

Geology of the Cosio Knob and Espinosa Canyon Quadrangles Monterey County, California

GEOLOGICAL SURVEY BULLETIN 1161-H



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By DAVID L. DURHAM

CONTRIBUTIONS TO GENERAL GEOLOGY

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



UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGY OF THE COSIO KNOB AND ESPINOSA CANYON QUADRANGLES, MONTEREY COUNTY, CALIFORNIA

By DAVID L. DURHAM

ABSTRACT

The Cosio Knob and Espinosa Canyon quadrangles are on the west side of the Salinas Valley in southern Monterey County, Calif. They include hills that flank the high Santa Lucia Range and lie between the San Antonio and Salinas Rivers.

Granitic rocks of the basement complex crop out near the northwest corner of the Cosio Knob quadrangle. They are correlated with the Santa Lucia Quartz Diorite of Trask (1926), and are presumably of Late Cretaceous age.

The Reliz Canyon Formation of Eocene age nonconformably overlies the basement complex. It is mainly thick-bedded arkosic sandstone that is probably marine. The formation is at least 500 feet thick where it is exposed in the Cosio Knob quadrangle, but it is absent or unrecognized in wells drilled in the map area.

The Vaqueros Formation overlies the Reliz Canyon Formation with apparent conformity and has two members. The lower member is mainly massive conglomeratic arkosic sandstone that is probably nonmarine. The upper member is chiefly thick-bedded arkosic marine sandstone and interbedded siltstone. Each member is at least 1,250 feet thick in the Cosio Knob quadrangle, but the formation is absent in the subsurface near the Salinas River. The Vaqueros is of early Miocene and possibly Oligocene age.

The Monterey Shale overlies the Vaqueros Formation with a gradational contact. The Monterey that is exposed in the map area is about 45 percent mudstone, 35 percent porcelaneous mudstone, 15 percent porcelanite, less than 5 percent carbonate beds and concretions, and less than 1 percent sandstone. About one-third of the unit is thin bedded or shaly. The upper part of the formation is mainly noncalcareous. The lower part, which is chiefly calcareous shale and interbedded mudstone and sandstone, is distinguished as the Sandholdt Member. Exposures of sandstone in the Monterey are restricted to the Sandholdt Member, but sandstone occurs in the upper part of the formation in the subsurface near the Salinas River. The Monterey is apparently at least 5,800 feet thick in the center of the map area, but it is absent in the subsurface near the Salinas River. The formation is marine and of at least middle and late Miocene age.

An unnamed formation that consists of fine-grained sandstone and interbedded mudstone and porcelaneous rocks conformably overlies the Monterey Shale. It is nearly 900 feet thick near the west edge of the Cosio Knob quadrangle, but is much thinner near the Salinas River. Marine fossils in the unit suggest a Pliocene age.

The nonmarine Paso Robles Formation, which overlies the unnamed formation with apparent conformity, contains poorly bedded and poorly sorted conglomerate, sandstone, and mudstone. It is at least 550 feet thick and is of Pliocene and Pleistocene(?) age.

Older alluvium unconformably overlies the Paso Robles and older formations and covers the bottoms of valleys in the map area. It resembles the Paso Robles Formation and is of Pleistocene and possibly Recent age.

Recent alluvium along the major streams is chiefly sand and gravel. The most common trend of faults and folds in the map area is northwest. The basement complex is structurally high near the Salinas River, where it has only a thin cover of Pliocene and younger sedimentary rocks. It is overlain by a thick sequence of Cenozoic strata southwest of the Salinas River, where Monterey Shale is the principal exposed formation. Folds in the Monterey Shale are generally structures restricted to the fault block in which they occur, rather than segments of larger structures offset by cross faults. The basement complex is structurally low near the San Antonio River, where it is covered by the Vaqueros and younger formations.

Twenty-one exploratory wells were drilled in the map area before 1962, but none of them were commercially successful. The operators of most of the wells sought oil from either the Vaqueros Formation or sandstone beds in the Monterey Shale.

An unsuccessful placer operation for the recovery of gold from the Paso Robles Formation or the older alluvium was conducted in the Cosio Knob quadrangle.

INTRODUCTION

PURPOSE AND SCOPE

Cenozoic sedimentary rocks crop out in an area about 80 miles long and as much as 30 miles wide in the southern two-thirds of the Salinas Valley, Monterey, and San Luis Obispo Counties, Calif. The rocks are generally well exposed and their distribution along the length of the valley is favorable for study of individual formations over a large area. A study of this kind is important, both regionally, as a contribution to understanding the geologic history of the California Coast Ranges, and locally, in attacking problems connected with the economic development of the area.

This report, the second that presents results of U.S. Geological Survey studies in the Salinas Valley, describes the geology of the Cosio Knob and Espinosa Canyon 7½-minute quadrangles. The first report (Durham, 1963) described the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles (fig. 1). Both reports are preliminary in that some of the interpretations, and conclusions are tentative and may be modified when work in adjacent areas is complete.

LOCATION OF AREA

The Cosio Knob and Espinosa Canyon quadrangle are west of the Salinas River at the latitude of San Ardo in southern Monterey

County, Calif. (fig. 1). They extend from the edge of the high Santa Lucia Range at the northwest corner of the Cosio Knob quadrangle, to the plain of the Salinas River in the northeast part of the Espinosa Canyon quadrangle, and include part of the range of hills, formerly called San Antonio Hills, that lies between the Salinas and San Antonio Rivers.

PREVIOUS WORK

Geological investigations in and near the Cosio Knob and Espinosa Canyon quadrangles began in the middle of the 19th century, but published details about the geology of the area are few. Whitney (1865, p. 111) called the area between the San Antonio and Salinas Rivers by the local name, "San Antonio Hills." He described the part of the hills that he saw (Whitney, 1865, p. 150) as composed of "bituminous slate," an early term for the Monterey Shale. Fairbanks (1894, p. 519) observed that the hills between the rivers contain Miocene rocks, which he later (1900, p. 143) described as "flinty, organic shales of the oil-producing formation," that is, of Monterey Shale. He also noted surface indications of oil along the eastern slope of the hills (Fairbanks, 1900, p. 144), probably east of the Espinosa Canyon quadrangle. Hamlin (1904, p. 12) characterized the "San Antonio Hills" as a range that diverges from the most elevated part of the Santa Lucia Range and is deeply eroded by many canyons. C. A. Waring (1914, p. 419) also remarked on the divergence of the "San Antonio Hills" from the main Santa Lucia Range. G. A. Waring (1915, p. 276, 385) reported a "sulphur spring on Mission Creek" which was probably in the Cosio Knob quadrangle. Waring and Bradley (1917, p. 606) reported on placer mining for gold in Old Man Canyon in the southern part of the Cosio Knob quadrangle. English (1918, p. 245) noted the widespread occurrence of Monterey Shale in the "San Antonio Hills," and concluded (1918, p. 236) that any oil found there would be in sandy lenses or crushed zones within the shale. Vander Leck (1921, p. 87) described the "San Antonio Hills" as a detached part of the Santa Lucia Range that is bordered on the northeast by a major fault along the Salinas River—later called King City fault by Reed (1925, p. 590)—and on the southwest by a fault extending southeast from sec. 3, T. 22 S., R. 7 E., along the margin of the San Antonio River valley. He recognized the Monterey Shale as the principal formation of the area and regarded the thickness and structure of the Monterey as obscured by intense folding and crushing. Dorn (1932) described cores from the Standard Oil Piedmont 1, a deep well drilled in the southern part of the Cosio Knob quadrangle. Reed (1933, p. 44) represented the "San Antonio Hills" as underlain by a thick series of structurally

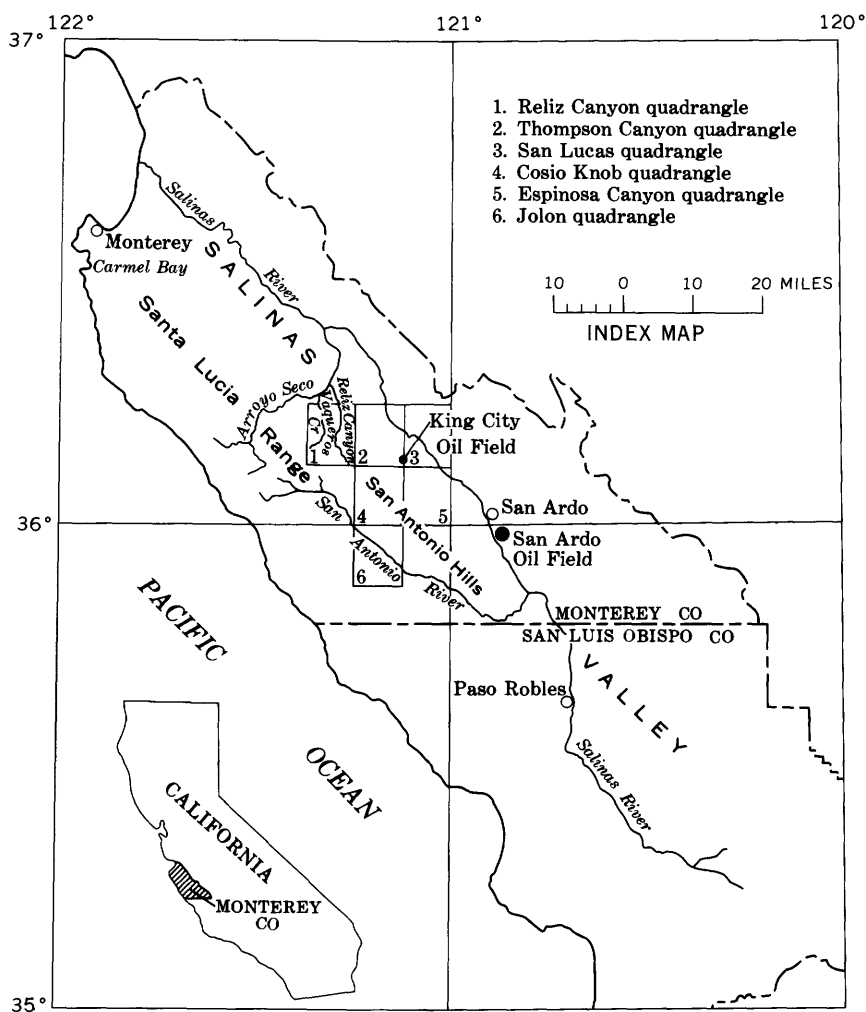


FIGURE 1.—Index map showing location of the area.

complex Miocene shale. Bramlette and Daviess (1944) recorded the presence of their Sandholdt Shale in the Oat Hills area of the Cosio Knob quadrangle, and gave the generalized distribution of their Vaqueros Sandstone and older rocks near Cosio Knob. They also showed structure contours on the top of their Vaqueros Sandstone for most of the area, and on the top of the basement complex near the Salinas River. Kilkenny (1948) summarized the stratigraphy and structure of the Salinas Valley and included a generalized geologic map of the region.

FIELDWORK AND ACKNOWLEDGMENTS

The Espinosa Canyon quadrangle was mapped in 1959 and 1960; the Cosio Knob quadrangle was mapped in 1960 and 1961. P. J. Pattee assisted in the field in December 1959. Field mapping on aerial photographs of approximately 1 : 20,000 scale was compiled on topographic maps of 1 : 24,000 scale.

The landowners in the map area were helpful in providing access to their property, and Lt. Frank H. Bosworth kindly gave permission to work on part of the Hunter Liggett Military Reservation. R. R. Thorup, consulting geologist, King City, generously furnished data on many wells in the map area, and H. H. Haun, Humble Oil and Refining Co., provided other well data.

Ellen J. Moore identified Mollusca from the area, and Patsy J. Smith identified Foraminifera.

STRATIGRAPHY

Granitic rocks of presumed Late Cretaceous age are overlain in the Cosio Knob and Espinosa Canyon quadrangle by strata of Eocene and later Cenozoic age. Plate 4 shows the succession, generalized lithology, and approximate thickness of the stratigraphic units in the map area. The older formations are absent near the Salinas River.

PRE-TERTIARY BASEMENT COMPLEX

Granitic rocks of the basement complex crop out in the northwest part of the Cosio Knob quadrangle in a fault-bounded block less than 1 square mile in area. They are part of the plutonic mass that Lawson (1893, p. 6) named the Santa Lucia Granite, and Trask (1926, p. 134) called the Santa Lucia Quartz Diorite.

The exposed granitic rocks generally are deeply weathered and resemble massive friable coarse-grained sandstone. They commonly contain quartz veins and aplite and pegmatite dikes as thick as 2 inches.

The granitic rocks underlie the Reliz Canyon Formation of Eocene age and presumably have an age similar to that of the granodiorite at Carmel Bay, which Curtis, Evernden, and Lipson (1958) determined by the potassium-argon method as 81.6 million years. This age is Late Cretaceous according to the geological time scale of Holmes (1959).

TERTIARY SYSTEM

EOCENE SERIES—RELIZ CANYON FORMATION

The type area of the Reliz Canyon Formation (Durham, 1963) is about 5 miles northwest of the Cosio Knob quadrangle in Reliz Can-

yon. In the map area the formation crops out only near the northwest corner of the Cosio Knob quadrangle. The contact between this unit and the underlying granitic rocks is apparently depositional near the SW cor. sec. 17, and the NE cor. sec. 19, T. 21 S., R. 7 E.

LITHOLOGY

The Reliz Canyon Formation in the Cosio Knob quadrangle is mainly arkosic sandstone in beds 1 to 3 feet thick. The sandstone is generally fine or medium grained and well sorted, but some beds contain scattered coarse grains. The finer grains are subangular or subrounded and the coarser grains are angular or subangular. A few beds contain granules and scattered rounded pebbles of granitic rock, and a sandstone bed near the east quarter corner, sec. 18, T. 21 S., R. 7 E., contains angular, tabular clasts of shale as long as $1\frac{1}{2}$ inches. The exposed sandstone is yellowish gray, grayish orange pink, or pale reddish brown, and much of it is noncalcareous. The formation includes a 3-foot bed of massive olive-gray siltstone at or near the base where it overlies plutonic rock near the NE cor. sec. 19, T. 21 S., R. 7 E.

THICKNESS

The Reliz Canyon Formation is at least 500 feet thick in sec. 18, T. 21 S., R. 7 E. It is absent or unrecognized in wells drilled in the map area.

AGE AND CONDITIONS OF DEPOSITION

The Reliz Canyon Formation in the map area is presumably of Eocene age. It lacks fossils in the Cosio Knob quadrangle, but at the type area it contains Foraminifera of Eocene age. The formation is at least partly marine at the type area and is probably at least partly marine in the Cosio Knob quadrangle as well.

OLIGOCENE(?) AND MIOCENE SERIES—VAQUEROS FORMATION

Hamlin (1904) applied the name Vaquero Sandstone to strata exposed along Vaqueros Creek about 5 miles northwest of the Cosio Knob quadrangle. The Vaqueros Formation of this report has two members at the type area (Durham, 1963): an upper, marine member, and a lower, probably nonmarine member. This is a modification of terminology used by Thorup (1941), who restricted the Vaqueros to marine beds and gave the name Berry Conglomerate to the underlying nonmarine beds.

The lower member of the Vaqueros Formation, which crops out in fault blocks in the northwest part of the Cosio Knob quadrangle, is mainly sandstone and conglomeratic sandstone. The sandstone beds

are generally more massive and conglomeratic than are those in the underlying Reliz Canyon Formation. The lower contact of the member is at the base of the stratigraphically lowest massive, cobble-bearing, conglomeratic sandstone bed above sandstone beds characteristic of the Reliz Canyon Formation. The contact is poorly exposed in the Cosio Knob quadrangle, but in sec. 17, T. 21 S., R. 7 E., the lower member apparently overlies the Reliz Canyon Formation conformably.

The upper member of the Vaqueros Formation also crops out in the northwest part of the Cosio Knob quadrangle. It is chiefly arkosic sandstone, but at some localities it contains interbedded fine-grained sandstone and siltstone. Unlike the lower member, the upper member contains marine fossils and generally lacks coarse-grained sandstone or conglomeratic beds. The depositional contact between the two members is concealed in the map area, but about 5 miles northwest of the Cosio Knob quadrangle, it is gradational and interfingering (Durham, 1963).

LITHOLOGY

Sandstone in the lower member of the Vaqueros Formation is mainly arkosic, massive or thick bedded, conglomeratic, poorly sorted, and locally cross-stratified. The sand grains are generally medium or coarse and angular to subrounded. The exposed sandstone is yellowish gray or grayish orange and is commonly friable. The sandstone contains pebbles, cobbles, and rare boulders of plutonic and metamorphic rocks, both in poorly defined lenses and scattered at random. A sandstone bed in the lower member in a small fault block in sec. 19, T. 21 S., R. 7 E., contains angular chips of siltstone as long as half an inch.

Sandstone in the upper member of the Vaqueros Formation is mainly arkosic, massive or thick bedded, medium or coarse grained, and poorly sorted. Locally it is fine grained, thin bedded or laminated, and interbedded with siltstone, but at a few other places it contains scattered granules and pebbles. The sandstone is generally friable and about half of it is calcareous. Moulds, casts, and fragments of mollusk shells are abundant in the sandstone at a few places, and cavernous weathering is common. The exposed sandstone is very light gray, pale yellowish orange, or dark yellowish orange.

Siltstone interbedded with sandstone of the upper member is massive, pale yellowish brown, calcareous, and has a hackly fracture.

THICKNESS

Only partial sections of the Vaqueros Formation are exposed in the map area. The thickness of the upper member near sec. 19,

T. 21 S., R. 7 E., measured on the geologic map of the Cosio Knob quadrangle (pl. 1), is about 1,250 feet. The lower member appears to be at least as thick near the northwest corner of the quadrangle, but the unit there is poorly exposed and complexly deformed. Beds correlated with the Vaqueros Formation were penetrated in the Union Oil Keens 1 for about 2,350 feet and in the Standard Oil Piedmont 1 for more than 2,200 feet (pl. 3).

AGE AND CONDITIONS OF DEPOSITION

Fossils from the Vaqueros Formation in the Cosio Knob quadrangle are too fragmentary or poorly preserved to be useful as indicators of the age of the unit. Nearby, in the Reliz Canyon quadrangle, the Vaqueros is of Oligocene(?) and early Miocene age (Durham, 1963). Fossils in the upper member indicate that it is marine; the lack of fossils, poor sorting, and cross-stratification of the lower member suggest that it is nonmarine.

MIocene SERIES—MONTEREY SHALE

Blake (1855) named the Monterey Shale for exposures about 40 miles northwest of the Cosio Knob quadrangle at the town of Monterey.

The Monterey Shale constitutes about 70 percent of the rock exposed in the map area. It crops out principally between the Salinas River and Jolon Valley in a northwest-trending belt about 7 miles wide.

The Monterey Shale in the map area is approximately 45 percent mudstone, 35 percent porcelaneous mudstone, 15 percent porcelanite, less than 5 percent carbonate beds and concretions, and less than 1 percent sandstone and chert. (Composition percentages are estimated from notes made at about 1,200 localities in the map area.) It is about 40 percent thin-bedded or shaly rocks, similar to those shown in figure 2. The Monterey is chiefly noncalcareous, except for the lower part, which is distinguished as the Sandholdt Member. Exposures of sandstone are restricted to the Sandholdt, but sandstone occurs stratigraphically higher in the formation in the subsurface near the margin of the hills west of the Salinas River.

The Monterey Shale is conspicuously finer grained and commonly thinner bedded than most of the underlying Vaqueros Formation. Where the Sandholdt Member of the Monterey overlies the Vaqueros in the northwest quarter of the Cosio Knob quadrangle, the lower contact of the Sandholdt is placed at the base of the stratigraphically lowest unit of calcareous shale above the dominantly sandy beds characteristic of the Vaqueros. The contact is poorly exposed; it is probably gradational and is not necessarily at the same stratigraphic horizon throughout the map area.



FIGURE 2.—Steeply dipping Monterey Shale exposed in sec. 30, T. 21 S., R. 7 E., near the west edge of the Cosio Knob quadrangle. Joints and fractures divide the rock into angular blocks no more than 2 or 3 inches in greatest dimension.

SANDHOLDT MEMBER

The type area of the Sandholdt Member (Durham, 1963) of the Monterey Shale is about 5 miles northwest of the Cosio Knob quadrangle in Reliz Canyon. The member corresponds approximately to the Sandholdt Shale of Thorup (1941) and of Bramlette and Daviess (1944).

The Sandholdt Member crops out in the northwest quarter of the Cosio Knob quadrangle. It is absent in wells drilled near and northeast of the edge of the hills along the Salinas River.

Its stratigraphic position and high proportion of calcareous rocks distinguish the Sandholdt Member from the upper part of the Monterey Shale. The Sandholdt contains minor, but at some places conspicuous, amounts of sandstone, chert, porcelanite, and carbonate beds. The upper contact of the Sandholdt is placed at the top of the stratigraphically highest beds of calcareous shale or mudstone in the Monterey and is not necessarily at the same stratigraphic horizon throughout the map area.

LITHOLOGY

Porcelaneous rocks.—Porcelanite of the Monterey Shale is a siliceous rock that resembles unglazed porcelain (Bramlette, 1946, p. 15). X-ray analysis of several porcelanite samples from Reliz Canyon indicates that the silica in the rock is dominantly cristobalite, quartz, and opal (R. A. Gulbrandsen, oral communication, 1962). The porcelanite is most commonly massive or poorly bedded, but some is thin bedded and may properly be called porcelaneous shale. Some thick-bedded porcelanite is laminated but not fissile. The rock is hard and brittle, and is generally divided by joints and fractures into blocks less than 2 or 3 inches in greatest dimension (fig. 2). The surfaces of the blocks are commonly curved and the edges may be sharp. The porcelanite is associated with carbonate beds at some localities and occurs as lenses and irregular layers in some chert beds. The exposed porcelanite is generally pinkish gray, very pale orange, or light brownish gray.

Porcelaneous mudstone of the Monterey Shale is intermediate in texture between porcelanite and mudstone. It consists of clay, silt, and scattered sand grains in a silica matrix. The porcelanite grades into porcelaneous mudstone and mudstone as the proportion of clastic material to silica matrix increases. The distribution of porcelanite, porcelaneous mudstone, and mudstone in the Monterey lacks apparent system or pattern. Some beds contain the three types of rock intermixed in irregular gradational layers or lenses. Porcelaneous mudstone is associated with carbonate beds and concretions at many localities.

About 60 percent of the porcelaneous mudstone is massive or poorly bedded and about 40 percent is laminated or in beds as thick as 1 foot. The rock is hard and brittle, has a hackly fracture, and commonly contains impressions of clam shells on bedding surfaces. The exposed porcelaneous mudstone is chiefly very pale orange or pinkish gray, but it has a wide range of colors that is mainly a weathering phenomenon.

Mudstone.—Mudstone of the Monterey Shale contains clay, silt, and scattered fine sand grains. About half of it is in laminae or beds as thick as 1 foot that properly may be termed shale. The rock has a hackly fracture and breaks into irregular blocks that are rarely as great as 1 foot in largest dimension. It ranges from hard and brittle to soft and friable, and is chiefly calcareous in the Sandholdt Member and noncalcareous in the upper part of the formation. The mudstone commonly contains fish scales, and at a few localities it also contains Foraminifera or impressions of clam shells. Foraminifera are best preserved in the calcareous mudstone. In most of

the noncalcareous beds they are represented only by external molds. Mudstone in the Sandholdt Member at some places has a fetid odor when it is freshly broken. The exposed mudstone is generally very pale orange, but locally it has a wide range of colors that is related to weathering of the rock.

Carbonate beds and concretions.—Carbonate beds and ellipsoidal concretions of similar composition are conspicuous in the Monterey Shale at many places (Bramlette, 1946, p. 20–22). The beds range from $\frac{1}{2}$ foot to 5 feet, but are generally about 2 feet thick. The concretions are 6 to 12 inches thick and as much as 3 feet long. The carbonate beds and concretions are associated with porcelaneous rocks and both calcareous and noncalcareous mudstone and shale. They are most common in thin-bedded rocks. The concretions occur in individual beds or groups of beds, rather than uniformly throughout the formation.

The carbonate beds consist of clay, silt, and an abundant carbonate cement. X-ray analysis of several samples of carbonate beds from Reliz Canyon suggests that the carbonate is a ferrous dolomite (R. A. Gulbrandsen, oral communication, 1962). The rock is hard and dense, and is generally more resistant to weathering than the enclosing beds. At some localities, the carbonate rock contains white calcite veins as thick as $\frac{1}{4}$ inch. The exposed rock is generally grayish orange, and less commonly pale yellowish brown, pale reddish brown, or very pale orange.

Chert.—Beds of chert 1 to 12 inches thick are interbedded with porcelaneous rocks and mudstone of the Monterey Shale. They commonly thicken and thin or pinch out along the strike. The chert is light brownish gray, brownish black, brownish gray, or pale brown. Some strikingly banded beds contain alternate layers or lenses of chert and light-colored porcelanite.

Sandstone.—Sandstone beds in the Sandholdt Member are generally 1 to 10 inches thick, and a few are as much as 3 feet thick. They commonly are grouped to form sandstone units several tens of feet thick. The sandstone is arkosic, fine to coarse grained, and calcareous, and it contains calcite veins. The exposed sandstone is medium light gray, yellowish gray, or pale yellowish brown. A thin section of sandstone from near the middle of the Sandholdt Member in sec. 16, T. 21 S., R. 7 E., contains about 40 percent calcite cement, 35 percent feldspar, 20 percent quartz, less than 5 percent rock fragments, and less than 1 percent mica and dark minerals.¹ The grains are subangular or subrounded and range from 0.25 to 1 mm in diameter.

¹ The percentages of minerals in this and other thin sections were determined by the Chayes point-count method.

A few sandy beds crop out in the Espinosa Canyon quadrangle near the east edge of the hills in projected secs. 30 and 32, T. 21 S., R. 9 E. Two thin sections from these beds contain about 50 percent clay and silt matrix, 20 to 25 percent feldspar, 10 percent quartz, as much as 2 percent mica, and 15 percent phosphatic pellets. The sand grains are angular and subangular and are generally less than 0.15 mm in diameter. The pellets range from 0.25 to 2 mm in diameter and are circular or elliptical in cross section. They consist mainly of clay- or silt-size material, but 60 to 70 percent of them surround one or more grains of quartz, feldspar, or rarely mica. They resemble phosphatic pellets in the Monterey Shale in the Reliz Canyon and Thompson Canyon quadrangles that contain carbonate fluorapatite (R. A. Gulbrandsen, oral communication, 1962).

Tuff.—A tuff bed in the Monterey Shale is poorly exposed on a ridge in the SW $\frac{1}{4}$ sec. 13, T. 21 S., R. 8 E. in the north part of the Espinosa Canyon quadrangle. It is probably no more than 3 feet thick. The tuff is yellowish gray, porous, and contains shards as long as 0.25 mm.

THICKNESS

The Monterey Shale is incompletely exposed in the map area. The thickness of the Sandholdt Member in the northwest part of the Cosio Knob quadrangle, is about 625 feet (measured section 1). The thickness of the entire formation near the Union Oil Keans 1, measured on structure section D-E-F (pl. 3), is apparently at least 5,800 feet. The Sandholdt Member is absent in wells drilled near the margin of the hills west of the Salinas River, and the entire formation is absent in the subsurface near the river (pl. 3).

AGE AND CONDITIONS OF DEPOSITION

At fossil locality Mf481, in sec. 17, T. 21 S., R. 7 E., the Sandholdt Member contains *Bolivina advena striatella*, *Bolivina sinuata ali-soensis*, *Bulimina carnerosensis*, *Buliminella curta*, and *Valvulineria depressa*, which suggest the middle Miocene lower Luisian or Relizian Stage of Kleinpell (Patsy B. Smith, written communication, 1960). Fossils are scarce or poorly preserved in the siliceous rocks of the formation, but the overlying unit contains mollusks considered to be of Pliocene age (E. J. Moore, written communication, 1961). Thus, in the map area, the Monterey Shale represents at least part of middle and most or all of late Miocene time.

PLIOCENE SERIES—UNNAMED FORMATION

An unnamed formation crops out around a structural high of Monterey Shale in the southwest quarter of the Cosio Knob quadrangle

and in a narrow strip that trends southeast across the center of the quadrangle and down the east side of Jolon Valley. Beds in and near sec. 13, T. 21 S., R. 8 E., in the Espinosa Canyon quadrangle that are sandy and stratigraphically higher than strata typical of the Monterey Shale are questionably assigned to the unnamed formation.

The unnamed formation contains very fine grained sandstone interbedded with mudstone and porcelaneous rocks similar to the Monterey Shale. The formation is about 60 percent sandstone, 25 percent mudstone, and 15 percent porcelaneous rocks. Composition percentages are estimated from notes made at about 150 localities in the map area.

The sandstone beds in the unnamed formation are the obvious lithologic feature that distinguishes the unit from the underlying Monterey Shale. These typically form resistant ledges on grassy tree-studded slopes (fig. 3). The lower contact of the unnamed formation is at the base of the stratigraphically lowest sandstone bed that overlies the finer grained rocks of the Monterey Shale. Where exposed, the contact is conformable, but it may not be at the same stratigraphic horizon throughout the map area. The unnamed formation apparently overlaps the Monterey Shale eastward and lies directly on the basement complex near the Salinas River (pl. 3).

The unnamed formation in the Cosio Knob quadrangle is equivalent to the unnamed formation that overlies the Monterey Shale 1 to



FIGURE 3.—Sandstone and mudstone beds of the unnamed formation exposed at the end of a strike ridge on the south flank of the syncline in projected sec. 31, T. 21 S., R. 7 E., near the west edge of the Cosio Knob quadrangle.

10 miles north of the map area in the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles (Durham, 1963). The unit is unnamed here because of uncertainty as to its relationship to beds east of the Salinas River that have been called the King City Formation by Clark (1940), Poncho Rico Formation by Reed (1925), and Etchegoin and Jacalitos Formations by English (1918, p. 231).

LITHOLOGY

Sandstone in the unnamed formation is mainly hard, fractured, fine and very fine grained, arkosic, and noncalcareous. Locally it is medium grained. Some rounded to angular pebbles of porcelaneous rock 1 to 3 inches in greatest dimension are scattered in fine-grained sandstone near the base of the formation. The sandstone beds are generally 1 to 4 feet thick and are commonly separated by thin beds or partings of mudstone, as illustrated in figure 4. Molds and casts of clam shells are abundant in some beds, especially near the base of the formation, but shell material is lacking. The exposed sandstone is very pale orange, yellowish gray, or dark yellowish orange. Three

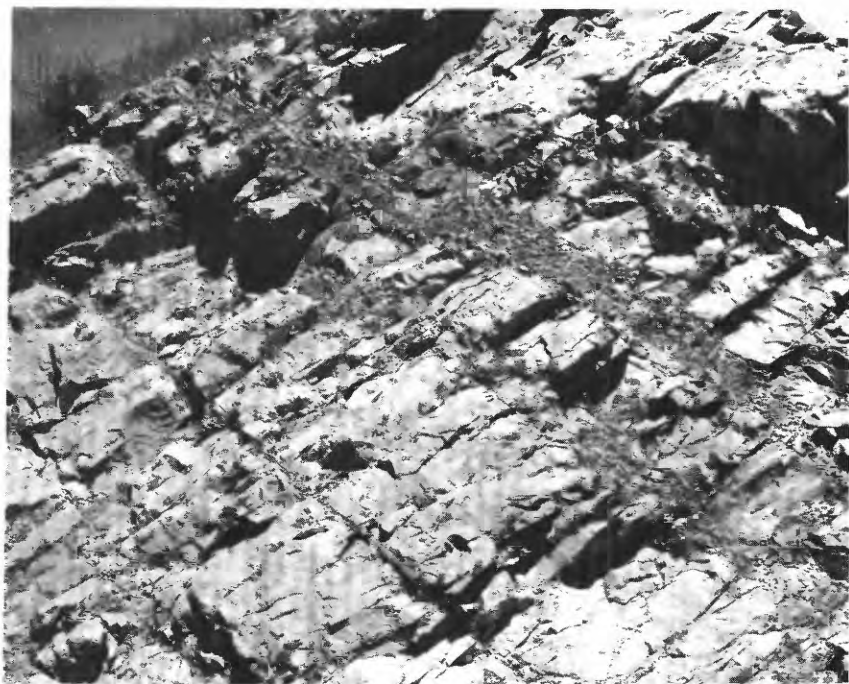


FIGURE 4.—Beds of fine-grained sandstone 1 to 2 feet thick, and thin beds and partings of mudstone of the unnamed formation in a cut on the Sulphur Canyon Road in projected sec. 4, T. 22 S., R. 7 E., Cosío Knob quadrangle.

thin sections of fine-grained sandstone from the Cosio Knob quadrangle contain 45 to 60 percent clay and silt matrix, 20 to 30 percent feldspar, 20 to 25 percent quartz, and less than 1 percent mica and dark minerals. The sand grains are mainly angular and subangular and less than 0.15 mm in diameter.

Sandstone exposed in the Espinosa Canyon quadrangle near the west line of sec. 13, T. 21 S., R. 8 E., and questionably assigned to the unnamed formation, is massive and friable, and contains some hard calcareous beds. A thin section from one of these calcareous beds contains about 60 percent calcite cement, 30 percent feldspar, 10 percent quartz, and less than 1 percent mica. A thin section from another of the beds contains about 70 percent calcite cement, 20 percent feldspar, 10 percent quartz, and less than 1 percent mica. The sand grains in the sections are angular or subangular and less than 0.15 mm in diameter.

Massive friable sandstone near the top of the unnamed formation in the Cosio Knob quadrangle in the NE $\frac{1}{4}$ projected sec. 31, T. 21 S., R. 7 E., is calcareous and contains scattered cherty pebbles and angular charcoal-like clasts as long as half an inch.

Mudstone in the unnamed formation is massive or poorly bedded, fractured, and noncalcareous. It commonly contains molds and casts of clam shells and at some localities it contains abundant diatoms. The weathered rock is yellowish gray, light gray, or light olive gray.

Porcelaneous rocks are interbedded with the mudstone and fine-grained sandstone. They are generally massive or poorly bedded and fractured. The porcelanite and porcelaneous mudstone contain molds and casts of clam shells at a few places.

THICKNESS

The thickness of the unnamed formation near the west edge of the Cosio Knob quadrangle in projected secs. 31 and 32, T. 21 S., R. 7 E., and projected sec. 6, T. 22 S., R. 7 E. (measured section 2), is nearly 900 feet. The formation is incompletely exposed elsewhere in the map area, but it must be thin near the Salinas River, where the Superior Oil Echenique 1 reached the basement complex 480 feet below the surface (pl. 3).

AGE AND CONDITIONS OF DEPOSITION

The meager molluscan fauna from the unnamed formation listed in table 1 is considered to be of Pliocene age (E. J. Moore, written communication, 1961). According to Patsy B. Smith (written communication, 1961), a sample from locality M1060, near the north quarter corner, sec. 2, T. 22, R. 7 E., contains a small poorly preserved benthonic foraminiferal fauna that indicates middle Miocene age, but

TABLE 1.—*Mollusks from the unnamed formation in the Cosio Knob quadrangle*

[Identified by E. J. Moore]

	Locality (USGS No.)						
	M1060	M1062	M1063	M1064	M1065	M1066	M1067
<i>Anadara (Anadara) cf. A. (A.) trilineata</i> (Conrad)					×		
<i>Modiolus?</i> sp.				×	×		
<i>Lyropecten?</i> cf. <i>L. terminus</i> (Arnold)	×	×		×	×		×
<i>Chlamys?</i> sp.				×			
<i>Luciniscia?</i> cf. <i>L. nutalli antecedens</i> (Arnold)			×		×		×
<i>Macoma</i> sp.					×	×	

the condition and preservation of the specimens suggest that they are reworked from older rocks. The same sample contains well-preserved unfilled specimens of *Globigerina bulloides*, a pelagic Foraminifera of indeterminate age. The fossil mollusks and indigenous fossil Foraminifera in the unnamed formation indicate that the unit is marine.

TERTIARY AND QUATERNARY(?) SYSTEMS

PLIOCENE AND PLEISTOCENE(?) SERIES—PASO ROBLES FORMATION

Fairbanks (1898) gave the name Paso Robles Formation to beds exposed about 37 miles southeast of the Cosio Knob quadrangle near the town of Paso Robles. The formation crops out along Jolon Valley and west to Mission Creek around the structural high in the southwest quarter of the Cosio Knob quadrangle. It contains conglomerate, conglomeratic sandstone, sandstone, and mudstone, and resembles older alluvium. Although the formation apparently is absent or concealed in the Espinosa Canyon quadrangle, some poorly exposed beds near the Salinas River that are mapped as older alluvium may belong to the Paso Robles.

The Paso Robles Formation is generally coarser and less well sorted and cemented than the underlying unnamed formation. The contact between the two units is poorly exposed in the map area, but it is apparently conformable. The contact is at the base of the stratigraphically lowest conglomerate bed above the fossiliferous fine-grained sandstone and mudstone of the unnamed formation. In the map area the contact is best exposed on a small hill north of the Sulphur Spring Road about 2 miles west of Jolon Road.

LITHOLOGY

Conglomerate in the Paso Robles Formation generally contains rounded pebbles in a poorly cemented matrix of sandstone or silty sandstone. The larger clasts are chiefly $\frac{1}{4}$ to 1 inch in greatest dimen-

sion, but a few are as long as 4 inches. They are nearly all of rocks similar to those in the Monterey Shale.

The conglomerate grades into conglomeratic sandstone and sandstone as the proportion of larger clasts to matrix decreases. The sandstone is arkosic, generally noncalcareous, massive or poorly bedded, friable, poorly sorted, and conglomeratic. The exposed sandstone is commonly very pale orange. A thin section of hard poorly sorted pebbly sandstone from near the base of the formation in the NW $\frac{1}{4}$ projected sec. 4, T. 22 S., R. 7 E., contains about 40 percent calcite cement, 30 percent feldspar, 15 percent quartz, 15 percent rock fragments, and less than 1 percent mica. The grains are angular to subrounded and generally less than 0.5 mm in diameter.

Mudstone of the Paso Robles Formation is massive or thick bedded and commonly contains scattered pebbles. It is locally calcareous and includes beds of fine-grained sandstone as thick as 1 foot. The exposed mudstone is generally very pale orange.

THICKNESS

The Paso Robles Formation is at least 550 feet thick, as measured on the geologic map, in projected sec. 31, T. 21 S., R. 7 E., near the west edge of the Cosio Knob quadrangle (pl. 1). It is apparently much thicker near Jolon Valley (pl. 3). The Paso Robles was partly removed by erosion prior to deposition of the older alluvium.

AGE AND CONDITIONS OF DEPOSITION

The Paso Robles Formation is unfossiliferous in the map area, but it overlies beds that contain marine fossils considered to be of Pliocene age. It is unconformably overlain by older alluvium, which is of Pleistocene and possibly Recent age.

The Paso Robles Formation is apparently nonmarine because it lacks marine fossils and generally resembles the overlying older alluvium. The base of the Paso Robles ideally represents the beginning of nonmarine deposition following the last withdrawal of the Tertiary sea from the map area.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT(?) SERIES—OLDER ALLUVIUM

The older alluvium consists of fluvial sediments that unconformably overlie the Paso Robles and older formations, and that are older than alluvium in the beds of active streams. It occurs mainly in areas of low relief near the Salinas and San Antonio Rivers and in the valleys of the larger tributary streams. The older alluvium near the northwest corner of the Cosio Knob quadrangle in sec. 17, T. 21 S.,

R. 7 E., occupies a remnant of a valley related to a nearly destroyed old erosion surface. Patches of older alluvium southwest of Espinosa Canyon in sec. 11, T. 22 S., R. 8 E., may be relics of deposits that formerly covered the bottom of an ancient valley. Older alluvium that caps ridges near the mouth of Broadhurst Canyon extends southwest through a break in the hills that apparently represents a former valley unrelated to modern streams.

Older alluvium, which ranges from friable uncemented sediment to well-cemented rock, is mainly poorly consolidated mudstone, pebbly mudstone, pebbly sandstone, and conglomerate, or their unconsolidated equivalents. It is massive or poorly bedded, and noncalcareous, except locally where it is associated with caliche. It contains pebbles of rocks common in the Monterey Shale that are subangular to rounded and less than 2 inches in greatest dimension. It is yellowish gray or grayish orange at most localities.

Small remnants of formerly more extensive alluvial deposits that lie on ridges or the sides of canyons are generally omitted from the geologic maps (pls. 1 and 2). They commonly contain abundant angular pebbles of Monterey Shale that appear to be of local derivation.

Older alluvium resembles part of the Paso Robles Formation, but unlike the Paso Robles, it is undeformed. The contact between the two units on the geologic map of the Cosio Knob quadrangle (pl. 1) is at some places drawn arbitrarily at the break in slope at the base of hills composed of the Paso Robles.

The older alluvium is most extensive and perhaps thickest near the Salinas River in the northeast part of the Espinosa Canyon quadrangle. Hills that are as much as 200 feet above the river may be composed entirely of older alluvium, or they may be only mantled with it.

The older alluvium overlies the Paso Robles Formation of Pliocene and Pleistocene(?) age and is older than alluvium in active streams. Its age is thus limited to Pleistocene and possibly Recent.

RECENT SERIES—ALLUVIUM

Alluvium along the Salinas and San Antonio Rivers and Mission Creek is chiefly sand and gravel. About three-fourths of the larger clasts on a gravel bar near the main channel of the Salinas River at the bridge in the northeast part of the Espinosa Canyon quadrangle are from the basement complex and volcanic rocks, but nearly all the larger clasts in the alluvium farther from the main channel are of porcelaneous rocks. About 80 percent of the larger clasts in the San Antonio River are from the basement complex and the rest are porcelaneous rocks, chert, and sandstone. Clasts from the basement com-

plex are much more common in the alluvium than in either the older alluvium or the Paso Robles Formation.

STRUCTURE

GENERAL FEATURES

The major structural divisions of the map area, listed from northeast to southwest, are (a) the area near the Salinas River, where the basement complex has only a thin sedimentary cover; (b) the hills between the Salinas River and Jolon Valley, where a thick sequence of beds, mainly Monterey Shale and older units, overlies the basement complex; and (c) the area near and west of Jolon Valley, where a thick sequence of beds, including units younger than the Monterey Shale, overlies the basement complex. The divisions are separated, in a general way, by fault zones near the margins of the hills between the Salinas River and Jolon Valley.

The basement complex is structurally high near the Salinas River, where it is 480 feet below the surface at the Superior Oil Echenique 1 (pl. 3). It is overlain there by strata that are unlike the Monterey Shale and older formations and that are presumably of Pliocene or younger age. The basement complex is deeper near the margin of the hills southwest of the river, but whether the basement surface slopes steeply, or steps down across one or more faults, is unclear.

A belt more than 5 miles wide of Monterey Shale and older formations extends diagonally southeast across the map area from the northwest part of the Cosio Knob quadrangle. It is characterized by large northwestward-trending faults and lesser northeastward-trending cross faults, except in the northwest quarter of the Cosio Knob quadrangle near the edge of a structural high that extends into the map area from the northwest. Formations older than the Monterey Shale crop out in the map area only in and around this structural high. Monterey Shale crops out elsewhere in the belt, except near the margins, where the unnamed formation of Pliocene age occurs locally. The Monterey Shale, Sandholdt Member of the Monterey, and Vaqueros Formation occur above the basement complex in wells drilled in the southwest half of the belt. In wells drilled near the Salinas River, sandstone is common in the Monterey, and both the Sandholdt Member and Vaqueros Formation are absent.

The area along and west of Jolon Valley is structurally and topographically lower than the belt of Monterey Shale and older rocks to the northeast. The Paso Robles Formation and older alluvium crop out over most of the area, except near the west edge of the Cosio Knob quadrangle, where Monterey Shale and a fringe of the unnamed formation of Pliocene age form a local structural high. The Monterey

Shale and Vaqueros Formation overlie the basement complex in wells drilled near Jolon Valley. Westward- to northwestward-trending faults and folds are common west of Jolon Valley, but near the west edge of the Cosio Knob quadrangle, northeastward-trending cross faults modify the general structure.

Plate 3 illustrates the structure in the Cosio Knob and Espinosa Canyon quadrangles as interpreted from surface evidence and data of exploratory wells. Most of the faults on the structure sections are arbitrarily shown as vertical because indication of their dip is generally lacking. The Vaqueros Formation is undivided on the structure sections because strata typical of the lower member are absent or unrecognized in the wells. The Reliz Canyon Formation is also absent, or possibly unrecognized, in wells drilled in the map area. The structure sections incorporate the following assumptions: (a) exposed faults and folds extend into the subsurface without marked change in character; (b) the thickness of stratigraphic units in the subsurface is constant, or changes uniformly where well data indicate change; (c) the basement complex surface slopes evenly between wells; (d) the Reliz Canyon and Vaqueros Formations and the Monterey Shale thin to the northeast by progressive overlap of older beds by younger.

FAULTS

Faults in the Monterey Shale are generally obscure because they juxtapose similar rocks. They are generally marked by zones of crushed, contorted, or steeply dipping beds, and are also evidenced by the termination of sets of folds or by other abrupt changes in structure across their trace. The inferred faults shown on the geologic maps (pls. 1 and 2) are suggested to account for apparent structural anomalies in areas of poor exposure.

A fault system that in places is at least a mile wide parallels the front of the hills southwest of the Salinas River between sec. 23, T. 21 S., R. 8 E., and sec. 4, T. 22 S., R. 9 E. It contains blocks bounded by northwestward-trending faults and northward- or northeastward-trending cross faults. The pattern of folds in each block is different from that in adjacent blocks, indicating that the folds are at least partly contemporaneous with or younger than the bounding faults.

The fault that trends from sec. 12, T. 21 S., R. 7 E., in the northeast part of the Cosio Knob quadrangle, to sec. 26, T. 21 S., R. 8 E., in the central part of the Espinosa Canyon quadrangle, is the southeast end of a major structure that extends more than 15 miles northwest of the map area to and beyond the Arroyo Seco (fig. 1). It dips 70° southwest where it is exposed on the bank of the Arroyo Seco, but its attitude in the Cosio Knob and Espinosa Canyon quadrangles is unknown.

The fault trace in the map area is a zone of crushed and contorted beds against which nearby faults and folds terminate.

The fault that extends southeast from sec. 11, T. 21 S., R. 7 E., in the northeast part of the Cosio Knob quadrangle, to sec. 34, T. 21 S., R. 8 E., west of the center of the Espinosa Canyon quadrangle, is marked by a zone of crushed beds and discordant structure north of Quinado Canyon, and by steeply dipping beds in Mansfield and upper Feliz Canyons. The fault may extend farther southeast than indicated on the geologic map of the Espinosa Canyon quadrangle (pl. 2), but its trace is obscure in the area of poor exposures southeast of Feliz Canyon. As shown on structure section *A-B-C'* (pl. 3), the basement-complex surface is probably downdropped to the northeast along this or a nearby fault.

The fault that trends southeast from sec. 11, T. 22 S., R. 8 E., in the south part of the Espinosa Canyon quadrangle, extends at least 8 miles beyond the south edge of the map area. It may extend farther northwest than shown on the geologic map of the Espinosa Canyon quadrangle (pl. 2), but its trace beyond the mouth of Loridon Canyon is indistinct. In upper Espinosa Canyon, the fault is expressed as a zone of crushed and contorted beds more than 500 feet wide. As indicated on structure section *D-E-F* (pl. 3), the basement complex may be downdropped on the northeast side of this fault.

A complex fault system forms the southwest border of the belt of Monterey Shale and older formations that extends diagonally across the map area. It is most conspicuous north and northwest of Jolon Valley, where overturned beds of Monterey Shale and the younger unnamed formation are in fault contact with the Paso Robles Formation. East of Jolon Valley, the fault system is marked by structural discordances, steep or overturned beds and downfaulted blocks that contain sandstone beds of the unnamed formation. The fault at the edge of the hills in sec. 18, T. 22 S., R. 8 E., is shown dipping northeast on structure section *D-E-F* (pl. 3) to account for the anomalous sequence of beds in the Humble Oil and Refining Burchard 1, although the attitude of the fault is concealed at the surface.

The inferred fault near the edge of the hills northeast of the San Antonio River near the southwest corner of the Cosio Knob quadrangle, is the northwest projection of a large fault in the Jolon quadrangle to the south. Direct evidence of the fault is lacking in the Cosio Knob quadrangle because the beds along its presumed trace are poorly exposed.

FOLDS

The folds in the map area are generally structures restricted to the fault block in which they occur, rather than segments of larger struc-

tures offset by cross faults. This implies that the folds were formed independently in each block during or after, instead of before, movement on the faults.

Folds near the margins of the belt of Monterey Shale that extends diagonally across the map area are commonly tighter and more closely spaced than are those near the middle of the belt. The folds, like the faults, generally trend northwestward except where the pattern is disrupted near the structural high in the north part of the Cosio Knob quadrangle.

ECONOMIC GEOLOGY

PETROLEUM

Twenty-one exploratory wells drilled in the Cosio Knob and Espinosa Canyon quadrangles before 1962 are listed in table 2. The principal objective for most of the wells drilled near the edge of the hills southwest of the Salinas River was oil-bearing sandstone beds in the Monterey Shale. The chief objective for wells drilled farther southwest was oil in the Vaqueros Formation. The Espinosa Canyon quadrangle is midway between the San Ardo and King City oil fields. For descriptions of the San Ardo oil field see Baldwin (1950), Barger and Zulberti (1950), and Bradford and Lawrence (1956); for a description of the King City oil field see Thorup (1961).

GOLD

The operators of the Ruby placer mine, in Old Man Canyon near the south edge of the Cosio Knob quadrangle, attempted briefly in 1914 to recover gold in commercial quantities from the Paso Robles Formation or older alluvium. They installed a hoist with a dragline bucket and washed loosely consolidated sand and gravel through a rotary tube with water from small reservoirs that held runoff of winter rains behind dams in nearby canyons. Although they reportedly found good indications of gold while prospecting with a pan, their recovery of gold with a screen and riffle board was too small to be commercially profitable (Waring and Bradley, 1917, p. 606).

TABLE 2.—*Wells drilled for oil in the Cosio Knob and Espinosa Canyon quadrangles before 1962*

[Well elevations taken from topographic map are preceded by an asterisk (*); elevations supplied by operator are: Kelley bushing, kb; ground, gr; or derrick floor, df]

No. on pls. 1 or 2 ¹	Operator	Well	Location			Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks, and depths, in feet
			Quadrangle	Sec.	T. S.	R. E.			
1	Humble Oil and Refining Co.	J. J. Barbree 1.	Espinosa Canyon.	21	21	8	825 gr	6,743	Drill stem tests: 2,690 to 2,722, open 45 min., recovered 120 ft mud with spots of low gravity black oil; 2,790 to 2,834, open 1 hr 50 min., recovered 140 ft gas-cut mud with traces of low gravity black oil; reported top of upper Luisian Stage of Klempell, 3,659; top of upper Relizian Stage of Klempell, 4,299; on structure section A-B-C.
2	do.	Edith M. Burchard 1.	Cosio Knob.	18	22	8	1,340 kb	3,869	On structure section D-E-F.
3 2	do.	Mervin V. Merritt, et al. 1.	do.	36	21	7	1,320 gr	2,932	Reported dips 85°-90° in core from 1,459 to 1,477; granodiorite in core from 2,920 to 2,929; top "Miocene sand," 1,780; on structure section A-B-C.
4	Independent Exploration Co. and Oceanic Oil Co.	Cooper 1.	Espinosa Canyon.	3 13	21	8	489 gr	1,502	Reported bottom in "gneiss"; on structure section A-B-C.
5	do.	Trescony 1.	do.	3 32	21	9	730 kb	3,266	On structure section D-E-F.
6	Kadane, G. E., and Sons.	Echenique 1-30.	do.	3 30	21	9	672 df	3,383	Reported bottom in basement complex(?).
7	do.	Standard-Sargenti 1.	do.	16	21	8	821 kb	4,512	Reported in Monterey Shale to bottom.
8	Kidd, Barron.	Anderson Nicolini 1.	do.	10	21	8	611 kb	2,995	Reported bottom in upper Miocene rocks.
9	do.	Carmine Dunn 1.	Cosio Knob	17	21	8	651 kb	3,000	Redrilled to 2,730.
10	do.	Trescony 2.	Espinosa Canyon.	31	21	9	701 kb	4,354	Reported bottom in Miocene rocks.
11	do.	Trescony 3.	do.	31	21	9	715 kb	2,505	
12	do.	Julius Trescony 4.	do.	31	21	9	708 kb	3,496	
13	do.	Julius Trescony 5.	do.	31	21	9	706 kb	3,076	
14	Reserve Oil and Gas Co.	Trescony-Echenique 1.	do.	30	21	9	610 kb	3,365	Tested interval from 3,305 to 3,365.
15 2	Standard Oil Co.	Piedmont 1.	Cosio Knob.	3 23	22	7	*1,140 (?)	6,093	Gas shows 3,052 to 3,077 and 5,840 to 5,851; dips 5°-10° to 2,500, 10°-20° to 4,200; 5°-15° below 4,200 (Bramlette and Davies, 1944); discussed by Dorn (1932) and Klempell (1938, p. 50 and table 9); also called King City on 1; structure section D-E-F.

TABLE 2.—*Wells drilled for oil in the Cosio Knob and Espinosa Canyon quadrangles before 1962—Continued*

[Well elevations taken from topographic map are preceded by an asterisk (*); elevations supplied by operator are: Kelley bushing, kb; ground, gr; or derrick floor, df]

No. on pls. 1 or 2 ¹	Operator	Well	Location			Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks, and depths, in feet
			Quadrangle	Sec.	T. S. R. E.				
16	Superior Oil Co.	Echenique 1	Espinosa Canyon.	³ 28	21	9	430 kb	490	Reported gneissic sand 350 to 480; top solid gneiss 480; on structure section <i>D-E-F</i> .
17	do.	Trescony 1	do.	³ 32	21	9	568 kb	2,465	Reported top Monterey Shale 700; top gneiss 2,460; on structure section <i>D-E-F</i> .
18	Tallafiero and Turner.	Mohawk-MJM and M 9-G-1.	do.	9	22	8	*2,020	3,878	Reported top "granite" 3,849; on structure section <i>D-E-F</i> .
19	The Texas Co.	Cooper 1	do.	³ 19	21	9	*510	3,004	Reported bottom in upper Miocene rocks.
² 20	Union Oil Co.	Kearns 1	Cosio Knob.	8	22	8	1,810 df	5,588	Reported bottom in basement complex; on structure section <i>D-E-F</i> .
² 21	do.	Page 1	do.	8	22	8	*2,000	3,215	Reported bottom in basement complex; on Monterey Shale to 2,480; Sandholdt Member 2,480 to 3,005; Vaqueros Formation at bottom (Bramlette and Davies, 1944).

¹ Nos. 2, 3, 9, 15, 20, 21 are on plate 1.² Location approximate.³ Projected section.

TABLE 3.—Fossil localities
[Projected sections are marked by an asterisk (*)]

USGS No.	Location				Member or formation	Types of fossils	
	Quadrangle	Sec.	T. S.	R. E.		Foram-inifera	Pelecypods
Mf481.....	Cosio Knob.....	17	21	7	Sandholdt Member of Monterey Shale.	X	-----
M1060.....	do.....	2	22	7	Unnamed formation...	X	X
M1062.....	do.....	33	21	7	do.....	-----	X
M1063.....	do.....	34	21	7	do.....	-----	X
M1064.....	do.....	*6	22	7	do.....	-----	X
M1065.....	do.....	*8	22	7	do.....	-----	X
M1066.....	do.....	*32	21	7	do.....	-----	X
M1067.....	do.....	*8	22	7	do.....	-----	X

MEASURED SECTIONS

1. Section northeast of Oat Hills in sec. 17, T. 21 S., R. 7 E., Cosio Knob quadrangle

	Thickness (feet)
Monterey Shale (in part) :	
18. Porcelanite and porcelaneous mudstone, very pale orange (10YR 8/2), beds ½ to 1 in. thick, well-bedded, fractured.....	118+
17. Covered	48

Monterey Shale, in part..... 166+

Approximate contact, apparently conformable.

Sandholdt Member of Monterey Shale :

16. Covered	25
15. Sandstone, arkosic, pale-orange (10YR 8/2), very fine grained, calcareous, well-cemented; contains beds of carbonate rock, light-olive-gray (5Y 6/1), hard, dense, massive, ½ to 1 ft thick.....	18
14. Siltstone, light-olive-gray (5Y 6/1), calcareous, hard, dense; laminated but not fissile; fetid odor when freshly broken.....	4
13. Covered	53
12. Siltstone, light-olive-gray (5Y 6/1), calcareous, hard, dense; laminated but not fissile; fetid odor when freshly broken.....	8
11. Covered	29
10. Sandstone, arkosic, pale-yellowish-brown (10YR 6/2), medium- to coarse-grained; contains scattered granules and small pebbles of quartz and basement rock; calcareous, massive; fetid odor when freshly broken.....	2
9. Siltstone, grayish-orange (10YR 7/4), calcareous, dense, shaly; thin interbeds of sandstone and mudstone near base.....	30
8. Sandstone, arkosic, white (N 9), medium- to coarse-grained, slightly calcareous, friable, contains interbeds 1 to 2 feet thick of harder well-cemented sandstone	41

Section northeast of Oat Hills, Cosio Knob quadrangle—Continued

	<i>Thickness (feet)</i>
7. Sandstone, arkosic, dark-yellowish-orange (10YR 6/6), medium-grained, calcareous, friable-----	14½
6. Siltstone, grayish-orange (10YR 7/4), calcareous, massive; hackly fracture; contains Foraminifera-----	2
5. Sandstone, arkosic, dark-yellowish-orange (10YR 6/6) and white (N 9), medium-grained; contains scattered small pebbles of basement rock; calcareous, friable -----	1½
4. Sandstone, arkosic, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4), fine-grained, calcareous, well-bedded; beds 1 to 6 in thick; silty, fetid odor when freshly broken-----	42
3. Covered -----	353
<hr/>	
Total Sandholdt Member-----	623

Contact projected to line of section along strike from east; apparently conformable.

Vaqueros Formation (upper part) :

2. Covered -----	75
1. Sandstone, arkosic, very pale orange (10YR 8/2), medium-grained; contains lenses of granules and small pebbles; calcareous, massive; forms bold outcrops -----	237+
<hr/>	
Total Vaqueros Formation, upper part-----	312+

2. Section east of Mission Creek in projected sec. 6, T. 22 S., R. 7 E., and projected secs. 31 and 32, T. 21 S., R. 7 E., Cosio Knob quadrangle

	<i>Thickness (feet)</i>
Paso Robles Formation (in part) :	
20. Conglomerate; larger clasts are rounded pebbles of porcelaneous rocks and chert; matrix is friable, silty, poorly sorted sandstone; poorly exposed---	50+
<hr/>	
Paso Robles Formation, in part-----	50+

Contact projected to line of section along strike from east; apparently conformable.

Unnamed formation :

19. Sandstone, arkosic; very light gray (N 8) stained dark yellowish orange (10YR 6/6); fine to medium grained, friable, massive; molds of clam shells; slightly calcareous-----	60
18. Covered -----	162
17. Porcelaneous mudstone; light olive gray (5Y 6/1) speckled with moderate yellowish brown (10YR 5/4); beds 2 to 3 ft thick; irregular bedding surfaces -----	39
16. Covered -----	60
15. Porcelaneous mudstone, light-brownish-gray (5YR 6/1); beds 1 to 3 ft thick, irregular bedding surfaces; molds and casts of clam shells; interbedded	

Section east of Mission Creek, Cosio Knob quadrangle—Continued

	<i>Thickness (feet)</i>
with sandstone; arkosic; very pale orange (10YR 8/2); very fine grained; beds 1 to 3 ft thick; non-calcareous -----	100
14. Covered -----	33
13. Sandstone, arkosic, yellowish-gray (5Y 8/1); very fine grained; massive; molds of fish vertebrae-----	3
12. Porcelaneous mudstone, very pale orange (10YR 8/2), massive; hackly fracture; fish scales-----	120
11. Sandstone, arkosic, pale yellowish-brown (10YR 6/2); very fine grained; massive; noncalcareous; partly covered-----	133
Line of section offset along strike at base of unit 11 to next ridge to west.	
10. Sandstone, arkosic, very pale orange (10YR 8/2), very fine grained; beds 1 to 2 ft thick, noncalcareous -----	36
9. Porcelanite and porcelaneous mudstone, very light gray (N 8); massive-----	2
8. Sandstone, arkosic, very pale orange (10YR 8/2), very fine grained; scattered fine and medium grains; noncalcareous-----	38
7. Porcelanite, light olive-gray (5Y 6/1), massive; molds of fish vertebrae-----	4
6. Porcelaneous mudstone, yellowish-gray (5Y 8/1) and very pale orange (10YR 8/2; beds 2 to 3 ft thick-----	35
5. Sandstone as in unit 8-----	18
4. Porcelaneous mudstone as in unit 6-----	15
3. Sandstone as in unit 8-----	17
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Total unnamed formation-----	875
Contact conformable.	
Monterey Shale (upper part):	
2. Porcelaneous mudstone, very pale orange (10YR 8/2); beds 2 to 3 ft thick; irregular bedding surfaces; fish scales; molds and casts of clam shells-----	32
1. Porcelanite and interbedded porcelaneous mudstone, very pale orange (10YR 8/2) and yellowish-gray (5Y 8/1); beds 2 to 4 ft thick; fish scales; molds of fish vertebrae -----	353
Monterey Shale, part measured-----	385

REFERENCES

- Baldwin, T. A., 1950, San Ardo—a stratigraphic analysis of a California oil field: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 10, p. 1981-1989.
- Barger, R. M., and Zuberli, J. L., 1950, San Ardo oil field: California Div. Oil and Gas, Summ. Operations California Oil Fields, 35, no. 2, p. 15-20.
- Blake, W. P., 1855, Notice of remarkable strata containing the remains of Infusoria and Polythalamia in the Tertiary formation of Monterey, California: Acad. Nat. Sci. Philadelphia Proc., v. 7, p. 328-331, [1856].
- Bradford, W. C., and Lawrence, E. D., 1956, San Ardo oil field: California Div. Oil and Gas, Summ. Operations California Oil Fields, v. 42, no. 2, p. 27-31.

- Bramlette, M. N., 1946, The Monterey formation of California and the origin of its siliceous rocks: U.S. Geol. Survey Prof. Paper 212, 57 p.
- Bramlette, M. N., and Daviess, S. N., 1944, Geology and oil possibilities of the Salinas Valley, California: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 24.
- Clark, B. L., 1940, Two new Pliocene formations in California [abs.]: Geol. Soc. America Bull., v. 51, No. 12, p. 1956-1957.
- Curtis, G. H., Evernden, J. F., and Lipson, J. I., 1958, Age determination of some granitic rocks in California by the potassium-argon method: California Div. Mines Spec. Rept. 54, 16 p.
- Dorn, C. L., 1932, Report on a deep boring in Salinas Valley, California: Micro-paleontology Bull., v. 3, p. 28-29.
- Durham, D. L., 1963, Geology of the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles, Monterey County, California: U.S. Geol. Survey Bull. 1141-Q, p. Q1-Q141. [1964.]
- English, W. A., 1918, Geology and oil prospects of the Salinas Valley-Parkfield area, California: U.S. Geol. Survey Bull. 691-H, p. 219-250.
- Fairbanks, H. W., 1894, Geology of northern Ventura, Santa Barbara, San Luis Obispo, Monterey, and San Benito Counties: California Mining Bur. 12th Rept. State Mineralogist, p. 493-526.
- 1898, Geology of a portion of the southern Coast Ranges: Jour. Geology, v. 6, p. 551-576.
- 1900, Monterey County, [chap.] 1 of pt. 8, of Watts, W. L., Oil and gas yielding formations of California: California Mining Bur. Bull. 19, p. 143-146.
- Hamlin, Homer, 1904, Water resources of Salinas Valley, California: U.S. Geol. Survey Water-Supply Paper 89, 91 p.
- Holmes, Arthur, 1959, A revised geological time-scale: Edinburgh Geol. Soc. Trans., v. 17, pt. 3, p. 183-216.
- Kilkenny, J. E., 1948, Geology and exploration for oil in Salinas Valley, California: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 2254-2268.
- Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 450 p.
- Lawson, A. C., 1893, The geology of Carmelo Bay: California Univ., Dept. Geology Bull., v. 1, no. 1, p. 1-59.
- Reed, R. D., 1925, The post-Monterey disturbance in the Salinas Valley, California: Jour. Geology, v. 33, p. 588-607.
- 1933, Geology of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 355 p.
- Thorup, R. R., 1941, Vaqueros formation (Tertiary) at its type locality, Junipero Serra quadrangle, Monterey County, California [abs.]: Geol. Soc. America Bull., v. 52, p. 1957-1958.
- 1961, King City oil field, Monterey County, California [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 130.
- Trask, P. D., 1926, Geology of the Point Sur quadrangle, California: California Univ., Dept. Geol. Sci. Bull., v. 16, no. 6, p. 119-186.
- Vander Leek, Lawrence, 1921, Petroleum resources of California with special reference to unproved areas: California Mining Bur. Bull. 89, 186 p.
- Waring, C. A., 1914, Geology and possibilities of oil in portions of Monterey, San Luis Obispo, and San Benito Counties, [chap.] 10 of McLaughlin, R. P., Petroleum Industry of California: California Mining Bur. Bull. 69, p. 418-438.

- Waring, C. A., and Bradley, W. W., 1917, Monterey County, *in* Bradley, W. W., Huguenin, Emile, Logan, C. A., and Waring, C. A., The counties of Monterey, San Benito, San Luis Obispo, Santa Barbara, Ventura : California Mining Bur. 15th Rept. State Mineralogist, pt. 5, p. 595-615.
- Waring, G. A., 1915, Springs of California : U.S. Geol. Survey Water-Supply Paper 338, 410 p.
- Whitney, J. D., 1865, Report of progress and synopsis of the field work from 1860 to 1864 : California Geol. Survey, Geology, v. 1, 498 p.



