact of the Paso Robles there is at the base of the lowest conglomerate unit above fossiliferous Santa Margarita sandstone beds.

Southwest of the San Marcos and Jolon faults, the Paso Robles Formation unconformably overlies the Monterey Shale or Tierra Redonda Formation. Where the Paso Robles overlies the Sandholdt Member of the Monterey, the lower contact of the Paso Robles is at the base of the lowest unit of conglomerate or sandstone above calcareous shale of the Sandholdt. In a canyon just south of the San Antonio River near the west edge of the map area (projected sec. 9, T. 24 S., R. 9 E.), conglomerate of the Paso Robles unconformably overlies porcelaneous rocks presumably of the upper part of the Monterey. On a ridge north of Harris Valley (SE¼ projected sec. 22, T. 24 S., R. 9 E.), the Paso Robles unconformably overlies the Tierra Redonda Formation. Conglomerate of the Paso Robles there is easily distinguished from that in the underlying Tierra Redonda, for it contains cherty rocks from the Monterey; such cherty rocks are lacking in the older unit. Pebbles and cobbles scattered on many ridgetops southwest of the San Antonio River are no doubt remnants of a once more extensive blanket of the Paso Robles.

LITHOLOGY

The Paso Robles Formation in the map area is chiefly conglomerate and sandstone, but limestone beds are conspicuous at many places.

Strata at the base of the formation near the San Antonio and Nacimiento Rivers are locally impregnated with tar.

Conglomerate of the Paso Robles Formation is in beds or units a few feet to several tens of feet thick. It contains clasts as large as boulders at a few places, but ordinarily it consists of pebbles or small cobbles in a matrix of poorly sorted sand. The composition of the conglomerate varies considerably from place to place. More than half of the pebbles and larger clasts at most localities are composed of porcelaneous rocks and chert derived from the Monterey Shale; other clasts are of granitic rock, gneiss, schist, quartzite, volcanic rock, porphyry, or well-indurated sandstone. At some places a few pebbles are composed of glaucophane schist and red and green chert from the Franciscan Formation. The conglomerate ranges from friable to well cemented and is most commonly yellowish gray. Some, but not all, of the well-indurated rock has calcareous cement. A thin section from conglomerate on the north side of the Nacimiento River (measured section 2, unit 76) has a martix of impure fine-grained calcite, and larger clasts have a rim of coarser grained calcite 0.05–0.14 mm wide. Conglomerate at the base of the Paso Robles at a locality north of the San Antonio River (sec. 34, T. 24 S., R. 10 E.) has an opaline matrix and is so well cemented that it breaks across, rather than around, the pebbles of chert.

Sandstone of the Paso Robles Formation ranges from massive to well bedded. It commonly is interbedded with conglomerate or occurs as lenses in units of conglomerate. Some beds grade either laterally or vertically from conglomerate through pebbly sandstone into sandstone. The sandstone is very fine to coarse grained, poorly sorted, and friable to well cemented; some is calcareous. The rock commonly is yellowish gray, grayish orange, very pale orange, or yellowish brown. It contains cross-strata and channels at some places. Sand grains are mainly angular or subangular and are chiefly of quartz and feldspar, although grains of chert, porcelanite, or mudstone are conspicuous in some beds, and mica flakes are common in most of the rock.

Limestone in the Paso Robles Formation is in beds 1–3 feet thick that are associated with sandstone. The limestone is generally very pale orange, contains scattered sand grains, and includes voids encrusted with calcite crystals. A thin section of limestone from a bed about 1 foot thick that is exposed in a bluff on the north side of the Nacimiento River (sec. 34, T. 24 S., R. 11 E.) is about 10 percent scattered angular and subangular sand grains 0.05–0.7 mm in diameter. Calcite in veins that cross the thin section is more coarsely crystalline than most of the limestone.

THICKNESS

The maximum thickness of the Paso Robles Formation in the map area is uncertain, but it must be many hundreds of feet. Part of the Paso Robles exposed in bluffs near the mouth of the Nacimiento River is greater than 400 feet thick. The Oakridge Oil Sargent 1 well, located near the Salinas River in Bradley, where the beds are probably nearly flatlying, reportedly drilled within the Paso Robles to a depth of 1,050 feet (Bramlette and Daviess, 1944). If this figure is considered as the subsurface thickness of the Paso Robles and is added to the 300–400 foot thickness exposed nearby in the hills on both sides of the Salinas River, the total thickness of the Paso Robles near Bradley would be at least 1,350–1,450 feet.

The thickness of the Paso Robles near the San Antonio River in the northwestern part of the map area is unknown, but in nearby places south of the river, it is at least 200 feet.

AGE AND CONDITIONS OF DEPOSITION

Fossils have not been found in the Paso Robles Formation in the map area, but at some places the unit overlies with little or no discordance the Pancho Rico Formation, which in nearby areas contains fossils of early Pliocene age. At some other places the Paso Robles conformably overlies the Santa Margarita Formation, which contains fossils of late Miocene age. These stratigraphic relations imply that the base of the Paso Robles where the formation overlies the Santa Margarita is older than it is where the unit overlies the Pancho Rico. By further implication, the older Paso Robles may be the nonmarine lateral equivalent of the Pancho Rico. The lower extreme of the age range of the Paso Robles is limited at some places by the upper Miocene Santa Margarita Formation and at other places by the lower Pliocene Pancho Rico Formation. The upper extreme of the age range is limited by older alluvium that unconformably overlies the Paso Robles and that is considered to be of Pleistocene and Recent(?) age. Thus, by its stratigraphic position alone, the Paso Robles Formation can reasonably be assigned to the Pliocene and probably Pleistocene Epochs. On the same basis, however, part of the Paso Robles could be as old as late Miocene in age.

Poor sorting, crude bedding, cross-stratification, and channeling in parts of the Paso Robles Formation suggest that the unit is nonmarine and largely fluviatile in origin. At many places the Paso Robles is lithologically indistinguishable from nearby younger alluvial sediments clearly related to modern rivers. Limestone beds in the Paso Robles have been considered of lacustrine origin (Taliaferro, 1943a, p. 148), but direct evidence that the limestone beds formed in lakes is lacking in the map area.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT(?) SERIES

OLDER ALLUVIUM

Older alluvium comprises fluviatile sediments that uncomformably overlie the Paso Robles Formation and older units and that are older than Recent alluvium of modern streams. It occurs in the mapped area mainly along the larger streams, where it forms terraces that are remnants of formerly more extensive fluviatile deposits. The older alluvium is chiefly poorly sorted semiconsolidated conglomerate and sandstone. It resembles parts of the Paso Robles Formation, and where the Paso Robles is nearly undeformed, the distinction between the two units is not readily apparent. In places where hills of the Paso Robles are adjacent to terraces of older alluvium, the contact between the two units is arbitrarily placed at the greatest change in slope at the base of the hills. The thickness of the older alluvium, based on the elevation of the surface of terraces above the Salinas River near Bradley, apparently is at least 60 feet; it is probably no more than 50 feet beneath terraces along the upper San Antonio River. The older alluvium is limited to Pleistocene and possibly Recent age by its stratigraphic position between the Paso Robles and Recent alluvium.

RECENT SERIES

ALLUVIUM

Alluvium forms the beds of all streams in the map area, but only in the Salinas, Nacimiento, and San Antonio Rivers is it extensive enough to be shown on plates 1 and 2. It is mainly sand and gravel and is probably less than 25 feet thick in most places. Siliceous debris from the Monterey Shale is abundant in alluvium of the San Antonio River, but is rare in alluvium of the Nacimiento River. This contrast reflects differences in the kinds of rocks exposed in the drainage basins of the two streams and is of practical importance in determining the economic uses of the alluvium (see discussion under "Economic geology").

STRUCTURE

GENERAL FEATURES

The primary structural features of the Tierra Redonda Mountain and Bradley quadrangles are the Jolon and related faults, which trend northwest across the middle of the map area. Exposures of upper Miocene and younger strata predominate northeast of the Jolon fault, and outcrops of middle Miocene and older beds are most common to the southwest. Less obvious, but of considerable importance to an understanding of the regional structure, is the contrast across the

Jolon fault of the mainly contemporaneous Tertiary stratigraphic sections. Table 1 summarizes these contrasts, which are discussed in more detail in descriptions of individual stratigraphic units. Figure 6 shows the fault pattern in the map area and the interpretation of the structure. The Jolon and closely related faults are considered to be the reflection in the sedimentary blanket of considerable movement on a large lateral fault in the underlying basement complex. Strata near the Jolon fault, especially the Monterey Shale, are severely deformed (fig. 7), but farther away, both to the northeast and to the southwest, the exposed beds generally form broad folds or monoclines and dip moderately.

FAULTS

JOLON FAULT

The Jolon fault is a major northwest-trending structural feature in the San Antonio River valley. It is exposed as a system of anastomotic faults in the hills north and northwest of the community of Jolon

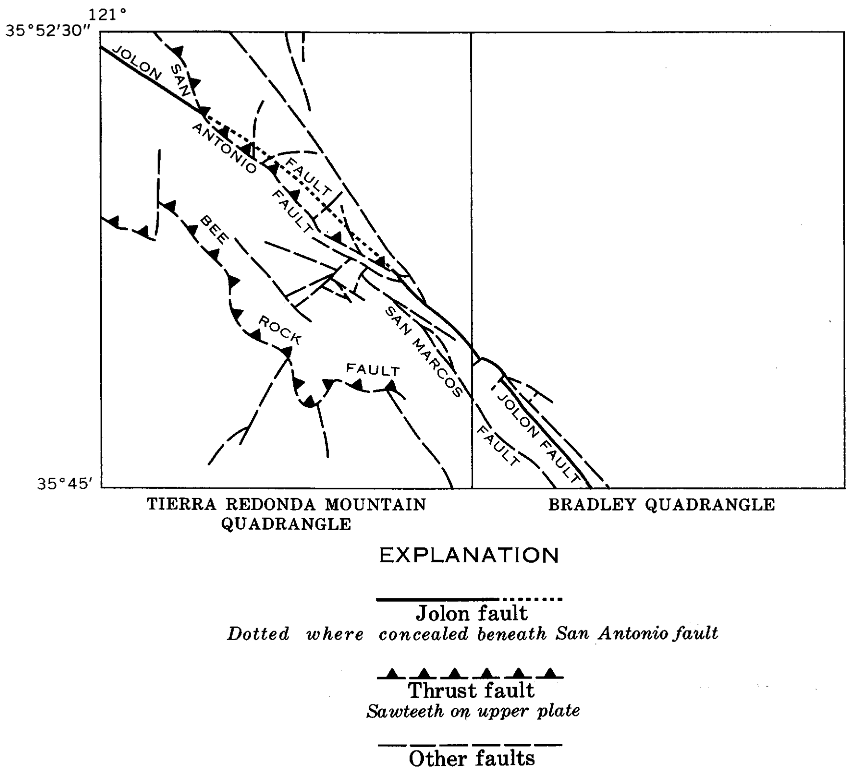

FIGURE 6.—An interpretation of the fault pattern in the Tierra Redonda Mountain and Bradley quadrangles.

(fig. 1), and it is marked by steeply dipping beds in the hills just north of the San Antonio River in the southern part of the Williams Hill quadrangle. The first published application of the name "Jolon" to the fault was by Jennings (1958) in a compilation based on unpublished maps of N. L. Taliaferro and on data on faults in the San Antonio River area from L. A. Tarbet. Although Clark (1929, fig. 1; 1930, p. 780, 781, 801, 802) earlier applied the name "San Antonio fault" to the same feature, the more recent name is used here to avoid confusion with a different but nearby fault called San Antonio by Jennings (1958).

In the San Antonio River valley near Jolon, the Jolon fault forms the boundary between two distinct stratigraphic sections, one to the northeast in which the Vaqueros Formation lies directly on the pre-Tertiary basement complex, and one to the southwest in which the Vaqueros is preceded by a thick sequence of strata. The major northwest-trending fault across the middle of the Tierra Redonda Mountain and Bradley quadrangles (Jolon fault of fig. 6) separates contrasting stratigraphic sections of the same type and in the same manner. For this reason and also because of its alinement with the Jolon fault farther northwest, the major fault in the map area is considered to be the southeast extension of the Jolon fault.

The Jolon fault is exposed in the map area from near the Nacimiento River at the south edge of the Bradley quadrangle northwestward to the San Antonio River in the eastern part of the Tierra Redonda Mountain quadrangle. Along this part of its trace, the fault separates contrasting upper Miocene and Pliocene stratigraphic sections (table 1). The section exposed northeast of the fault comprises the Monterey Shale, including the Buttle Member, and the overlying Pancho Rico and Paso Robles Formations. The section exposed southwest of the fault includes the Monterey Shale, succeeded by the Santa Margarita and Paso Robles Formations. The regional relations of these unlike, but contemporaneous, strata juxtaposed across the fault suggest right-lateral displacement along the fault of at least 11 miles in and near the map area (Durham, 1965b, p. 108).

Where the Jolon fault crosses the ridge northwest of the Nacimiento River, porcelaneous rocks of the Monterey Shale are fractured and have slickensides. The trace of the fault there indicates that the fault surface dips steeply northeast. Farther northwest, beyond a tear fault in sec. 2, T. 25 S., R. 10 E., the trace of the fault suggests that the fault surface dips southwest, but the dip must steepen at shallow depth, for apparently the nearby Union Oil Union–Texaco–Connell 1 well (pl. 2, No. 21; table 7) did not penetrate the fault. The varying direction of dip of the exposed fault is considered to be the surficial result of local deformation of a nearly vertical fault surface. This interpretation is shown on structure sections *C–D–E* and *F–I–E* (pl. 3).

SAN ANTONIO FAULT

The San Antonio fault is a thrust fault along the edge of the hills at the northeast margin of the San Antonio River valley. The earliest published use of the name "San Antonio" for this feature was by Jennings (1958).

The upper part of the Monterey Shale overrides the Paso Robles Formation along the San Antonio fault near the northwest corner of the Tierra Redonda Mountain quadrangle and overrides the Tierra Redonda Formation and the Sandholdt Member of the Monterey along the fault farther southeast. The Monterey Shale above the San Antonio fault is deformed at most places into closely spaced folds and is commonly crushed or brecciated. The Sandholdt below the fault in projected secs. 29 and 30, T. 24 S., R. 10 E., includes crushed cherty rocks and brecciated dolomitic carbonate beds. The best exposure of the fault is in the riverbank in the southern part of projected sec. 19, T. 24 S., R. 10 E., where crushed and fractured porcelanite of the upper part of the Monterey is thrust over calcareous shale of the Sandholdt. The fault dips 33° NE. there and is marked by a zone of gouge several inches thick. The thrust effect of the fault is especially obvious in the NW¼ of projected sec. 29, T. 24 S., R. 10 E., where an abbreviated sequence of upper Miocene and Pliocene strata overlies lower middle Miocene beds. The San Antonio fault presumably terminates to the southeast beneath the San Antonio River against another fault that strikes northwest through secs. 28 and 29, T. 24 S., R. 10 E.

SAN MARCOS FAULT

Taliaferro (1943a, p. 153) used the name "San Marcos fault" for a major structural feature south of the map area in the Adelaida quadrangle. This fault extends northwest into the Bradley and Tierra Redonda Mountain quadrangles, where its trace generally separates younger beds of the stratigraphic section characteristic of the area southwest of the Jolon fault from older beds of the same section. The San Marcos fault apparently terminates at the northwest end against a complex system of northeast-trending crossfaults at the serpentine bend of the San Antonio River (secs. 29, 30, 31, and 32, T. 24 S., R. 10 E.). The exposures of the Santa Margarita Formation in this system of crossfaults are interpreted as fault blocks downdropped into the older Sandholdt Member of the Monterey Shale.

BEE ROCK FAULT

The Sandholdt Member of the Monterey Shale lies with structural discordance on the Vaqueros Formation and older strata southeast of Bee Rock (sec. 7, T. 25 S., R. 10 E.), although nearby the Tierra Redonda Formation occurs in stratigraphic sequence between the Sandholdt and Vaqueros. The absence of the Tierra Redonda below the Sandholdt southeast of Bee Rock is considered good evidence that there the contact between the Sandholdt and older strata is a fault, here named the Bee Rock fault. An alternative explanation that would consider the contact an unconformity would require that 2,000–3,000 feet of strata be locally removed prior to deposition of the Sandholdt, and direct regional evidence for such an unconformity is lacking.

The trace of the Bee Rock fault is obscure east of sec. 7, T. 25 S., R. 10 E., although it apparently forms the contact between the Sandholdt Member and older strata for a mile or more in that direction. Farther east the trace of the fault either disappears in the complicated folds of the Sandholdt Member, as suggested in plate 1, or terminates against a northwest-trending fault that separates Sandholdt and older strata in sec. 9, T. 25 S., R. 10 E.

The Bee Rock fault is thought to extend northwest of the Bee Rock Canyon and to form the contact between the Sandholdt Member and the Tierra Redonda Formation from Bee Rock to the west edge of the mapped area. Its presence would explain the structural discordance across the contact at several places. The fault probably extends at least 2 miles west of the mapped area to Copperhead Creek, where beds of the uppermost part of the Monterey Shale are thrust over the Sandholdt Member, which there contains foraminifers of the lower Miocene Saucesian Stage (Patsy J. Smith, written commun., 1966).

FAULTS BETWEEN SAN ANTONIO RIVER AND HAMES VALLEY

The fault that trends southeast from sec. 1, T. 24 S., R. 9 E., and the nearby inferred fault in sec. 7, T. 24 S., R. 10 E., are at the southeast end of a system of en echelon faults that extends northwest for at least 13 miles into the Espinosa Canyon quadrangle. North of the mapped area, the basement complex southwest of the fault system is several thousand feet higher structurally than it is across the fault system to the northeast. This relationship may extend into the Tierra Redonda Mountain quadrangle, but subsurface information in support of this idea is lacking. The fault traces are confined to the Monterey Shale and are marked by linear zones of crushed and contorted beds across which the structure of the Monterey is discordant.

INTERPRETATION OF FAULTS

The interpretation of the fault pattern in the mapped area shown in figure 6 is based largely on the distribution of contrasting Miocene and Pliocene stratigraphic sections. The Jolon fault is interpreted to be concealed in part of the Tierra Redonda Mountain quadrangle beneath rocks thrust over it from the northeast along the San Antonio fault. This interpretation maintains the character of the Jolon fault as a persistent feature from the type area southeastward along the San Antonio River valley to and beyond the Nacimiento River.

The San Marcos fault marks the southwest border of a long narrow fault block that is bounded on the northeast side by the Jolon fault. The block is structurally depressed relative to the area across the San Marcos fault, for beds equivalent to those exposed in the block have been stripped away to the southwest. The San Marcos and Jolon faults are related, but in at least the map area the San Marcos is considered secondary in importance to the Jolon.

FOLDS

Large anticlines and synclines are uncommon in the Tierra Redonda Mountain and Bradley quadrangles, but the Monterey Shale at many places is deformed into closely spaced and generally steep limbed folds, like those exposed along a road (not shown on pl. 1) between Nacimiento Dam and Sulphur Canyon. The folding is particularly severe near the base of the Sandholdt (fig. 7), presumably because there the shale is buttressed against the more rigid sandstone of the Tierra Redonda Formation beneath. Some slippage is necessary along bedding faults or other kinds of faults to permit contortion of the shale beds without comparable deformation of the nearby sandstone beds. These folds in the Sandholdt generally are too small to show properly on the geologic maps (pls. 1 and 2), and they are shown only diagrammatically on the structure sections (pl. 3).

AGE OF FAULTS AND FOLDS

Most of the faults and folds in the map area appear to be related to the same, and most recent, episode of deformation. This episode followed deposition of the sediments of the Pliocene Pancho Rico Formation and probably spanned at least part of the time of deposition of the sediments of the Paso Robles Formation, for the Pancho Rico is deformed to the same degree as underlying beds and the Paso Robles is deformed to the same degree as older beds at some places and less than the older beds at others. Since the Paso Robles is of Pliocene and Pleistocene(?) age, and the overlying undeformed older alluvium is of Pleistocene and Recent(?) age, the deformation may have begun in the Pliocene and continued into the Pleistocene.

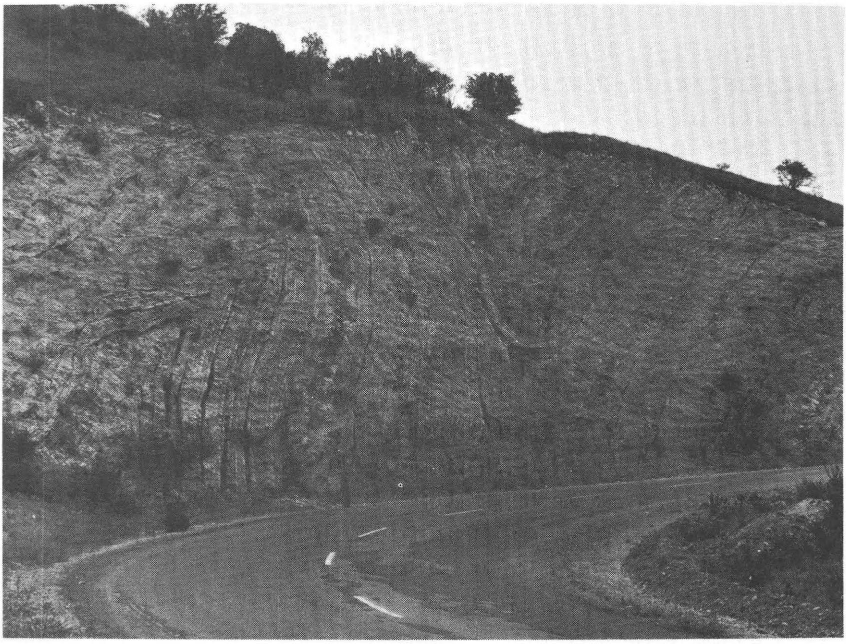

FIGURE 7.—Folds in the Sandholdt Member of the Monterey Shale in roadcut north of Nacimiento Dam, about 1,000 feet from tilted but otherwise undeformed sandstone beds of the underlying Tierra Redonda Formation.

The unconformity at the base of the Vaqueros Formation records a pre-Miocene orogeny, but details of the event are obscure. Boulders of basement rock in the Tierra Redonda Formation may indicate uplift during the Miocene of a nearby area of granitic rock, perhaps across the Jolon fault, but again details are lacking.

ECONOMIC GEOLOGY

PETROLEUM

Tar-impregnated sandstone and conglomerate beds at the base of the Paso Robles Formation crop out near the San Antonio River (secs. 34 and 35, T. 24 S., R. 10 E., and sec. 2, T. 25 S., R. 10E.) and are depicted on plate 2. Similar beds near the Nacimiento River (secs. 12 and 13, T. 25 S., R. 10 E.) occur in the Paso Robles and Pancho Rico(?) Formations and are intercalated with porcelaneous and cherty rocks of the Monterey Shale, but they are too thin or too limited in extent to be indicated on plate 2. Tar is also conspicuous in joints and bedding surfaces of fractured porcelaneous and cherty rocks of the Monterey north of the San Antonio River (sec. 34, T. 24 S., R. 10 E.) and in the heart of an anticline near the Nacimiento River (NW¼ sec. 12, T. 25 S., R. 10 E.). Waring and Bradley (1917,

p. 596) reported that bituminous sandstone exposed near the Nacimiento River was quarried at one time for use on roads and bridges near King City, which is about 35 miles to the north. An abandoned adit in tar-impregnated pebbly sandstone is located about a quarter of a mile south of the San Antonio River (sec. 2, T. 25 S., R. 10 E.).

The tar-impregnated sandstone beds that crop out in the map area attracted the attention of pioneer oil seekers of the Salinas Valley region. Early wells in the area were generally shallow and were apparently intended to tap nearby tarry beds or an underlying source of the tar and oil in them. Later wells were generally much deeper and less obviously related to surface features. The objective of the later wells was probably oil from either fractured Monterey Shale or sandstone beds beneath the Monterey.

Twenty-four wells were drilled for oil in the Tierra Redonda Mountain and Bradley quadrangles before 1966 (table 7). None of these produced oil in commercial quantities.

DIATOMITE

Diatomite in the Buttle Member of the Monterey Shale crops out in a belt that extends from the north edge of the mapped area southeastward to the San Antonio River. Diatomaceous rocks of the same unit crop out south of the San Antonio River in Oro Fino Canyon and on the north side of the Nacimiento River. The purer diatomite grades into diatomaceous mudstone by an increase in the proportion of sand, silt, and clay to diatomaceous debris.

The Buttle Member is about 585 feet thick where measured in the northwestern part of the Tierra Redonda Mountain quadrangle (measured section 1). About 98 percent of this thickness is diatomite, including one unit (no. 48) 237 feet thick. The diatomite is generally massive, but contains thin beds of porcelanite and dolomitic carbonate rock.

Adits and other evidence of mining or prospecting in the diatomite remain in secs. 9 and 15, T. 24 S., R. 10 E. Diatomite, at least in small quantities, was shipped from the area as early as 1904 (Aubury, 1906, p. 292). According to Laizure (1925, p. 32–33), diatomite mining began in section 15 in 1922. The material was taken both from open-cuts and from tunnels as long as 150 feet and was trucked 14 miles to a mill at San Miguel. The operation was intermittent and depended upon demand for the product.

SAND, GRAVEL, AND ROCK

Sand and gravel have been quarried for local use from along both the San Antonio and Nacimiento Rivers. A quarry in older alluvium in a terrace by the San Antonio River (sec. 35, T. 24 S., R. 10 E.) yielded

TABLE 7.—*Exploratory wells drilled before 1966*

[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 and 2)	Operator	Well	Location				Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks (depths in feet)
			Quadrangle	Sec.	T.(S.)	R.(E.)				
1	Associated Oil Co.	King 1	Bradley	36	24	10	1917	740 t	2,035	Reported: Paso Robles Formation, 0–800?; marine Pliocene rocks, 800?–1,327?; Santa Margarita sandstone, 1,327?–1,445; Monterey Shale, 1,445–2035; tar, 1,320–1,327 (Bramlette and Daviess, 1944). Mentioned by Waring (1914, p. 435) as Bradley Oil Co. well and by English (1918, p. 242; fig. 36 shows location) as King well of Bradley Oil Co.
2	Cavanaugh	1	do	11	25	10	1905	900 t	800	Reported Monterey Shale at bottom (Bramlette and Daviess 1944). Mentioned by Waring (1914, p. 436) and by English (1918, p. 242; fig. 36 shows location).
3	do	2	do	11	25	10		920 t	2,500	Reported Monterey Shale at bottom (Bramlette and Daviess, 1944). Mentioned by English (1918, p. 242; fig. 36 shows location).
4	Continental Oil Co.	Nacimiento 1	do	32	24	11	1929	900 t	5,955	Reported: Paso Robles Formation, 0–900?; marine Pliocene rocks 900?–2,200?; Monterey Shale 2,200?–4,747; Sandholdt Shale, 4,747–5,746; Vaqueros Sandstone, 5,746–5,955; tar (in fractures) 2,200–4,670; gas show, 3,834–3,846; oil show, 5,802–5,825 (Bramlette and Daviess, 1944); *Siphogenerina hughesi* subzone at 5,372, or 430 ft. above base of shales; hard gray arkosic sansdtone, 5,802–5,955, probably Vaqueros (Wilson 1931, p. 103). Also called Marland Oil Nacimiento 1 well and Bradley Nacimiento Ranch 1 well.
5	Great American Oil Co.	1	do	2	25	10	?	860 t	?	Reportedly drilled through bituminous rock into Monterey Shale without reaching productive oil sand (Hamlin, 1904, p. 19). Mentioned by Waring (1914, p. 436).
6	Hames Valley Oil Co.	Metropolis 1	do	35	24	10	1911–13	645 t	3,100	Reported: Monterey Shale, 1,000–3,100; oil show (Bramlette and Daviess, 1944). Mentioned by English (1918, p. 242; fig. 36 shows location).
7	King Petroleum Co.	Moser 1	do	26	24	10	1955	612 kb	3,800	Reported: Monterey Shale, 700; bottom in Miocene rocks (California Oil Fields, v. 41 no. 2, p. 114).
8	Loma Grande Oil Co.	Corey 1	do	23	24	10	1940–42	1,420 t	4,318	Reportedly in Monterey Shale to bottom (Bramlette and Daviess, 1944).
9	M. J. M. and M. Oil Co.	Konekamp-Union 1–3.	do	3	25	10	1959–62	1,201 kb	8,009	Reported: Vaqueros Formation, 6,380 (California Oil Fields, v. 45, no. 2, p. 118); bottom in Miocene rocks (California Oil Fields, v. 48, no. 2, p. 171). Originally drilled by Thornbury, Geis, and Robinson, and called Konekamp 1–3; abandoned 1959. Taken over by M.J.M. and M. Oil in 1962. Reported: cleaned out to 4,625, set whipstock at 4,454, redrilled to 4,925; formation test, 4,877–4,925, open 1 hr recovered 45 ft gas-cut drilling fluid; reabandoned.

TABLE 7.—*Exploratory wells drilled before 1966*—Continued

Map No. (pls. 1 and 2)	Operator	Well	Location				Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks (depths in feet)
			Quadrangle	Sec.	T.(S.)	R.(E.)				
10	Monterey Oil Co.		Bradley	27	24	10	1914	880 t	1,100	Reportedly in Monterey Shale to bottom (Bramlette and Daviess, 1944). Mentioned by Hamlin (1904, p. 19), Waring (1914, p. 436), and English (1918, p. 242; fig. 36 shows location).
11	Nacimiento?	1	do	18	25	11	1901	599 t	700?	Reported: Paso Robles Formation or marine Pliocene rocks at bottom; oil show 700 (Bramlette and Daviess, 1944). Mentioned by Waring (1914, p. 436).
12	Oakridge Oil Co.	Sargent 1	do	8	24	11	1920–23?	540 t	3,986	Reported: Paso Robles Formation, 0–1,050; marine Pliocene rocks, 1,050–2,074; Santa Margarita Formation (McLure Shale lithology), 2,074–2,674; Monterey Shale, 2,674–3,638; Sandholdt shale, 3,638–3,986; sand, 3,661–3,816; oil and gas shows, 1,540–1,550, 3,710–3,816; gas show, 3,818–3,860 (Bramlette and Daviess, 1944).
Not on map.	Paradise?	1	Tierra Redonda Mountain.	34	24	10	?	1,250?	?	Listed by Bramlette and Daviess (1944).
13	Pleyto Oil Co.	1	Bradley	26	24	10	1909–12	620 t	3,300	Reported: in Monterey Shale to bottom; oil shows, 3,100–3,300; gas shows, 3,217–3,237 (Bramlette and Daviess, 1944); produced a small amount of crude oil (Kilkenny, 1948, p. 2,267). Mentioned by Waring (1914, p. 436) and English (1918, p. 242; fig. 36 shows location). Was oozing oil in 1964.
14	Royalty Service Corp.	Federal 1	Tierra Redonda Mountain.	21	24	10	1943	1,360 t	7,773	Reported: Monterey Shale, 0–6,600; Sandholdt shale, 6,600–7,773 (Bramlette and Daviess, 1944).
15	Shell Oil Co.	Branch 1	do	34	24	10	1937	650 t	8,994	Reported: Monterey Shale, 0–3,379; Sandholdt Shale, 3,379–7,261; Vaqueros Formation, 7,261–8,373; Berry Formation, 8,373–8,974; granitic basement, 8,974–8,994; oil show, 4,100; oil and gas shows, 6,855–6,931, 7,261–7,332, 8,340 (Bramlette and Daviess, 1944). Mentioned by Kilkenny (1948, p. 2,267).
16	do	Branch 2	do	34	24	10	1936–37	860 t	8,662	Reported: Monterey Shale, 0–3,438?; Sandholdt Shale, 3,438?–8,140; Vaqueros Formation, 8,140–8,662; oil and gas shows, 8,164–8,234; 8,432 (Bramlette and Daviess, 1944).
17	Statewide Oil Co.	Sulphur Canyon 1.	Bradley	3	25	10	1961–64	1,009 kb	5,430	Reported: Relizian Stage, 3,695; bottom in Monterey Shale (California Oil Fields, v. 50, no. 2, p. 174). Drilled by Bradley, Muhl, and Johnson to 3,534 and abandoned in 1962; deepened by Statewide Oil in 1964.
18	The Texas Co.	Shell (NCT-1) 1.	Tierra Redonda Mountain.	6	24	10	1956–57	1,671 gr	11,994	Reportedly in Miocene rocks at bottom (California Oil Fields, v. 43, no. 2, p. 124).

19	do	Signal 1	do	28	24	10	1952	1,572 kb	10,480	Reported: top Vaqueros sandstone, 9,800; bottom in lower Miocene rocks (California Oil Fields. v. 38, no. 2, p. 97).
20	Thornbury, William.	Shell Fee 1	Bradley	26	24	10	1964	629 kb	3,000	Reportedly in Monterey Shale at bottom (California Oil Fields, v. 50, no. 2, p. 174).
21	Union Oil Co	Union-Texaco-Connell 1.	do	2	25	10	1961	1,090 gr	6,869	Reported: Vaqueros Formation, 6,110; bottom in Miocene rocks (California Oil Fields, v. 47, no. 2, p. 147).
22	Veratina	1	do	35	24	10		695 t		Reported considerable salt water and some gas (English, 1918, p. 243).
23	White Oaks Oil Co.	1	do	35	24	10	1900?	670 t	800	Reported oil show at 300 (Bramlette and Daviess, 1944). Mentioned by Hamlin (1904, p. 19), Waring (1914, p. 436), and English (1918, p. 242; fig. 36 shows approximate location).

TABLE 8.—*Fossil localities*

[Projected sections are marked by an asterisk]

USGS loc.	Location				Formation or member	Type of fossils							
	Quadrangle	Sec.	T.(S.)	R.(E.)		Foraminifers	Gastropods	Pelecypods	Cephalopods	Brachiopods	Barnacles	Scaphopods	Echinoids
Mf639	Tierra Redonda Mountain.	*19	24	10	Sandholdt Member of Monterey Shale.	X	--	--	--	--	--	--	--
Mf640	do	*19	24	10	do	X	--	--	--	--	--	--	--
Mf641	do	*15	24	9	do	X	--	--	--	--	--	--	--
Mf642	do	*14	24	9	do	X	--	--	--	--	--	--	--
Mf643	do	*15	24	9	do	X	--	--	--	--	--	--	--
Mf644	do	*15	24	9	do	X	--	--	--	--	--	--	--
Mf778	do	*25	24	9	do	X	--	--	--	--	--	--	--
Mf779	do	25	24	9	do	X	--	--	--	--	--	--	--
Mf780	do	32	24	10	do	X	--	--	--	--	--	--	--
Mf781	do	*29	24	10	do	X	--	--	--	--	--	--	--
Mf782	do	*30	24	10	do	X	--	--	--	--	--	--	--
Mf783	do	*29	24	10	do	X	--	--	--	--	--	--	--
Mf784	do	*25	24	9	do	X	--	--	--	--	--	--	--
Mf785	do	*24	24	9	do	X	--	--	--	--	--	--	--
Mf786	do	*22	24	9	do	X	--	--	--	--	--	--	--
Mf787	do	*21	24	9	do	X	--	--	--	--	--	--	--
Mf788	do	*15	24	9	do	X	--	--	--	--	--	--	--
Mf820	Bradley	14	25	10	do	X	--	--	--	--	--	--	--
Mf825	Tierra Redonda Mountain.	10	25	10	do	X	--	--	--	--	--	--	--
Mf826	do	3	25	10	do	X	--	--	--	--	--	--	--
Mf827	do	3	25	10	do	X	--	--	--	--	--	--	--
Mf828	do	4	25	10	do	X	--	--	--	--	--	--	--
Mf829	Bradley	14	25	10	do	X	--	--	--	--	--	--	--
Mf830	Tierra Redonda Mountain.	32	24	10	do	X	--	--	--	--	--	--	--
Mf831	do	10	25	10	do	X	--	--	--	--	--	--	--
Mf832	do	32	24	10	do	X	--	--	--	--	--	--	--
Mf853	do	7	25	10	do	X	--	--	--	--	--	--	--
Mf854	do	5	25	10	do	X	--	--	--	--	--	--	--
Mf893	do	5	25	10	do	X	--	--	--	--	--	--	--
Mf899	do	15	25	10	do	X	--	--	--	--	--	--	--
Mf901	do	9	25	10	do	X	--	--	--	--	--	--	--
M1936	do	*29	24	10	Santa Margarita Formation	--	--	X	--	--	--	--	--
M1937	do	20	24	10	Pancho Rico Formation	--	X	X	--	--	--	--	--
M1938	do	*22	24	9	Sandholt Member of Monterey Shale.	--	--	X	--	--	--	--	--
M1940	do	33	24	10	Santa Margarita Formation	--	X	X	--	--	--	--	X
M2046	Bradley	11	25	10	do	--	--	X	--	X	--	--	--
M2300	do	14	24	10	Pancho Rico Formation	--	--	--	--	--	X	--	--
M2301	do	15	24	10	do	--	--	X	--	--	X	--	--
M2302	do	26	24	10	do	--	X	X	--	--	--	--	--
M2304	do	2	25	10	Santa Margarita Formation	--	X	X	--	X	--	--	--
M2307	Tierra Redonda Mountain.	*29	24	10	Pancho Rico Formation	--	--	X	--	--	--	--	--
M2308	do	*32	24	10	Santa Margarita Formation	--	X	X	--	--	--	--	X
M2670	do	7	25	10	Vaqueros Formation	--	X	--	--	--	--	--	--
M2672	do	18	25	10	Unnamed formation of Late Cretaceous and early Tertiary age.	--	X	X	X	--	--	X	--
M2688	do	7	25	10	Vaqueros Formation	--	X	--	--	--	--	--	--
M2689	do	12	25	9	do	--	X	--	--	--	--	--	--
M2691	do	14	25	9	do	--	X	--	--	--	--	--	--
M2692	do	15	25	9	do	--	X	--	--	--	--	--	--
M3242	do	10	25	9	do	--	--	X	--	--	--	--	--
M3249	do	7	25	10	do	--	X	X	--	--	--	--	--
M3250	do	10	25	9	do	--	X	X	--	--	--	--	--

sandy gravel used for road base in 1964. A quarry in alluvium in the bed of the Nacimiento River (sec. 14, T. 25 S., R. 10 E.) yielded sand and gravel used in concrete for the San Antonio Dam in 1964 and 1965. Material from the Nacimiento River was used in preference to that from the San Antonio River because the Nacimiento River alluvium contains much less cherty debris from the Monterey Shale; the cherty debris is likely to cause excessive expansion of concrete in which it is used. A local illustration of problems involved in using cherty rock in concrete was given by Stanton (1948, p. 1058–1060), who described buckling and cracking of concrete pavement made with fine aggregate from Oro Fino Canyon in the Bradley quadrangle. Extensive tests demonstrated that clasts of opaline rock derived from the Monterey are acted upon by the caustic reaction products of high-alkali cement hydration to form sodium or potassium silica gel. This cause of excessive expansion is avoided if the concrete is made with an aggregate that lacks opaline debris or is made with a low-alkali cement.

Riprap facing on the San Antonio Dam came from dolomitic carbonate beds in the Sandholdt Member of the Monterey Shale on the ridge north of the Nacimiento River.

MEASURED SECTIONS

SECTION 1.—*On southwest side of Hames Valley in sec. 9, T. 24 S., R. 10 E., Tierra Redonda Mountain quadrangle*

	Thickness (feet)	Thickness (inches)
Paso Robles Formation (lower part only):		
56. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), massive, poorly sorted, fine- to coarse-grained, pebbly, noncalcareous, well-indurated; grains angular to subrounded; pebbles subrounded, mainly of basement rocks; top covered, overlain by pebbly soil	3+	0
Total, lower part of Paso Robles Formation	3+	0
Approximate contact, apparently conformable.		
Monterey Shale:		
Buttle Member:		
55. Covered; pieces of diatomaceous mudstone in soil	165	0
54. Diatomite, white (*N*9), massive, noncalcareous, friable, light-weight; hackly fracture; top covered	46	0
53. Porcelanite, yellowish-gray (5*Y* 8/1); hackly fracture; pinches out nearby		2
52. Diatomite, like unit 54	1	2
51. Porcelanite, like unit 53; lower contract distinct		7
50. Diatomite, like unit 54	56	0
49. Dolomitic carbonate rock, yellowish-gray (5*Y* 8/1), massive, dense; lower contact gradational	1	8
48. Diatomite, like unit 54; some structures that resemble burrows	237	0
47. Porcelanite, pale-yellowish-brown (10*YR* 6/2), and dolomitic carbonate rock, very pale orange (10*YR* 8/2), mixed irregularly in single bed		3
46. Diatomite, like unit 54	1	8

SECTION 1.—*On southwest side of Hames Valley in sec. 9, T. 24 S., R. 10 E., Tierra Redonda Mountain quadrangle*—Continued

	Thickness (feet)	Thickness (inches)
Monterey Shale—Continued		
Buttle Member—Continued		
45. Porcelanite, pale-yellowish-brown (10*YR* 6/2); hackly fracture; thickens and thins nearby		2
44. Diatomite, like unit 54	14	0
43. Diatomite, like unit 54; includes lenses of porcelanite about half an inch thick and as long as 2 ft. at about 8 and 18 in. above base; lower contact distinct, but irregular	2	5
42. Porcelanite, light-olive-gray (5*Y* 6/1); hackly fracture; thickens and thins nearby; lower contact distinct, but irregular		5
41. Diatomite, like unit 54; contains structures that resemble burrows		4
40. Porcelanite, pale-yellowish-brown (10*YR* 6/2); hackly fracture; thickens and thins nearby		2
39. Diatomite, like unit 54; contains structures that resemble burrows	1	3
38. Porcelanite, like unit 40; lower contact distinct, but irregular		1
37. Diatomite, like unit 54; pinches out nearby		1
36. Porcelanite, like unit 40		11
35. Diatomite, like unit 54		1
34. Dolomitic carbonate rock, very pale orange (10*YR* 8/2), dense; lower contact distinct, but irregular		3
33. Porcelanite, like unit 40; lower contact irregular; pinches out nearby		2
32. Dolomite carbonate rock, like unit 34; lower contact distinct, but irregular		3
31. Diatomite, like unit 54, except lower part is shaly; lower contact distinct, but irregular		5
30. Porcelanite, light-olive-gray (5*Y* 6/1) mottled dark-yellowish-brown (10*YR* 4/2); beds 3–6 in. thick; bedding surfaces irregular, conchoidal fracture; thickens and thins nearby; lower contact distinct	1	10
29. Diatomite, like unit 54; includes lense of porcelanite 1 in. thick, and 15 in. long about 2 ft below top	32	0
28. Porcelanite, yellowish-gray (5*Y* 7/2), massive; lower contact gradational		3
27. Diatomite, like unit 54; lower contact gradational	1	10
26. Dolomitic carbonate rock, yellowish-gray (5*Y* 7/2), massive; less dense than underlying unit; lower contact gradational		7
25. Dolomitic carbonate rock, yellowish-gray (5*Y* 7/2), massive, dense; forms resistant ledge	2	0
24. Porcelanite, like unit 28; contains fish scales; gradational lower contact		3
23. Porcelaneous mudstone, yellowish-gray (5*Y* 8/1); hackly fracture; contains fish scales and scattered diatom frustules; lower contact gradational	1	0

SECTION 1.—*On southwest side of Hames Valley in sec. 9, T. 24 S., R. 10 E., Tierra Redonda Mountain quadrangle*—Continued

	Thickness (feet)	Thickness (inches)
Monterey Shale—Continued		
Buttle Member—Continued		
22. Diatomite, like unit 54; lower contact gradational	2	1
21. Porcelanite, light-olive-gray (5*Y* 6/1), massive; lower contact gradational	1	0
20. Diatomite, like unit 54; lower contact gradational	2	6
19. Porcelaneous mudstone, like unit 23; includes a few porcelanite layers or lenses about one-eighth of an inch thick; lower contact gradational	1	0
18. Diatomite, like unit 54; lower contact gradational	1	9
17. Porcelanite, like unit 21; lower contact gradational		1
16. Diatomite, like unit 54; lower contact gradational		8
15. Porcelaneous mudstone, yellowish-gray (5*Y* 7/2); includes bands and lenses of pale-yellowish-brown (10*YR* 6/2) porcelanite; lower contact gradational		1
14. Diatomite, like unit 54; lower contact gradational	1	11
13. Porcelanite, like unit 21; lower contact gradational		1
12. Diatomite, like unit 54; lower contact gradational		11
11. Porcelanite, like unit 21; lower contact gradational		1
10. Diatomite, like unit 54; lower contact gradational	2	6
9. Porcelanite, yellowish-gray (5*Y* 7/2) to pale-yellowish-brown (10*YR* 6/2); hackly fracture; lower contact gradational		2
8. Diatomite, like unit 54; contains fish scales; lower contact gradational		5
Total, Buttle Member	585	6
Monterey Shale below Buttle Member (upper part only):		
7. Porcelanite, light-olive-gray (5*Y* 6/1); hackly fracture; lower contact gradational		4
6. Porcelaneous mudstone, very pale orange (10*YR* 8/2), poorly bedded; hackly fracture; contains fish scales and scattered diatom frustules; interbedded with and locally grades into light-olive-gray (5*Y* 6/1) porcelanite	5	0
5. Covered	28	0
4. Porcelaneous rocks, like unit 6; partly covered	37	0
3. Porcelanite, yellowish-gray (5*Y* 7/2), massive; conchoidal fracture; partly covered	9	0
2. Dolomitic carbonate rock, like unit 25; contains scattered impressions of fish scales	5	0
1. Porcelanite, yellowish-gray (5*Y* 8/1), poorly bedded; conchoidal fracture; grades locally into porcelaneous mudstone and diatomaceous mudstone; partly covered; base concealed	10+	0
Total, Monterey Shale below Buttle Member (part measured)	94+	4
Total, Monterey Shale, including Buttle Member (part measured)	679+	10

SECTION 2.—*On north side of Nacimiento River in sec. 12, T. 25 S., R. 10 E., Bradley quadrangle*

	Thickness (feet)	Thickness (inches)
Paso Robles Formation (lower part only):		
82. Conglomerate, yellowish-gray (5*Y* 8/1); pebbles and cobbles as large as 6 in., chiefly basement rocks; noncalcareous; friable; cross-stratified, fills channels in underlying unit; includes beds and lenses of sandstone; top covered	17	0
81. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), fine- and medium-grained, noncalcareous, friable, lenticular	16	0
80. Conglomerate, like unit 82	27	0
79. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), fine-grained; scattered coarse grains; noncalcareous; hackly fracture; contains gypsum along joints and bedding surfaces	9	0
78. Sandstone, arkosic, yellowish-gray (5*Y* 8/1) and grayish-orange (10*YR* 7/4), massive, chiefly fine- and medium-grained; scattered coarse grains and lenses of small pebbles; noncalcareous; friable; contains gypsum along joints	25	6
77. Sandstone, like unit 79	31	6
76. Conglomerate, yellowish-gray (5*Y* 8/1) stained yellowish-orange (10*YR* 6/6), massive; pebbles and cobbles chiefly basement rocks, but some porcelaneous rocks and chert; generally noncalcareous, but locally well cemented with calcite	21	6
75. Mudstone, medium-light-gray (*N*6), massive, noncalcareous; contains scattered pebbles of porcelaneous rocks and chert; hackly fracture; gypsum in fractures; includes some lenses of sandstone	21	0
74. Sandstone, arkosic, yellowish-gray (5*Y* 8/1), massive, mainly fine-grained; scattered medium and coarse grains; some pebbles near base; noncalcareous; porous; contains gypsum along joints	9	6
73. Sandstone, arkosic, very pale orange (10*YR* 8/2), massive, fine- and medium-grained; scattered coarse grains of chert; some pebbles near base; calcareous; well cemented	2	9
72. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), massive, chiefly fine-grained; scattered medium and coarse grains; slightly calcareous; hackly fracture; contains gypsum along joints	6	0
71. Conglomerate, yellowish-gray (5*Y* 7/2); rounded pebbles of basement rocks, porcelaneous rocks, chert, and sandstone; a few small cobbles as long as 3 in.; noncalcareous; includes lenses of sandstone	28	0
70. Sandstone, arkosic, yellowish-gray (5*Y* 8/1), massive, fine- and medium-grained, noncalcareous, friable; includes calcareous concretions as long as 3–10 in. about 6 ft above base; lower contact gradational	10	0
69. Conglomerate, like unit 71; lower contact gradational	8	0

SECTION 2.—*On north side of Nacimiento River in sec. 12, T. 25 S., R. 10 E., Bradley quadrangle*—Continued

	Thickness (feet)	Thickness (inches)
Paso Robles Formation (lower part only)—Continued		
68. Sandstone, arkosic, light-gray (*N*7), massive, fine- and medium-grained; conspicuous medium and coarse grains of dark-colored chert; noncalcareous; generally friable	2	6
67. Conglomerate, yellowish-gray (5*Y* 7/2) stained yellowish-orange (10*YR* 6/6); pebbles mainly of mudstone, some granules and pebbles of chert; noncalcareous; contains gypsum along joints; lower contact distinct		6
66. Sandstone, arkosic, pale-yellowish-brown (10*YR* 6/2), medium-grained, calcareous, well-cemented		9
65. Sandstone, arkosic, light-gray (*N*7), massive, noncalcareous, friable	1	6
64. Conglomerate, yellowish-gray (5*Y* 7/2); well-rounded pebbles and cobbles as large as 9 in.; noncalcareous; larger clasts chiefly of porphyry and mainly in upper part of unit; pebbles mainly of porcelaneous rocks and chert; lower contact irregular	2	0
Total, Paso Robles Formation (part measured)	240	0
Pancho Rico(?) Formation:		
63. Sandstone, arkosic, light-gray (*N*7), massive, mainly fine- and medium-grained; includes irregular masses of mudstone in lower 1 ft, scattered rounded pebbles of chert and porcelanite in lower 3 ft, irregular band of pebbles and small cobbles near middle of unit; contains conspicuous grains of dark-colored chert, noncalcareous, upper part friable, but lower part well indurated; lower contact gradational	25	0
Total, Pancho Rico(?) Formation	25	0
Monterey Shale (upper part only):		
62. Mudstone, very pale orange (10*YR* 8/2) and pale-yellowish-brown (10*YR* 6/2), massive, noncalcareous; scattered medium and coarse sand grains, contains fish scales		5
61. Porcelanite, dark-yellowish-brown (10*YR* 4/2); hackly fracture		1¼
60. Mudstone, like unit 62		2¼
59. Porcelanite, like unit 61		1½
58. Mudstone, like unit 62		5½
57. Porcelanite, like unit 61		1
56. Mudstone, like unit 62		9
55. Porcelanite, like unit 61		4½
54. Mudstone, like unit 62	1	4
53. Chert, olive-black (5*Y* 2/1), and interbedded yellowish-gray (5*Y* 7/2) noncalcareous mudstone; beds ⅛–1 inch thick, bedding irregular	1	2

SECTION 2.—*On north side of Nacimiento River in sec. 12, T. 25 S., R. 10 E., Bradley quadrangle*—Continued

Monterey Shale (upper part only)—Continued	Thickness (feet)	Thickness (inches)
52. Chert, dark-greenish-gray (5*GY* 5/1); beds contorted; brecciated; includes some intermixed porcelanite	6	
51. Mudstone, yellowish-gray (5*Y* 7/2), massive, noncalcareous; scattered medium sand grains; contains fish scales; hackly fracture		2
50. Porcelanite, light-olive-gray (5*Y* 6/1); includes layers of chert; hackly fracture		3
49. Mudstone, like unit 51		1
48. Porcelanite, light-olive-gray (5*Y* 6/1); hackly fracture		1
47. Mudstone, like unit 51		1½
46. Porcelanite, like unit 48		1½
45. Mudstone, like unit 51; includes lenses of porcelanite ¼–1 in. thick		5
44. Porcelanite, like unit 48		3
43. Mudstone, like unit 51		9
42. Bentonitic clay, moderate-yellowish-brown (10*YR* 5/4), flaky		1
41. Mudstone, like unit 51		4
40. Porcelanite, like unit 48		2
39. Mudstone, like unit 51		3
38. Porcelanite, like unit 48		2
37. Mudstone, like unit 51		1
36. Porcelanite, light-olive-gray (5*Y* 6/1); scattered fine sand grains; contains fish scales; hackly fracture		4
35. Mudstone, like unit 51		2
34. Porcelanite, moderate brown (5*YR* 4/4); hackly fracture		2½
33. Mudstone, like unit 51		2
32. Porcelanite, dark-yellowish-brown (10*YR* 4/2); contains fish scales		2
31. Mudstone, like unit 51		2
30. Chert, olive-black (5*Y* 2/1); includes bands of light-olive-gray (5*Y* 6/1) porcelanite as thick as a quarter of an inch	1	3
29. Mudstone, like unit 51	1	6
28. Chert, olive-black (5*Y* 2/1) and dusky-yellowish-green (5*GY* 5/2), brecciated	2	0
27. Porcelaneous mudstone, white (N9), massive, noncalcareous; includes beds and lenses of chert ¹⁄₁₆–1 in. thick	3	5
26. Chert, like unit 28		3
25. Porcelaneous mudstone, white (*N*9); hackly fracture; contains scattered diatom frustules		4
24. Porcelanite, white (*N*9); grades into dusky-yellow-green (5*GY* 5/2) chert; massive; hackly fracture		2
23. Porcelanite, white (*N*9), finely brecciated	1	0
22. Porcelanite, white (*N*9); grades into dusky-yellow-green (5*GY* 5/2) chert; massive; hackly fracture		9

SECTION 2.—*On north side of Nacimiento River in sec. 12, T. 25 S., R. 10 E., Bradley quadrangle*—Continued

Monterey Shale (upper part only)—Continued	Thickness (feet)	Thickness (inches)
21. Porcelaneous mudstone, very pale orange (10*YR* 5/2); includes bands of dusky-yellow-green (5*GY* 5/2) porcelanite as thick as one-eighth of an inch; hackly fracture		6
20. Diatomaceous mudstone, very pale orange (10*YR* 8/2), noncalcareous; contains fish scales; lower contact gradational	1	2
19. Porcelanite, dark-yellowish-brown (10*YR* 4/2); hackly fracture		4
18. Bentonitic clay, dark-yellowish-brown (10*YR* 4/2), flaky; contains gypsum		1
17. Diatomaceous mudstone, like unit 20	1	1
16. Porcelanite, like unit 19		10
15. Covered	6	6
14. Diatomaceous mudstone, like unit 20		9
13. Porcelanite, dark-yellowish-brown (10*YR* 4/2); grades into olive-black (5*Y* 2/1) chert; hackly fracture		3
12. Diatomaceous mudstone, like unit 20; includes lenses of porcelanite and chert	1	3
11. Chert, olive-black (5*Y* 2/1), fractured		3½
10. Diatomaceous mudstone, like unit 20	1	0
9. Porcelanite, like unit 13		1
8. Diatomaceous mudstone, like unit 20		2½
7. Chert, like unit 11		4
6. Diatomaceous mudstone, like unit 20		2
5. Porcelanite, like unit 13		4
4. Diatomaceous mudstone, like unit 20; lower contact gradational		2
3. Porcelanite, like unit 13; lower contact gradational		½
2. Diatomaceous mudstone, like unit 20		5
1. Porcelanite, dark-yellowish-brown (10*YR* 4/2); beds 2–4 in. thick, well-bedded, hackly fracture	20+	0
Total, Monterey Shale (part measured)	62+	0

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