Geology of the Reliz Canyon Thompson Canyon, and San Lucas Quadrangles Monterey County, California

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, California

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GEOLOGY OF THE RELIZ CANYON, THOMPSON CANYON, AND SAN LUCAS QUADRANGLES, MONTEREY COUNTY, CALIFORNIA

By David L. Durham

ABSTRACT

The Reliz Canyon, Thompson Canyon, and San Lucas quadrangles are near King City in the Salinas Valley, Monterey County, Calif. They lie near the northwest end of a belt of Tertiary marine strata that is about 80 miles long and as wide as 30 miles.

The oldest rocks in the map area belong to the pre-Tertiary basement complex. This unit comprises metamorphic rocks, which are correlated with the Sur Series of Trask, and plutonic rocks, which are correlated with the Santa Lucia Quartz Diorite of Trask. The metamorphic rocks include schist, gneiss, crystalline limestone, and hornblendite. They are intruded by plutonic rocks and cut by aplite and pegmatite dikes. As determined by the potassium-argon method, the age of the Santa Lucia Quartz Diorite of Trask near Monterey Bay is 81.6 million years.

The Reliz Canyon Formation, a newly named unit, overlies the basement complex and has three members. The lower member is chiefly medium- to coarse-grained arkosic sandstone and is pebbly near the base. The middle member is mainly massive siltstone. The upper member is massive medium- to coarse-grained arkosic sandstone. The formation is undivided where the middle member is absent. The maximum thickness of the lower member is about 180 feet, that of the middle member is 350 feet, and that of the upper member is at least 1,500 feet. The middle member contains fossil Foraminifera of Eocene age; the formation is probably all marine.

The Vaqueros Formation, which overlies the Reliz Canyon Formation with apparent conformity, has two members. The lower member is chiefly massive cross-stratified unfossiliferous arkosic sandstone and conglomerate and is presumably nonmarine. The upper member is mainly fossiliferous marine sandstone and siltstone. The contact between the two members is gradational and is not everywhere at the same stratigraphic horizon. The maximum thickness of the lower member is about 1,100 feet and that of the upper member is about 2,000 feet. The Vaqueros in the map area is of Oligocene(?) and early Miocene age.

The Sandholdt, herein redefined as the basal member of the Monterey Shale, overlies the Vaqueros Formation; the contact is gradational. The Sandholdt Member consists of calcareous shale and interbedded mudstone, siltstone, por-

celanite, chert, sandstone, and dolomitic carbonate beds. It has a maximum thickness of about 2,000 feet, is of Miocene age, and is marine.

The contact between the Sandholdt Member and the upper part of the Monterey Shale is gradational and may not be everywhere at the same stratigraphic horizon. The upper part of the Monterey consists of mudstone, porcelaneous mudstone, porcelanite, shale, fine-grained sandstone, and dolomitic carbonate concretions and beds. It may be as much as 6,600 feet thick, is of middle and late Miocene age, and is marine.

An unnamed formation overlies the Monterey Shale. The contact between the two units is gradational and is probably not at the same stratigraphic horizon throughout the map area. The unnamed formation contains arkosic sandstone, mudstone, siltstone, shale, claystone, porcelanite, and diatomaceous rock. It is probably more than 1,000 feet in maximum thickness and contains marine fossils of Pliocene age.

The Paso Robles Formation overlies the unnamed formation. The two units appear conformable, but the contact between them is probably a regional unconformity. The Paso Robles consists of nonmarine conglomerate, sandstone, and mudstone. Its base is marked at most places by a hard, resistant conglomerate that contains pebbles of Monterey Shale in a siliceous matrix. The Paso Robles has a maximum thickness in the map area of at least 1,400 feet. It is probably late Pliocene and Pleistocene(?) in age.

Older alluvium unconformably overlies the Paso Robles Formation and older rocks. It is mainly rudely stratified sandy gravel and sandy silt and is of late Pleistocene and Recent(?) age.

The outcrops of basement complex in the southwestern part of the Reliz Canyon quadrangle are separated in most places from the bordering sedimentary rocks by vertical or normal faults. Faults and associated folds west of the Salinas River trend generally northwestward, except in the northern part of the Reliz Canyon quadrangle, where they bend around the exposed basement complex and trend more to the west. Between Reliz Canyon and the Salinas River, the concealed surface of the basement complex strikes northwestward and rises to the northeast. The Monterey Shale and older formations thin eastward or are otherwise removed in the subsurface between Reliz Canyon and the Salinas River. East of the Salinas River, nearly undeformed Pliocene and younger strata lie on the basement complex.

At least 43 wells and core holes were drilled in search of petroleum in the map area. Many of them were drilled near the border of the hills west of the Salinas River, where sandstone beds in the Monterey Shale were the chief objective. Development of an oil field near the southwest corner of the San Lucas quadrangle began in 1960.

INTRODUCTION

PURPOSE AND SCOPE

The sequence of Cenozoic sedimentary rocks in the Salinas Valley is similar to that at many other places in the California Coast Ranges; but beyond this generality, the geologic history of the valley is not well understood. The chief mineral resource of the southern Salinas Valley is petroleum, but production there is not commensurate with the size and apparent potential of the area. Detailed study of the Cenozoic formations along the valley to determine their complex structure, stratigraphy, and depositional history is a necessary prelude to evaluating potentially productive parts of the area and to comparing them with known oil fields.

This report is the first of several planned to describe the geology of a large part of the Salinas Valley. It includes geologic maps of the Reliz Canyon, Thompson Canyon, and San Lucas 7½-minute quadrangles (pls. 1, 2, and 3) and a structure section across the three quadrangles (pl. 4). The report is preliminary in that the discussion is limited to three quadrangles, and questions that depend on work to be done in adjoining areas remain unanswered. The emphasis of the study is on stratigraphy and structure of the Tertiary rocks. Some of the correlations and interpretations may be revised when work in adjacent areas is complete.

LOCATION OF AREA

The Reliz Canyon, Thompson Canyon, and San Lucas quadrangles span the northwestward-trending valley of the Salinas River at the latitude of King City in the central part of Monterey County, Calif. (fig. 1). They are near the northwest end of a belt of Tertiary marine strata about 80 miles long and as wide as 30 miles that coincides approximately with the southern two-thirds of the Salinas River drainage basin. The type area of the Vaqueros Formation and the type locality of the Miocene Relizian Stage of Kleinpell (1938, p. 117) are in the Reliz Canyon quadrangle. The generalized stratigraphy of the map area is shown in plate 5.

PREVIOUS WORK

Among the first accounts of California geology are descriptions of the Salinas Valley by Trask (1854), Antisell (1855, 1856), and Blake (1856), but these reports are general and do not mention, in particular, parts of the Reliz Canyon, Thompson Canyon, or San Lucas quadrangles. At least 16 published papers or abstracts are relevant to the geology of the three quadrangles. Eldridge (1901) described bituminous sandstone 2 miles northeast of the San Lucas quadrangle and sedimentary rocks east of the Salinas River. Hamlin (1904) defined the Vaqueros Formation, summarized the stratigraphy of the Salinas Valley, and mentioned bituminous sandstone that is exposed near the mouth of Thompson Canyon. Pack and English (1914) discussed the stratigraphy of the area east of King City between San Lorenzo Creek (index map, fig. 1) and the Salinas River. English (1918) summarized the stratigraphy of the Salinas Valley, in general, and of the area south and southeast of the San Lucas quadrangle in detail. Stalder (1924) described the Monterey Shale exposed in Pine

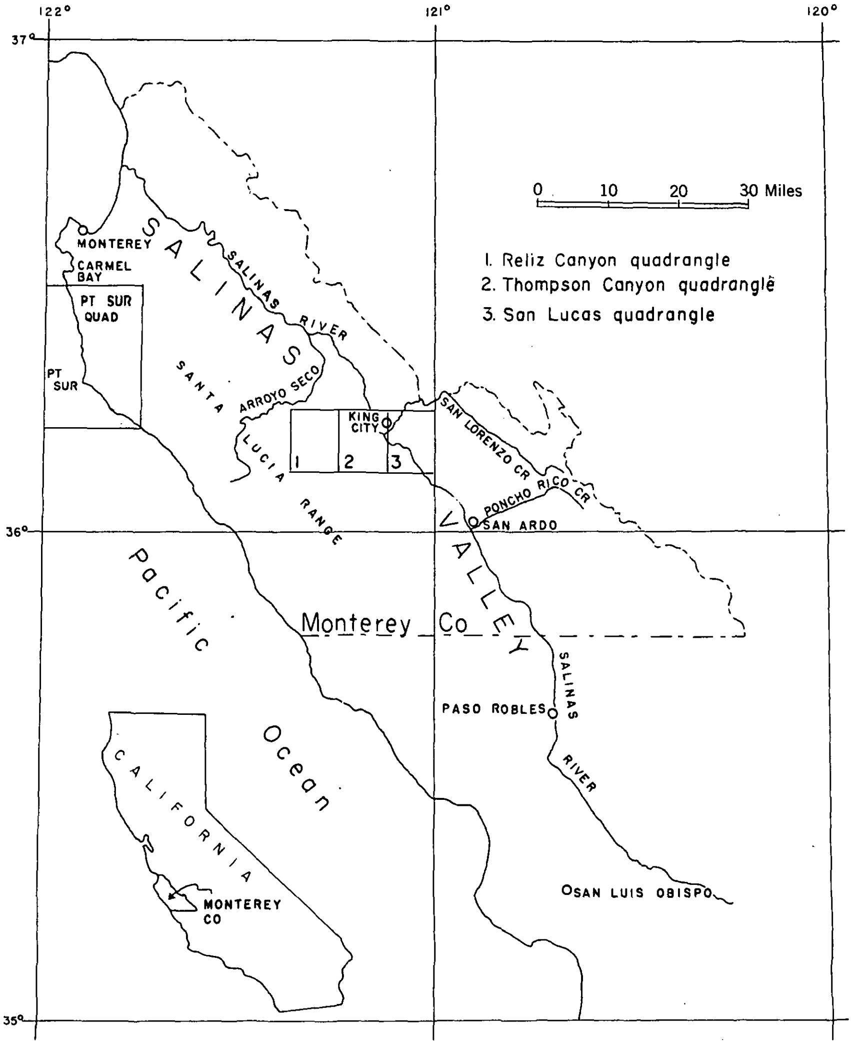

FIGURE 1.—Index map showing location of the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles, Monterey County, Calif.

Canyon, in the Thompson Canyon quadrangle, but failed to consider repetition or omission of strata by faults when he estimated the thickness of the formation. Reed (1927a) reported oolitic phosphate beds in the Monterey Shale along Vaqueros Creek in the Reliz Canyon quadrangle. Later Reed (1927b) analyzed the physiography and soil east of the Salinas River, where valleys are asymmetric and soil is thickest on steep northward-facing slopes, and attributed conditions there to the accumulation of aeolian soil on shady slopes. Kleinpell (1932, 1938) reported on Miocene Foraminifera from Reliz Canyon, including those from the type section of his Relizian Stage. Loel and Corey (1932) listed megafossils from the type area of the Vaqueros Formation. Schenck (1935) discussed the Vaqueros Formation at the type area and in Reliz Canyon. Clark (1940) mentioned strata east of the Salinas River, including his King City Formation. Thorup (1941) summarized pre-middle Miocene stratigraphy in Vaqueros and Reliz Canyons, restricted the Vaqueros Formation, and named five new units. Later Thorup (1943) described the geology of the type area of the Vaqueros Formation. Bramlette and Daviess (1944) summarized the geology of the Salinas Valley and showed the distribution of the Vaqueros Formation and the basement complex. Kilkenny (1948) outlined the geology of the Salinas Valley, with emphasis on petroleum occurrences and possibilities.

FIELDWORK AND ACKNOWLEDGMENTS

The Thompson Canyon quadrangle was mapped in October, November, and December 1958, with the assistance of R. P. Hunter, and in April 1959, with the assistance of J. C. Robinson, who worked mainly along and south of Pine Canyon. The Reliz Canyon quadrangle was mapped in May, October, and November 1959, with the assistance in October and November of P. J. Pattee, who mapped areas west of Vaqueros and upper Reliz Creeks. The San Lucas quadrangle was mapped in December 1959, with the assistance again of Pattee. Mapping was done on aerial photographs of approximately 1:20,000 scale, and the field data were transferred to topographic maps of 1:24,000 scale.

Ellen J. Moore identified fossil mollusks from the map area. J. Wyatt Durham identified fossil echinoids. Patsy B. Smith identified Miocene and Pliocene Foraminifera, and M. C. Israelsky identified Eocene Foraminifera

Many landowners in the map area were courteous and helpful in granting access to their property. W. S. Harris, Texaco, Inc., R. R. Thorup, consulting geologist, and A. R. Weller, Shell Oil Co., kindly provided information on wells.

STRATIGRAPHY

GENERAL FEATURES

Metamorphic and plutonic rocks of pre-Tertiary age are overlain in the map area by strata of Eocene and later Cenozoic age. Plate 5 shows the succession, generalized lithology, and approximate thickness of the stratigraphic units. The older sedimentary formations are absent near and east of the Salinas River.

PRE-TERTIARY BASEMENT COMPLEX

Metamorphic and plutonic rocks of the basement complex are the oldest rocks in the map area. The metamorphic rocks are correlated with the Sur Series of Trask (1926). The type area of the Sur Series is in the Point Sur 15-minute quadrangle, which is about 25 miles west of Reliz Canyon. As described by Trask, the Sur at the type area consists chiefly of schist, quartzite, gneiss, and crystalline limestone of sedimentary origin and injection gneiss associated with the intrusion of plutonic rocks.

Plutonic rocks that intrude the Sur Series of Trask in the Reliz Canyon quadrangle are correlated with the Santa Lucia Quartz Diorite of Trask (1926). Lawson (1893) first applied the name Santa Lucia Granite to granitic rocks in the vicinity of Carmel Bay. Trask (1926, p. 134) broadened use of the term to include the entire mass of plutonic rocks in the Santa Lucia Range. The unit contains quartz diorite, granodiorite, granite, hornblendite, aplite, and pegmatite.

The basement complex crops out in the southwestern part of the Reliz Canyon quadrangle and in two small areas in Sweetwater Canyon in the San Lucas quadrangle. At least 13 wells in the map area have reached it (table 2).

Metamorphic rocks in the Reliz Canyon quadrangle are chiefly schist and gneiss cut by veins and dikes of quartz, aplite, and pegmatite. Hornblendite crops out in upper Reliz Canyon near the E¼ cor. sec. 35, T. 20 S., R. 6 E., and crystalline limestone crops out near the W¼ cor. sec. 5, T. 20 S., R. 6 E. Biotite schist crops out in the San Lucas quadrangle.

Most of the exposed plutonic rock is deeply weathered, friable, and resembles weathered sandstone of the overlying Reliz Canyon Formation. Unweathered plutonic rock is most common in stream bottoms. A thin section of fine- to medium-grained quartz monzonite from the basement complex in sec. 36, T. 20 S., R. 6 E., contains[1] about 10 percent quartz, 30 percent orthoclase and microcline, 40 percent andesine, and 20 percent biotite. A thin section from a pegmatite dike in the same area contains about 25 percent quartz, 58 percent orthoclase, 16 percent albite, and 1 percent biotite.

As determined by the potassium-argon method, the age of granodiorite near Carmel Bay is reportedly 81.6 million years (Curtis, Evernden, and Lipson, 1958). Plutonic rocks in the Reliz Canyon quadrangle are presumably of similar age, that is, Late Cretaceous. The metamorphic rocks are of unknown age, but they are certainly older than the plutonic rocks. The Reliz Canyon Formation of

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

Eocene age overlies the basement complex in the Reliz Canyon quadrangle.

TERTIARY SYSTEM

EOCENE SERIES—RELIZ CANYON FORMATION

Sandstone and siltstone beds that unconformably overlie the pre-Tertiary basement complex and underlie the Vaqueros Formation in Reliz and Vaqueros Canyons are herein named the Reliz Canyon Formation. In the Reliz Canyon quadrangle, the formation has three members: the lower member, which corresponds to the Junipero Sandstone of Thorup (1941); the middle member, which corresponds to the Lucia Shale of Thorup (1941); and the upper member, which corresponds to The Rocks Sandstone of Thorup (1941). The formation is undifferentiated where the middle member is absent, as in sec. 4, T. 20 S., R. 6 E.

The Reliz Canyon Formation is here named for its exposure in upper Reliz Canyon, which is designated the type locality. It forms a belt of outcrops a mile or more wide that fringes the basement complex and extends from the center of the Reliz Canyon quadrangle into the southwestern part of the Thompson Canyon quadrangle. The lower member consists of fine- to coarse-grained arkosic sandstone and locally is conglomeratic near the base. It is best exposed in and around the SW¼ sec. 21, T. 20 S., R. 6 E., and in sec. 1, T. 21 S., R. 6 E. (see measured section 1, p. Q31). It overlies the basement complex in both areas. The middle member is mainly massive siltstone. It contains limy concretions throughout and includes thin sandstone beds near the top at some localities. Complete sections of the middle member crop out in the SW¼ sec. 21, T. 20 S., R. 6 E., and in sec. 1, T. 21 S., R. 6 E. (measured section 1). The lower contact of the middle member, which is conformable, is at the base of the stratigraphically lowest siltstone beds above sandstone of the lower member. The upper member is massive medium- to coarse-grained arkosic sandstone interbedded with thin units of finer grained sandstone. The sandstone in the upper part of the member is especially thick bedded and massive. The upper member is the most prominent and widespread part of the formation. In upper Reliz Canyon, it forms bold outcrops named "The Rocks" (fig. 2). It is conspicuous on the west side of Vaqueros Creek and in the southwest corner of the Thompson Canyon quadrangle. Complete sections of the upper member crop out in secs. 21 and 26, T. 20 S., R. 6 E. (see measured section 2, p. Q31). The lower contact, which is gradational, is at the base of the stratigraphically lowest thick sandstone bed overlying siltstone and thin sandstone beds of the middle member.

FIGURE 2.—Dip slope of massive sandstone in the upper member of the Reliz Canyon Formation in Reliz Canyon; these bold exposures are named "The Rocks".

LITHOLOGY

The Reliz Canyon Formation is composed mainly of calcareous arkosic sandstone in beds 2 or 3–20 feet thick. The sandstone is fine to coarse grained and poorly sorted. Ellipsoidal limy concretions as long as 3 feet are common in the upper member. The weathered sandstone is mainly yellowish gray, pale olive, grayish orange, or light olive gray. Four thin sections of random samples of the sandstone contain 50–60 percent quartz, 30–40 percent feldspar, and less than 10 percent biotite and rock fragments. The rock fragments are chiefly quartzite. The sand grains are angular to subrounded and 0.12–1.5mm in diameter. Three of the thin sections contain 20–35 percent calcite matrix; the other contains about 20 percent silt matrix.

Siltstone in the Reliz Canyon Formation is massive, mainly noncalcareous, and breaks with a hackly fracture. The weathered siltstone is chiefly grayish orange or light olive gray, and less commonly pale yellowish brown or dusky yellow. It contains scattered fine sand grains and mica flakes. Ellipsoidal concretions associated with the siltstone consist of calcite and scattered silt particles. The concretions are cut by veins of calcite that stand in relief on weathered surfaces. They are medium olive gray or pale yellowish brown and are 3–12 inches long.

THICKNESS

The lower member is about 180 feet thick near the SW cor. sec. 21, T. 20 S., R. 6 E. It may be thicker in sec. 36, T. 20 S., R. 6 E., but measurement there is hampered by lack of good exposures. The middle member is about 350 feet thick near the SW cor. sec. 21, T. 20 S., R. 6 E., 120–250 feet thick near the southeast corner of the Reliz Canyon quadrangle, and absent in the northern half of the quadrangle. The upper member is about 1,450 feet thick in sec. 26, T. 20 S., R. 6 E.

AGE AND CONDITIONS OF DEPOSITION

The Reliz Canyon Formation unconformably overlies the pre-Tertiary basement complex and underlies the unfossiliferous lower member of the Vaqueros Formation, which in turn underlies the upper member which contains marine fossils of early Miocene age. Fossil Foraminifera are abundant in some siltstone beds in the middle member of the Reliz Canyon Formation. According to M. C. Israelsky (written communication, 1960), a foraminiferal fauna of more than 50 species from fossil locality Mf482 (table 3) indicates that the member is younger than the Domengine Formation of middle Eocene age, and the fauna apparently pertains to Ulatisian Stage of Mallory (1959). The entire formation is considered to be Eocene in age on the basis of the Foraminifera in the middle member, but older or younger series could be represented in the unit. The only fossil found in either the upper or lower members is a single Foraminifera in a thin section of sandstone from the upper member in sec. 1, T. 21 S., R. 6 E. Certainly part, and presumably all, of the Reliz Canyon Formation is marine.

OLIGOCENE(?) AND MIOCENE SERIES—VAQUEROS FORMATION

Homer Hamlin (1904) applied the name Vaquero Sandstone to strata exposed along Vaqueros Creek in the Reliz Canyon quadrangle. The name Vaqueros Formation is here considered preferable to Hamlin's term, Vaquero Sandstone, because the unit contains significant amounts of siltstone and conglomerate. The Formation has two members. The lower member is chiefly massive cross-stratified, unfossiliferous sandstone and conglomerate (fig. 3), and is presumably nonmarine. It corresponds approximately to the Berry Conglomerate of Thorup (1941) and the Berry Formation of Bramlette and Daviess (1944). The upper member is mainly fossiliferous marine sandstone and siltstone. The Vaqueros as described by Hamlin (1904) included some strata herein placed in the Reliz Canyon Formation.

The Vaqueros Formation crops out adjacent to older rocks in the southwestern part of the Reliz Canyon quadrangle and near the southwest corner of the Thompson Canyon quadrangle. At least one well drilled in the map area reached the Vaqueros (table 2) ; the formation is absent in the subsurface northeast of a line 3 or 4 miles southwest of the Salinas River.

On the geologic maps (pls. 1 and 2) the lower contact of the Vaqueros Formation is at the base of the first conglomerate bed stratigraphically above massive sandstone characteristic of the upper part of the Reliz Canyon Formation (measured section 2, p. Q31). The two formations are apparently conformable. The contact between the lower and upper members of the Vaqueros is at the base of the stratigraphically lowest fossiliferous bed above unfossiliferous sandstone and conglomerate of the lower member (measured section 3, p. Q32). This contact is not at the same stratigraphic horizon throughout the map area.

LITHOLOGY

Sandstone in the Vaqueros Formation is chiefly arkosic, fine to coarse grained, thick bedded or massive, poorly sorted, and calcareous. The grains are subangular to subrounded. Ten thin sections of random samples of sandstone from the Vaqueros average about 50 percent quartz, 40 percent feldspar, 5 percent biotite, and 5 percent rock fragments. The composition ranges from 35–70 percent quartz, 27–56 percent feldspar, 0–17 percent biotite, and 0–10 percent rock frag-

FIGURE 3.—Massive conglomeratic cross-stratified sandstone in the lower member of the Vaqueros Formation along Reliz Creek near NW cor. sec. 23, T. 20 S., R. 6 E.

ments. Eight of the thin sections contain 25–40 percent calcite matrix; another has a matrix of calcite and silt, and the tenth has a matrix of silt only. The feldspar includes orthoclase, microcline, and plagioclase, and some of it is altered. Most of the rock fragments are quartzitic or granitic. Many sandstone beds, especially in the lower member, contain scattered granules and pebbles. Some sandstone in the lower member is also cross-stratified. The weathered rock is chiefly yellowish gray or grayish orange. Well-cemented relatively unweathered sandstone is hard and dense. Some beds in the upper member contain abundant poorly preserved fossil mollusks and scattered shell fragments. A few beds contain fossil echinoids, sand-filled tubes, and poorly preserved woody material.

Siltstone and thin sandstone beds are common in the upper member of the Vaqueros Formation. The siltstone is massive, has a hackly fracture, and most of it is hard, dense, brittle, and calcareous. The weathered rock is chiefly pale yellowish brown. The siltstone at some localities contains fossil Foraminifera, fish scales, and impressions of mollusk shells. Some of it has a fetid odor on freshly broken surfaces.

The lower member and basal part of the upper member of the Vaqueros Formation contain conspicuous beds of conglomerate and conglomeratic sandstone. Most of the pebbles and cobbles of the conglomerate are well rounded and are of rocks common in the nearby basement complex. The larger clasts are generally 1–4 inches in diameter, but a few boulders are as much as 2 feet across. The conglomerate has a matrix of sandstone similar to other sandstone in the formation.

THICKNESS

The lower member of the Vaqueros Formation is about 650 feet thick west of upper Vaqueros Creek in sec. 16, T. 20 S., R. 6 E. It thickens to the southeast, mainly at the expense of the upper member, and is about 1,100 feet thick in the vicinity of Pine Canyon in sec. 31, T. 20 S., R. 7 E. The upper member is at least 1,100 feet thick along upper Vaqueros Creek in sec. 16, T. 20 S., R. 6 E., is nearly 2,000 feet thick in upper Reliz Canyon in sec. 26, T. 20 S., R. 6 E., and is about 850 feet thick along Pine Canyon in sec. 4, T. 21 S., R. 6 E.

AGE AND CONDITIONS OF DEPOSITION

The Vaqueros Formation overlies the Reliz Canyon Formation, at least part of which is of Eocene age. In the map area, the unfossiliferous lower member of the Vaqueros may represent part, if not all, of Oligocene time. The upper member contains fossils of early Miocene age (Loel and Corey, 1932, p. 161). The lower part of the overlying Sandholdt Member of the Monterey Shale in Reliz Canyon contains Foraminifera of Kleinpell's lower Miocene, Saucesian Stage (Patsy B. Smith, written communication, 1961).

The lower member of the Vaqueros Formation is probably nonmarine; it lacks fossils and has the poor sorting, rude bedding, and cross-stratification common in fluviatile rocks. The upper member is marine.

MIOCENE SERIES—MONTEREY SHALE

Blake (1855) named the Monterey Shale for exposures about 40 miles northwest of the map area near Monterey. The formation crops out in a belt as wide as 5 miles in the northern part of the Reliz Canyon quadrangle and the southwestern part of the Thompson Canyon quadrangle. The unit is absent east of the Salinas River in the San Lucas quadrangle.

On the geologic maps (pls. 1 and 2), the lower contact of the Monterey Shale is at the base of the sequence of dominantly shaly rocks that overlies sandstone of the Vaqueros Formation. It is gradational and may not be at the same stratigraphic horizon throughout the map area. Interbedded sandstone and siltstone near the contact are included in the Vaqueros Formation. The dominantly calcareous shale in the lower part of the Monterey is distinguished locally and described separately as the Sandholdt Member.

LITHOLOGY

The Monterey Shale contains mudstone, shale, porcelaneous mudstone, porcelaneous shale, porcelanite, fine-grained sandstone, dolomitic carbonate beds, and dolomitic carbonate concretions. The different kinds of rock are interbedded and so distributed in the Monterey that, except for the Sandholdt Member, subdivision of the unit in the map area on lithologic character is meaningless. The Monterey is chiefly mudstone and porcelaneous mudstone. Except for the Sandholdt Member, sandstone is scarce in the formation and is restricted to thin isolated beds. Dolomitic carbonate beds and concretions are prominent, but they constitute only a small fraction of the unit. Bedding is conspicuous in good exposures of the Monterey (fig. 4).

PORCELANEOUS ROCKS

Porcelanite is a siliceous rock that has the dull luster of unglazed porcelain and that is not as hard, dense, and vitreous as chert (Bramlette, 1946, p. 15). X-ray analysis of several samples of porcelanite indicates that the silica in the rock is chiefly cristobalite, quartz, and opal (R. A. Gulbrandsen, oral communication, 1962). Porcelanite generally lacks fissility. Units of porcelanite a few inches to several tens of feet thick are interbedded with other rocks. Porcelanite is hard and brittle and breaks into blocks less than 2 or 3 inches in greatest dimension. The fracture surfaces are curved and are commonly marked with one or more sets of arcuate concentric ridges. Weathered porcelanite is chiefly pale yellowish brown or very pale orange. The porcelanite contains a few fossil diatoms, impressions of fish scales, molds of Foraminifera, and molds of fish vertebrae.

Porcelaneous mudstone consists of clay, silt, and scattered fine-grained sand in a silica matrix. It is intermediate in texture between porcelanite and clastic mudstone. Porcelanite grades into porcelaneous mudstone by an increase in the proportion of clastic material to silica matrix. Some beds contain porcelanite, porcelaneous mudstone, and clastic mudstone together in irregular and gradational layers. Large pieces of the rock give a ringing sound when struck with a pick.

The porcelanite and porcelaneous mudstone are generally massive or poorly bedded, but some porcelaneous rocks are fissile and are properly called porcelaneous shale.

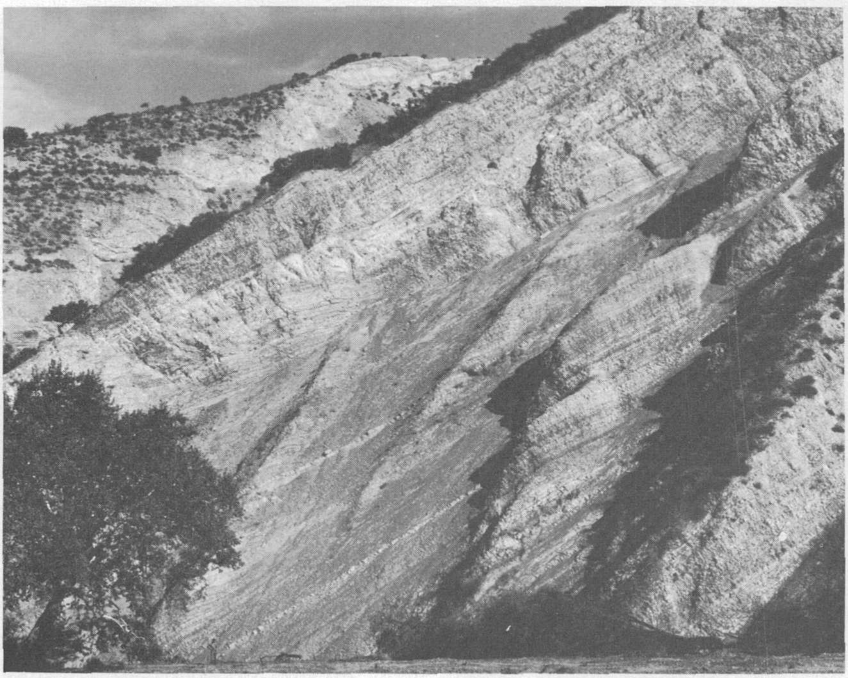

FIGURE 4.—Monterey Shale along Reliz Creek near NW cor. sec. 1, T. 20 S., R. 6 E.

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CLASTIC ROCKS

Mudstone is second in importance to porcelaneous rocks in the Monterey Shale. Most of the mudstone is in massive units several feet thick, but some is thin bedded and shaly. Friable shale and bentonitic clay are common as partings between beds of porcelaneous rock. The mudstone generally contains clay, silt, as much as 10 percent mica, and 5–20 percent fine- or very fine-grained sand, all bound by a siliceous cement. Calcareous mudstone and shale are scarce in the Monterey, exclusive of the Sandholdt Member. The weathered mudstone and shale are chiefly very pale orange or yellowish gray, but they have a wide range of color that is mainly a weathering phenomenon. The mudstone is generally hard and moderately porous. Fossil Foraminifera or molds of Foraminifera are abundant in some beds of mudstone and lacking in others. They are most abundant in the Sandholdt Member. Other fossils in the mudstone include fish scales, diatoms, impressions of clam shells, fish teeth, molds of fish vertebrae, and crushed whole fish and crabs.

Except in the Sandholdt Member, sandstone in the Monterey Shale is limited to a few isolated beds not more than 1 or 2 feet thick. The sandstone is arkosic, fine or very fine grained, and well sorted. Three thin sections of the sandstone contain about equal amounts of angular quartz and feldspar and 1–3 percent biotite. One thin section contains about 15 percent silt and clay matrix, but the other two have little or no matrix. The weathered sandstone is medium light gray, olive gray, or yellowish gray. The sandstone is hard, noncalcareous, and generally of low porosity. Sandstone beds in the Monterey in the subsurface near the margin of the hills west of the Salinas River are the objective of many wells drilled for oil in the map area.

A 3-foot bed of mudstone near the top of the Monterey Shale in sec. 34, T. 19 S., R. 6 E., contains scattered pebbles of porcelaneous mudstone and granitic rock. The pebbles are ¼–1 inch in diameter, well rounded, and limited to the middle one-third of the bed. The pebbly bed also contains scattered sand grains and angular chips of charcoallike material as large as a quarter of an inch.

Beds 1–2 feet thick that contain phosphatic pellets crop out at several places. They are commonly near, but above, the upper contact of the Sandholdt Member. X-ray analysis of the pellets indicates that they contain carbonate fluorapatite (R. A. Gulbrandsen, oral communication, 1962). The pellets are spherical or ellipsoidal and are 0.25–0.5mm in diameter. Some lack internal structure and others have concentric layers around a core of silt or clay; a few have a sand grain in the center. The pellets dissolve in dilute hydrochloric acid and leave a little silty residue. They occur in a matrix of slightly calcareous clay, silt, and fine-grained sand. A thin section of the rock contains about 40 percent pellets, 35 percent silt and clay, and 25 percent fine-grained sand. One bed contains pellets, scattered angular pebbles of porcelaneous mudstone, and irregular rounded phosphatic nodules as large as half an inch. The rock is yellowish gray or yellowish brown.

CARBONATE BEDS AND CONCRETIONS

Carbonate beds in the Monterey Shale are ½ foot to 3 feet thick and consist of silt and clay in an abundant carbonate matrix (see Bramlette, 1946, p. 20–22, for detailed description of carbonate rocks in the Monterey Shale). X-ray analysis of several samples from carbonate beds suggests that the carbonate is a ferrous dolomite (R. A. Gulbrandsen, oral communication, 1962). The carbonate beds are interspersed among the porcelaneous and clastic rocks. The weathered carbonate rock is grayish orange, pale yellowish orange, or pale yellowish brown. It is hard, dense, and of low porosity. Concretions of similar rock are abundant at some horizons. Concretions of similar rock are generally ellipsoidal, about 1 foot thick and 2–3 feet in diameter, and lie with their longer axes parallel to the bedding. Some of the carbonate beds and concretions contain poorly preserved fossil Foraminifera.

SANDHOLDT MEMBER

The Sandholdt, which is here defined as the basal member of the Monterey Shale, corresponds approximately to the Sandholdt Shale of Thorup (1941), who named the unit for exposures of shale in sec. 14, T. 20 S., R. 6 E., on the old Sandholdt Ranch in Reliz Canyon. The member is chiefly calcareous shale and interbedded sandstone and carbonate beds.

The Sandholdt Member crops out in an almost continuous belt from near the northwest corner of the Reliz Canyon quadrangle to the southwest quarter of the Thompson Canyon quadrangle. On the geologic maps (pls. 1 and 2), the upper contact is placed at the top of the stratigraphically highest beds of calcareous shale or mudstone in the Monterey Shale and is not necessarily at the same stratigraphic horizon throughout the map area.

LITHOLOGY

Shale in the Sandholdt Member forms irregular platy fragments ⅛–1 inch thick and as long as 1 foot. The weathered shale is mainly very pale orange and is generally hard, dense, and brittle. It has a calcareous cement and at some places is crisscrossed with calcite veins, which stand in relief on weathered surfaces. Fossil Foraminifera and fish scales cover many bedding surfaces. Much of the shale has a strong fetid odor when freshly broken.

Massive or thick-bedded siltstone in the lower part of the Sandholdt Member is similar to siltstone in the Vaqueros Formation. Porcelanite and porcelaneous mudstone near the top of the Sandholdt is similar to rock in the overlying Monterey Shale. The porcelanite is thin bedded, except where associated with chert.

Hard massive or poorly bedded arkosic sandstone forms a small but characteristic part of the Sandholdt Member. Most of the sandstone is fine or medium grained, but a few beds have scattered coarse grains and pebbles. The rock is grayish orange and is commonly streaked with iron stains. Four thin sections of the sandstone contain 35–65 percent quartz, 25–65 percent feldspar, and 3–10 percent biotite. Two of the thin sections contain 45 and 65 percent calcite matrix and the other two contain 12 and 60 percent silt or clay matrix. Most of the grains are angular and less than 0.25 mm in diameter.

Conspicuous lenses or beds of brownish-black chert as thick as 8 inches are interbedded with shale and porcelanite of the Sandholdt Member. Most beds enclosing chert layers are contorted. Thin veins of calcite cut both the chert and the surrounding rock.

The Sandholdt Member also contains hard yellowish-gray dolomitic carbonate beds, 6 inches to 3 feet thick, that are resistant to weathering and that at some places form the only outcrops. Chips of the rock dissolve in dilute hydrochloric acid and leave a muddy residue of clay, silt, and a few grains of very fine sand. Grain-size differences cause internal layering in some carbonate beds.

THICKNESS

A complete, unfaulted section of the Monterey Shale is lacking in the map area. The formation, exclusive of the Sandholdt Member, may be about 6,600 feet thick near the Shell Oil Honolulu-Thorup-USL 1 in sec. 4, T. 20 S., R. 7 E. It thins to the northeast and is absent east of the Salinas River in the San Lucas quadrangle.

The Sandholdt Member is about 1,200 feet thick at its type locality in Reliz Canyon in sec. 14, T. 20 S., R. 6 E. It is apparently more than 2,000 feet thick 5 miles to the northwest in sec. 31, T. 19 S., R. 6 E., where the base is not exposed. It is about 1,850 feet thick near the east border of the Reliz Canyon quadrangle.

AGE AND CONDITIONS OF DEPOSITION

In Reliz Canyon, the lower part of the Sandholdt Member contains Foraminifera of the lower Miocene upper Saucesian Stage of Kleinpell. The upper contact of the member is near the base of the upper Miocene Mohnian Stage of Kleinpell, but most of the unit contains

Foraminifera of the middle Miocene Relizian and Luisian Stages of Kleinpell (Patsy B. Smith, written communication, 1961). The Sandholdt in Reliz Canyon is the type locality for both the Relizian Stage and the *Uvigerinella obesa* zone of the upper Saucesian Stage (Kleinpell, 1938, p. 117).

The Monterey Shale above the Sandholdt Member in Reliz Canyon presumably represents Kleinpell's upper Miocene Mohnian and Delmontian Stages (Kleinpell, 1938, table 1), and is overlain by beds containing mollusks of Pliocene age.

The Monterey Shale is entirely marine. Kleinpell (1938, p. 17, 18) suggested that most of the Foraminifera from the Sandholdt Member in Reliz Canyon indicate open-sea conditions and a temperate-water environment at an estimated depth of 300–1,800 feet.

PLIOCENE SERIES—UNNAMED FORMATION

Strata between the Monterey Shale and Paso Robles Formation west of the Salinas River and beneath the Paso Robles Formation east of the river constitute a formation that is here unnamed. Reed (1925, p. 593) and Kleinpell (1938, p. 9) assigned part of the unnamed formation near Reliz Canyon to the Santa Margarita Formation. Many geologists correlate part or all the unnamed formation in Reliz Canyon with the Poncho Rico Formation of Reed. Some geologists include part of the fine-grained sandstone and interbedded finer-grained rocks in the unnamed formation between Reliz Canyon and the Salinas River with the Monterey Shale (for example, Kilkenny, 1948, fig. 1) or with the Poncho Rico Formation. The unnamed formation east of the Salinas River contains beds assigned to the Poncho Rico Formation of Reed (Bramlette and Daviess, 1944), to the King City Formation of Clark (1940), and to the Jacalitos and Etchegoin Formations (English, 1918).

West of the Salinas River, the lower contact of the unnamed formation is at the base of the stratigraphically lowest sandstone unit overlying porcelaneous rocks and mudstone of the Monterey Shale. The contact is gradational in that rocks similar to those in the Monterey also occur in the unnamed unit. East of the river, the unnamed formation lies on the basement complex. The base of the formation is almost certainly not at the same stratigraphic horizon throughout the map area.

LITHOLOGY

The unnamed formation contains interbedded fine-grained sandstone, coarse-grained sandstone, mudstone, siltstone, shale, claystone, porcelanite, and diatomaceous rock. Fine-grained massive siliceous arkosic sandstone, in units 3 feet to several tens of feet thick, is the most common and characteristic rock of the formation west of the Salinas River (fig. 5). It is moderately porous, lacks fissility, has a conchoidal fracture, and ranges from hard and brittle to soft and moderately friable. It contains very fine angular and subangular grains in a matrix of silt or clay. The fine-grained sandstone is generally well sorted, but some beds have scattered medium sand grains and a few beds contain pebbles of quartz as long as 1 inch. The weathered rock is yellowish gray or very pale orange and is mottled with darker stains. The fine-grained sandstone commonly contains fossil diatoms and sponge spicules(?) and more rarely contains angular chips of black carbonaceous material, impressions of fish scales, and molds of fish vertebrae.

Beds of medium- to coarse-grained sandstone, 1–10 feet thick, are common in the unnamed formation east of the Salinas River and in the upper part of the formation west of the river. The sandstone is generally poorly sorted, massive or poorly bedded, and has a wide range in hardness and porosity. Some of it is calcareous and most of it has an abundant matrix of very fine-grained sand, silt, and clay. Some beds contain fossil mollusks and echinoids, and rounded pebbles of porcelaneous mudstone or basement rock. The weathered coarse-grained sandstone is yellowish gray, dusky yellow, or yellowish brown.

Four thin sections of random samples of sandstone from the unnamed formation contain 55–60 percent quartz, 35–40 percent feldspar, as much as 12 percent rock fragments, and less than 1 percent biotite.

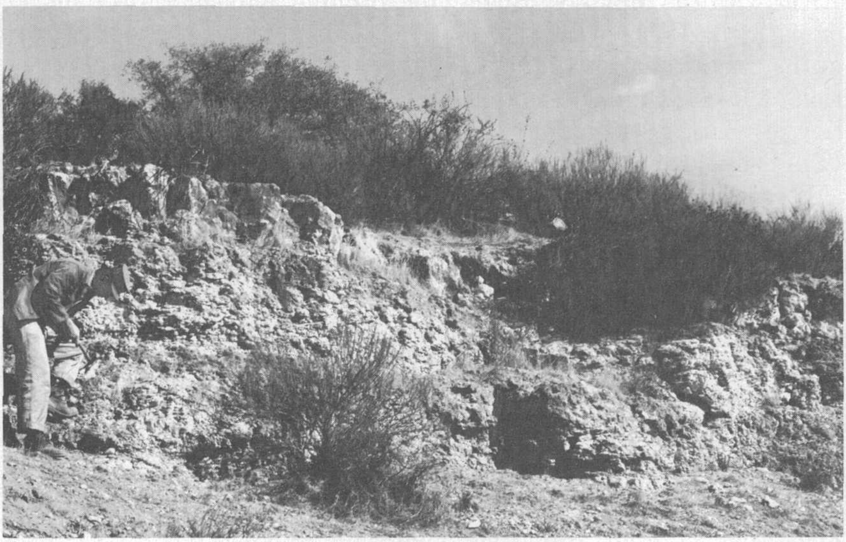

FIGURE 5.—Fossiliferous fine-grained sandstone in the unnamed formation at fossil locality M902 in Reliz Canyon.

The grains are angular or subangular and range in diameter from 0.1–0.25 mm. Two of the thin sections contain 40 and 57 percent silty matrix, and two have 31 and 40 percent calcite matrix.

The unnamed formation contains mudstone, siltstone, and claystone in units as thick as several tens of feet. The weathered fine-grained rocks are commonly yellowish gray or very pale orange. These fine-grained rocks are generally massive and break with an irregular or conchoidal fracture. They have a wide range in hardness and porosity, and some have a calcareous cement. Most of the fine-grained rocks west of the Salinas River are hard and brittle, but those east of the river are generally soft and friable. Four thin sections of mudstone contain 5–35 percent sand grains and less than 1 percent mica flakes in a matrix of silt and clay. Fossil diatoms are abundant in the fine-grained rocks, and molds of mollusk shells are preserved in some beds.

Porcelanite and porcelaneous mudstone are interbedded with sandstone and fine-grained rocks of the unnamed formation west of the Salinas River. A thin bed of yellowish-gray chert that crops out in sec. 33, T. 19 S., R. 7 E., contains spherical nodules of mudstone. The nodules are 0.5–1.5 mm in diameter and are spaced from 0.5–1 mm apart. A layer of white porcelanite, 1–2 mm thick, surrounds each nodule and underlies the weathered surface of the bed. The porcelanite contains excellently preserved silicified Foraminifera.

A breccia composed of angular porcelanite clasts, 1–3 inches long, in a matrix of fine-grained sandstone crops out in sec. 30, T. 19 S., R. 7 E. A pebbly poorly sorted sandstone bed just below the top of the unnamed formation in sec. 34, T. 19 S., R. 6 E., contains angular fragments of porcelaneous mudstone and irregular mudstone masses that grade into the surrounding sandstone matrix.

A bed, about 2 feet thick, of white friable diatomite in the upper part of the unnamed formation crops out in sec. 13, T. 20 S., R. 7 E. The diatomite contains some scattered very fine sand grains and mica flakes.

THICKNESS

The unnamed formation is probably more than 1,000 feet thick in the northeast corner of the Reliz Canyon quadrangle. It is about 850 feet thick at the mouth of Thompson Canyon and about 700 feet thick west of Reliz Canyon. The unit is only about 275 feet thick where the base is exposed in the northeastern part of the San Lucas quadrangle, but it is thicker to the north and is more than 400 feet thick 2 miles to the south.

AGE AND CONDITIONS OF DEPOSITION

Fossil collections from U.S. Geological Survey localities M902, M903, M912, M913, M915, M918, M920, M952, M981, M987, M988, M990, and M992 (see table 1 for checklist of fossils and table 3 for locality descriptions) in the unnamed formation are characterized by the abundance of *Forreria belcheri* (Hinds), *Lyropecten terminus* (Arnold), *Ostrea atwoodi* Gabb, and *Balanus gregarius* (Conrad). The collections from localities M902, M903, and M992 contain *Turritella cooperi* Carpenter; those from localities M902 and M981 contain *Anadara trilineata* (Conrad) and *Terebratalia occidentalis* (Dall). *Lyropecten terminus*, *Ostrea atwoodi*, and *Anadara trilineata* are limited to Pliocene strata. Ellen J. Moore stated (written communication, 1960):

> These faunas are Pliocene, perhaps early Pliocene, in age. According to Reinhart (1943, p. 58), *Anadara trilineata* is abundant in many of the Pliocene formations in California, and the reported Miocene occurrences in California, Oregon, and Washington are in doubt. *Lyropecten terminus* (Arnold) was thought by Arnold (1906, p. 76; cited as *Pecten estrellanus*, but considered to represent *Lyropecten terminus* by Woodring, 1938, p. 34) to come from a slightly higher horizon than *Lyropecten estrellanus* (Conrad), collected from the Santa Margarita Formation. He found *L. terminus* associated with *Ostrea atwoodi* Gabb.

TABLE 1.—*Fossils from unnamed formation*

[Identified by Ellen J. Moore]

Types of fossils	Locality												
	M902	M903	M912	M913	M915	M918	M920	M952	M981	M987	M988	M990	M992
Gastropods:													
Turcica n. sp	×	----	----	----	----	----	----	----	×	----	----	----	----
Turritella cooperi Carpenter	×	×	----	----	----	----	----	----	----	----	----	----	×
Crepidula cf. *C. princeps* Conrad	----	----	----	----	----	----	----	----	×	----	----	----	----
Forreria belcheri (Hinds)	----	?sp	?sp	×	----	----	×	----	----	----	----	×	----
Pelecypods:													
Anadara (*Anadara*) *trilineata* (Conrad)	×	----	----	----	----	----	----	----	×	----	----	----	----
Lyropecten terminus (Arnold)	?sp	cf	×	×	cf	×	×	×	----	cf	×	cf	----
Hinnites cf. *H. multirugosus* Gale	----	----	×	----	----	----	----	----	----	----	----	----	----
Lima cf. *L. hemphilli* Hertlein and Strong	----	----	×	----	----	----	----	----	----	----	----	----	----
Ostrea atwoodi Gabb	×	----	×	×	----	----	----	×	----	----	----	----	----
Brachiopod: *Terebratalia occidentalis* (Dall)	×	----	----	----	----	----	----	----	×	----	----	----	----
Barnacle: *Balanus gregarius* (Conrad)	×	----	----	×	×	----	----	----	×	----	×	×	----

According to J. Wyatt Durham (written communication, 1960), fossil echinoids from localities M912 and M987 indicate that these localities "would probably fall within the King City Formation or *Astrodapsis* '*antiselli*' (=*salinasensis* Richards) zone of B. L. Clark (1940). Younger than *A. tumidus* zone and older than Poncho Rico Formation or *A. peltoides* zone as Clark (1932; 1940; 1943) used them.

Therefore this would fall within the lowest Pliocene as used by Clark."

The unnamed formation is marine; fossil Foraminifera in it suggest shallow water, less than 300 feet deep (Patsy B. Smith, written communication, 1960).

TERTIARY AND QUATERNARY(?) SYSTEMS

PLIOCENE AND PLEISTOCENE(?) SERIES—PASO ROBLES FORMATION

Fairbanks (1898) named the Paso Robles Formation for exposures near the town of Paso Robles, about 45 miles southeast of King City. The formation consists of nonmarine conglomerate, sandstone, and mudstone. Some of the rock is poorly consolidated and resembles the overlying older alluvium.

The Paso Robles Formation covers much of the central part of the Salinas Valley. It crops out at the north edge of the Reliz Canyon quadrangle and in a strip as wide as 1 mile along the front of the hills west of the Salinas River. The unit is more widespread east of the river, where it caps most of the flat-topped hills.

The Paso Robles Formation is apparently conformable with the underlying beds in most of the map area, but the basal contact may be a regional unconformity that represents the beginning of nonmarine deposition following withdrawal of the Tertiary sea.

LITHOLOGY

A bed of hard, resistant siliceous conglomerate marks the base of the Paso Robles Formation in many places. It contains pebbles of chert, porcelanite, and porcelaneous mudstone and is so firmly cemented that it normally breaks across, rather than around, the larger clasts. The pebbles are subangular to subrounded and most are less than a half inch long. They are set in a yellowish-gray or light-gray matrix of silica and poorly sorted fine- to coarse-grained sand or sand and silt. At some places the matrix is missing and the rock is a porous mass of pebbles firmly cemented together by a coating of silica. The conglomerate is massive or poorly bedded and at some localities grades into, or includes, coarse-grained sandstone. It is locally at least 25 feet thick and may be thicker in some areas.

Conglomerate above the base of the Paso Robles Formation is commonly calcareous and consists almost entirely of pebbles of chert, porcelanite, or porcelaneous mudstone in a yellowish-gray, greenish-gray, or very pale orange matrix of poorly sorted fine- to medium-grained sand, scattered coarser grains, and abundant silt. The pebbles are subangular to subrounded and most are less than 1 inch long. Some of the coarser sand grains in the matrix are rounded, but the finer grains are angular or subangular. The rock is hard, moderately porous, and poorly bedded.

Sandstone in the Paso Robles Formation generally is poorly sorted, fine to coarse grained, and has a matrix of very fine-grained sand and silt. Scattered granules, pebbles, and cobbles are common in many beds. A few beds are better sorted and lack silt in the matrix. The sand grains are subangular or subrounded and are composed chiefly of quartz, feldspar, and chert or porcelanite. The sandstone is generally yellowish gray or very pale orange, porous, massive or poorly bedded, and poorly exposed. Most of it is calcareous. Some sandstone beds are cut by veins of calcite as thick as 2 or 3mm. Some beds contain dark-yellowish-brown material resembling plant remains.

Very pale orange and yellowish-gray mudstone is common in the upper part of the Paso Robles Formation. It is massive and contains fine to very coarse sand grains scattered in an abundant matrix of very fine-grained sand, silt, and clay. The coarser grains in the mudstone are composed of quartz, feldspar, chert, and mica. The mudstone is generally calcareous, moderately soft, and porous but not easily friable.

THICKNESS

The Paso Robles Formation is at least 1,400 feet thick near the mouth of Thompson Canyon, is no more than 400 feet thick in the syncline near the north edge of the Reliz Canyon quadrangle, and is at least 400 feet thick near the margin of the hills east of King City. The upper part of the formation is missing at these places.

AGE AND CONDITIONS OF DEPOSITION

The Paso Robles Formation overlies beds containing fossils of Pliocene age and is older than undeformed alluvial sediments of late Pleistocene and Recent age. The formation is presumably nonmarine, for it lacks fossils and consists largely of poorly sorted, poorly bedded, lenticular strata resembling younger sediments that obviously were deposited by the Salinas River.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT(?) SERIES—OLDER ALLUVIUM

Older alluvium covers the broad terraces that border the Salinas River and extends up the larger tributary valleys. The base of the older alluvium is a conspicuous angular unconformity in most parts of the map area. This unconformity is well displayed at the mouth of Thompson Canyon, where dipping beds of the Paso Robles Formation are overlain by nearly flat-lying older alluvium. Dips of as much as 5° in the older alluvium are probably initial dips. The older alluvium as herein defined includes deposits younger than the Paso Robles Formation and older than alluvium in present-day streams.

The older alluvium is mainly rudely stratified sandy gravel and sandy silt. The sandy gravel consists of rounded pebbles and small cobbles of chert, porcelanite, and porcelaneous mudstone in a matrix of poorly sorted angular and subangular sand and silt. It is pale yellowish brown, friable, porous, and crumbles in water. Sandy gravel in units as thick as several tens of feet is interbedded with, or interfingers with, sandy silt in units of similar thickness. Sandy silt is especially common in the San Lucas quadrangle. It is pale yellowish orange, massive, friable, porous, and crumbles in water. It is generally micaceous and calcareous and contains scattered pebbles.

The older alluvium is sandy at a few localities. Most of the sand is poorly sorted and silty, but some is well sorted. The low hills northwest of San Lucas are largely medium-grained sand with a silty matrix and a few scattered granules. Some of the larger clasts are basement rock. The sand is massive or poorly stratified, porous, friable, and crumbles in water. Some of the hills are dunelike, but the scattered granules and lack of cross-stratification in the sand do not suggest dune deposits.

Older alluvium exposed in bluffs northwest of King City is at least 60 feet thick. Some hills west of the Salinas River in the San Lucas quadrangle that are more than 200 feet high are mapped as older alluvium, but they may be only capped or mantled by alluvial deposits. The older alluvium is much thinner along tributaries of the Salinas River than it is in the main valley. It unconformably overlies the Paso Robles Formation and is of late Pleistocene and perhaps also Recent age.

RECENT SERIES—ALLUVIUM

Alluvium along the Salinas River is chiefly sand and gravel. Most of the larger clasts are chert or porcelaneous mudstone. The sand is fine to medium grained, and near the river it forms dunes related to the prevailing northwest wind. Quicksand is reportedly common in the riverbed.

STRUCTURE

GENERAL FEATURES

The major structural divisions of the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles are, from southwest to northeast, as follows: (a) a structurally high core of basement complex; (b) a belt of faulted Monterey Shale and older rocks; (c) a band of folded Monterey Shale and younger rocks in elongate fault blocks; and (d) an area of Pliocene and younger strata that lie on a shelflike tilted surface of basement complex. The dominant structural trend in each of the divisions is northwestward, except in the northern part of the Reliz Canyon quadrangle, where the sedimentary rocks wrap around the core of basement complex and trend more nearly westward. The stratigraphic section thins generally from southwest to northeast across the three quadrangles, largely by the progressive eastward loss of older strata in the subsurface.

The exposed basement complex in the southwestern part of the Reliz Canyon quadrangle is at the east margin of the mass of plutonic and igneous rocks that constitute the bulk of the northern Santa Lucia Range. It is in fault contact with the adjacent sedimentary rocks in most places in the quadrangle. The westward-trending fault that bounds the basement complex on the north dips 25°–30° N. at the surface. The east boundary of the exposed basement complex is partly a depositional contact and partly an eastward- to northeastward-dipping normal fault. In this part of the map area, only the Reliz Canyon Formation of Eocene age is in depositional contact with the basement complex; and where the formation is divided into members, only the lower member lies directly on the basement complex.

The exposed basement complex is bordered by a belt of Monterey Shale and older strata that is 1–4 miles wide. The northeast boundary of this belt is the line of inferred faults extending from sec. 30, T. 19 S., R. 6 E., to sec. 18, T. 20 S., R. 7 E., and from sec. 19, T. 20 S., R. 7 E., to sec. 4, T. 21 S., R. 7 E. Northwestward-trending faults, which turn more nearly westward in the northwestern part of the Reliz Canyon quadrangle, traverse the belt. They are chiefly vertical faults or normal faults that dip away from the exposed basement complex. They bound elongate fault blocks that are subdivided by northeastward-trending cross faults. In general, the strata in each block dip away from the exposed basement complex, and the exposed rocks are progressively younger to the northeast. The faults in this belt appear to be related to uplift of the nearby basement complex.

A band of elongate fault blocks of folded Monterey Shale and younger strata that is about 5 miles wide trends northwestward from the southwest corner of the San Lucas quadrangle, across the Thompson Canyon quadrangle, and into the northeast quarter of the Reliz Canyon quadrangle. Its northeast boundary is near the edge of the hills west of the Salinas River. Large northwestward-trending faults divide the area into elongate fault blocks, and shorter cross faults subdivide the blocks; but, unlike the strata in the belt of older rocks to the southwest, the beds in these fault blocks are deformed into numerous folds. The fold axes are parallel or nearly parallel to the bounding northwestward-trending faults. Faults generally terminate rather than offset the folds. Most of the faults are apparently nearly vertical. An exception is the fault that extends from sec. 26, T. 19 S., R. 6 E., to sec. 1, T. 21 S., R. 7 E., and that dips about 70° SW. in its northern part, at least. Northeast of this fault, the basement-complex surface strikes northwestward and rises to the northeast. Near the margin of the hills west of the Salinas River, the slope of the basement complex surface is 1,300–1,500 feet per mile. The stratigraphic section thins markedly from southwest to northeast, or in the same direction that younger rocks appear, perhaps by progressive overlap of older strata by younger beds or possibly by faulting.

The basement complex is comparatively shallow beneath and northeast of the Salinas River, where Pliocene rocks lie directly on the basement complex, and the thick pre-Pliocene stratigraphic section exposed west of the river is absent. The basement-complex surface rises northeastward and has an average slope of about 350 feet per mile from near the mouth of Thompson Canyon to the vicinity of The Texas Co. King City Nose Core Hole (projected sec. 31, T. 19 S., R. 8 E.), which is on a local structural high. The basement-complex surface rises northeastward and has an average slope of about 300 feet per mile beneath the hills in the San Lucas quadrangle. Northeast of the river, the basement-complex surface and thin cover of sedimentary rock are tilted slightly southwestward but are otherwise nearly undeformed. At least one large northwestward-trending fault is almost certainly concealed beneath the alluvium of the Salinas River.

Structure section *A–B–C–D* (pl. 4) illustrates four assumptions: (a) the contact between the basement complex and sedimentary rocks between Reliz Canyon and the Salinas River is depositional; (b) the Reliz Canyon Formation, Vaqueros Formation, and the Monterey Shale thin and successively pinch out to the northeast against a buried escarpment of basement complex; (c) faults and folds between Reliz Canyon and the Salinas River are not limited to the sedimentary rocks; and (d) rocks younger than the Monterey Shale are continuous across the valley of the Salinas River.

Another interpretation of the structure could be made by assuming that: (a) the contact of basement complex and sedimentary rocks between Reliz Canyon and the Salinas River is at least partly a fault and (b) the Reliz Canyon Formation, Vaqueros Formation, and the Monterey Shale do not thin markedly to the northeast but are lost mainly by faulting against the basement complex.

FAULTS

The faults in the Reliz Canyon and Thompson Canyon quadrangles are poorly exposed. The approximate position of faults that separate unlike rocks is generally apparent, but the location, or even the existence, of faults confined to one lithologic unit is commonly questionable. The inferred faults on the geologic maps of the Reliz Canyon and Thompson Canyon quadrangles are based on indirect evidence and are proposed as possible explanations for features that are difficult to account for by other means. The inferred faults are marked by local structural anomalies that are either alined in accordance with nearby structural features or located along the extension of a known fault.

The inferred fault that extends from sec. 30, T. 19 S., R. 6 E., to sec. 17, T. 20 S., R. 7 E., links several areas that have local peculiarities. Where this inferred fault crosses Sweetwater Creek, the normally northward-dipping Monterey Shale flattens and has a slight reversal of dip. Where the inferred fault crosses Vaqueros Creek, the Monterey Shale contains small folds and dips steeper than others in the vicinity. The inferred fault may cut out part of the Monterey Shale east of Vaqueros Creek, where the unit is apparently only about one-half as thick as it is in nearby areas. The northeastward-trending cross fault in sec. 3, T. 20 S., R. 6 E., which does not offset the upper contact of the Sandholdt Member of the Monterey Shale, may end against the inferred fault. Where the inferred fault crosses Reliz Canyon, the prevailing northeastward dip of the Monterey Shale is interrupted by a local reversal of dip. This inferred fault appears to terminate the cross fault in sec. 13, T. 20 S., R. 6 E., and the cross fault and southeastward-trending syncline in sec. 17, T. 20 S., R. 7 E.

The inferred fault that extends from sec. 19, T. 20 S., R. 7 E., to sec. 4, T. 21 S., R. 7 E., may account for at least part of the abnormal thinning of the Sandholdt Member in the vicinity of Pine Canyon. The thinning may be caused partly by interfingering of the Sandholdt and the upper part of the Monterey Shale, but it seems too abrupt to be accounted for by this explanation alone. The Sandholdt has a reversal of dip in Pine Canyon near this inferred fault.

The inferred fault in sec. 25, T. 19 S., R. 6 E., is an extension of the fault in sec. 30, T. 19 S., R. 7 E., and explains the apparent abnormal thickness of the unnamed formation in the northeast corner of the Reliz Canyon quadrangle.

The inferred faults in the southeast quarter of the Thompson Canyon quadrangle account for abrupt changes in structure in the Monterey Shale. The Monterey is crushed or contorted in some places along the inferred faults.

A fault that extends from sec. 26, T. 19 S., R. 6 E., at the north edge of the Reliz Canyon quadrangle, to sec. 1, T. 21 S., R. 7 E., at the south edge of the Thompson Canyon quadrangle, is expressed in the Monterey Shale as a zone of crushed and contorted beds. It is well exposed 2 miles north of the Reliz Canyon quadrangle on the north side of the Arroyo Seco, where it strikes N. 40° W. and dips 70° SW. The fault maintains this strike across the map area, but the dip apparently steepens to nearly vertical in the southern part of the Thompson Canyon quadrangle. The split in the fault in the subsurface shown on structure section *A–B–C–D* (pl. 4) is inferred from an apparent repetition of beds in the Shell Oil Shell-Texas-Beedy 1.

A fault or zone of faults that strikes about N. 40° W., the same strike as that of the basement-complex surface in the northern part of the Thompson Canyon quadrangle, may be concealed beneath the valley of the Salinas River. Sedimentary rock in the Murdock Oil Marian 1, east of the river, is about 3,000 feet thicker than would be expected by comparison with strata in nearby wells. The Murdock Oil Marian 1 may be in a block of sedimentary rock faulted against the basement complex before deposition of the unnamed formation of Pliocene age. This interpretation is illustrated on structure section *A–B–C–D* (pl. 4). A line that strikes N. 40° W. and that extends southeastward from the Murdock Oil Marian 1 passes between the Superior Oil Cooper 1 and the L. B. Tannehill Quinn 1. The top of the basement complex in the Superior Oil Cooper 1 is near sea level, but in the L. B. Tannehill Quinn 1, it is more than 2,000 feet below sea level. This evidence suggests that it may be offset by one or more northwestward-trending faults between the two wells.

FOLDS

The folds in the map area are obviously closely related to the faults. Most of them are in fault-bounded blocks, and they strike northwestward subparallel to the faults. Complex small folds are common in the Monterey Shale. Some large folds in the Monterey have small, subsidiary folds on their flanks. En echelon folds and drag folds are associated with many of the faults.

PETROLEUM

Petroleum exploration in the map area has been concentrated mainly on searching for oil-bearing sandstone beds in the Monterey Shale near the margin of the hills west of the Salinas River. Oil-stained fine-grained sandstone and siltstone beds crop out stratigraphically above the Monterey Shale near the mouth of Thompson Canyon. Much of the Sandholdt Member has a strong petroliferous odor on freshly broken surfaces. Several wells in the map area had indications of petroleum, and development of an oil field near the southwest corner of the San Lucas quadrangle began in 1960. Table 2 lists wells drilled in the map area through 1960.

TABLE 2.—*Wells drilled for oil in the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles through 1960*

[Several core holes are included. Elevation: kb, kelly bushing; gr, ground; df, derrick floor; topo, ground (from topographic map)]

Map locality	Operator	Well	Location: Quadrangle	Sec.	Township South	Range East	Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks
1	Associated Oil Co	1	Reliz Canyon	2	20	6	1925	760 topo	36	
2	Beach, Church, and Bell.	Baker 1	Thompson Canyon.	[1] 32	20	8	1960	489 kb	2,062	Completed on pump; estimated production: 240 bbl per day gross, 80 bbl per day net, 16.0°-gravity oil.
3	do	Salinas Land Co. 1	do	[1] 18	20	8	do	388 kb	2,314	Reported bottomed in weathered schist.
4 [2]	Excelsior Oil Co	1	San Lucas	4	21	8	1920–27		685	
5	C.C.M.O. Co	Salanco 1	Thompson Canyon.	[1] 2	20	7	1946	400 topo	2,627	Reported: Paso Robles Formation, 0–1,360 ft; unnamed formation, 1,360–2,436 ft; conglomerate, 2,436–2,566 ft; schist, 2,566–2,677 ft.
6	W. W. Holmes	Beedy 1	do	34	19	7	1954	700 topo	3,200	Reported: top of "Salanco oil sand," 1,735 ft; top of "Beedy oil sand," 2,975 ft; bottomed in middle Miocene rocks.
7	do	Kent 1	San Lucas	5	21	8	1960	540 topo	2,931	Formation test, 2,141–2,192 ft: open 1 hr, recovered 1,803 ft of fresh water and mud.
8	do	Kent 1-4	do	4	21	8	do	579 kb	2,500	
9	Barron Kidd	Spreckels 1	Thompson Canyon.	[1] 25	19	7	1959	279 kb	1,354	Reported bottomed in basement complex.
10	Marport Oil Co	Marport-Mozzini 1	do	13	20	7	1957	570 kb	3,124	Reported top of basement complex or conglomerate, 3,105 ft.
11	do	Marport-Mozzini 2	do	11	20	7	do	560 gr	3,073	Reported bottomed in middle Miocene rocks; plugged back to 2,312 ft; initial production, 2 bbl per day, 9.5°-gravity oil, 80-percent cut; after 30 days, 10 bbl per day, 9.5°-gravity oil, 30-percent cut.
12	do	Marport Mozzini Block 3-1.	do	12	20	7	do	505 kb	2,669	Reported: Monterey Shale, 910–2,490 ft; top of continental beds, 2,490 ft; bottomed in basement complex.
13	do	Marport Mozzini Block 4-1.	do	11	20	7	do	500 kb	3,262	Reported bottomed in Miocene strata.
14	do	Mozzini-MP 1	do	11	20	7	1959	455 kb	2,601	Reported top of Monterey Shale, 740 ft

15	Murdock Oil Co.	Marian 1	San Lucas	[1] 9	20	8	1952	400 topo	5,306	Reported bottomed in basement complex.
16 [3]	Okell Well Machinery Co.	1	Reliz Canyon	35	19	6	1921 (?)		295	
17 [3]	do	2	do	35	19	6	do		1,000	
18 [2]	Ross and Herbert	1	do	16	20	6	1923		110	
19 [3]	Santa Lucia Oil Co.	1	do	12	20	6	1921 (?)		1,170	
20	E. Schweninger; also John C. Guerrier, Schweninger and Associates, Schweninger and Henigan.	Smart 1	Thompson Canyon.	3	20	7	1924–26	500 topo	3,726	Reported top of basement complex 3,708 ft.
21	Shell Oil Co.	Honolulu-Thorup-USL 1.	do	4	20	7	1946–47	1,445 kb	6,777	Bottomed in Sandholdt Member (?).
22	do	Kidd-Beebe 87X-3	San Lucas	3	21	8	1960	510 df	2,657	
23	do	Kidd-Bernard 56X-33	do	33	20	8	do	510 df	3,261	
24	do	Shell-Texas-Beedy 1	Reliz Canyon	1	20	6	1957-58	1,145 df	9,204	Reported top of basement complex, 9,140 ft.
25 [3]	Superior Oil Co.	Cooper and others 1	San Lucas	[1] 6	21	9	1949		445	Reported in gneiss, 370–445 ft.
26	L. B. Tannehill	Quinn 1	do	[1] 35	20	8	1938	375	2,590	Reported top of basement complex, 2,510? ft.
27	The Texas Co.	Basham 1	Thompson Canyon.	36	20	7	1952	923 kb	5,477	Reported bottomed in Miocene strata.
28	do	Beedy (NCT-1) 1	do	33	19	7	1948	1,196 kb	5,147	Continental beds(?), 5,030–5,146 ft.
29	do	Beedy B (NCT-1) 1	do	34	19	7	1952	663 kb	3,354	Bottomed in continental beds?.
30 [3]	do	Currell 1	San Lucas	4	21	8	1946	586 gr	3,280	
31 [3]	do	Currell 2	do	4	21	8	1947	541 gr	2,444	
32	do	Doud anticline Core Hole.	do	[1] 21	20	8		320 topo	2,400	Top of basement complex, 1,650? ft.
33	do	Dunphy 1	Thompson Canyon.	30	19	7	1936–37	1,760 topo	4,759	Reported: top Sandholdt Member, 3,060? ft; top Vaqueros Formation, 3,674? ft; top continental beds, 3,982? ft.
34	do	East King City Core Hole.	San Lucas	[1] 11	20	8		470 topo	1,544	Reported top of basement complex, 1,526? ft.
35	do	Gabilan Mesa 4	do	30	20	9	1938	445	784	Top of basement complex, 784? ft.
36	do	King City nose Core Hole	Thompson Canyon.	[1] 31	19	8		302	1,288	Reported top of schist, 1,165 ft.
37	do	Pettitt 1	do	24	20	7	1951	561 kb	4,033	Reported: top of "Paraiso oil sand" (middle Miocene), 3,042 ft; top of continental beds, 3,465 ft.
38	do	Reich 1	do	24	20	7	do	597 kb	4,181	Reported bottomed in continental beds or in basement complex.
39	R. R. Thorup	Thomas Doud Estate 1.	do	[1] 29	20	8	1959	380 kb	1,597	

See footnotes at end of table.

TABLE 2.—*Wells drilled for oil in the Reliz Canyon, Thompson Canyon, and San Lucas quadrangles through 1960*—Continued

[Several core holes are included. Elevation: kb, kelly bushing; gr, ground; df derrick floor; topo, ground (from topographic map)]

Map locality	Operator	Well	Location: Quadrangle	Location: Sec.	Location: Township South	Location: Range East	Year(s) drilled	Elevation (feet)	Total depth (feet)	Remarks
40	R. R. Thorup	Thomas Doud Estate 2.	San Lucas	[1] 32	20	8	1959	530 kb	2,483	Plug at 2,130 ft; rated initial production 95 bbl per day, 15.1°-gravity oil.
41	do	Thomas Doud Estate 3.	do	[1] 5	21	8	do	540 topo	2,140	Top of oil sand, 2,007 ft; completed on pump, 414 bbl in 22 hr (gross), 16.0°-gravity oil, 0.6-percent cut.
42	do	Thomas Doud Estate 4.	do	[1] 32	20	8	1960	503 kb	2,136	Top of gas sand, 1.886 ft; top of oil sand, 1,985 ft; completed flowing at estimated 6 million cu ft per day through ¾-in bean; on 3-hr test through 22/64-in bean, flowed at 2,100,000 cu ft per day with 685/680 lb pressure.
43	Verde Enterprises	Gamboa Estate 41X-5.	Thompson Canyon.	5	21	8	do	500 topo	2,837	

[1] Projected section.
[2] Well not shown on geologic map.
[3] Location of well on geologic map is approximate.

MEASURED SECTIONS

1. Section west of upper Reliz Canyon in sec. 1, T. 21 S., R. 6 E., Reliz Canyon quadrangle

	Feet
Reliz Canyon Formation:	
Upper member (lower part only):	
3. Sandstone, arkosic, very pale orange (10*YR* 8/2), fine- or medium-grained (some coarse grains and granules), calcareous; grains subangular or subrounded	50+
Upper member (part measured)	50+
Contact conformable.	
Middle member:	
2. Siltstone, grayish-orange (10*YR* 7/4), mainly noncalcareous, massive; poorly exposed; hackly fracture; contains ellipsoidal olive-gray (5*Y* 4/1) calcareous concretions, 3–12 in. in diameter	117
Total, middle member	117
Contact conformable.	
Lower member:	
1. Sandstone, arkosic, light olive-gray (5*Y* 6/1) and pale yellowish-brown (10*YR* 6/2), stained blackish red (5*R* 2/2), dark reddish-brown (10*R* 3/4), and dark yellowish-orange (10*YR* 6/6), fine- or medium-grained, noncalcareous; grains subangular or subrounded	39
Total, lower member	39
Depositional contact on basement complex.	

2. Section along upper Reliz Canyon in sec. 26, T. 20 S., R. 6 E., Reliz Canyon quadrangle

	Feet
Vaqueros Formation:	
Lower member (lower part only):	
11. Sandstone, arkosic, grayish-orange (10*YR* 7/4), medium- to coarse-grained, conglomeratic, mainly calcareous; grains angular to subrounded; locally cross-stratified; pebbles and cobbles of basement complex scattered at random in most of unit but locally concentrated into beds or lenses of conglomerate	200+
Lower member (part measured)	200+
Contact apparently conformable, but poorly exposed.	
Reliz Canyon Formation:	
Upper member:	
10. Sandstone, arkosic, pale-olive (10*YR* 6/2) and light olive-gray (5*Y* 5/2), fine- to medium-grained, calcareous; grains subangular or subrounded; in beds 10–40 ft thick; some interbeds of poorly sorted noncalcareous sandstone that contains scattered coarse grains and granules; ellipsoidal calcareous concretions as long as 2 ft	944

2. Section along upper Reliz Canyon in sec. 26, T. 20 S., R. 6 E., Reliz Canyon quadrangle—Continued

	Feet
Reliz Canyon Formation—Continued	
Upper member—Continued	
9. Sandstone, yellowish-gray (5*Y* 8/1), chiefly medium-grained, calcareous; in beds 1–4 ft thick; some beds are graded and contain coarse grains and granules scattered in medium grains near the base; the thicker beds contain ellipsoidal calcareous concretions as long as 1 ft	105
8. Sandstone, yellowish-gray (5*Y* 7/2) and light olive-gray (5*Y* 5/2), chiefly fine-grained, scattered medium grains, mainly noncalcareous; some hard calcite-cemented lenses or beds protrude on weathered surfaces; contains a few angular chips of mudstone as long as a quarter of an inch	223
7. Sandstone, grayish-orange (10*YR* 7/4) and pale yellowish-brown (10*YR* 6/2), fine- to medium-grained, noncalcareous, friable; in beds 1–3 ft thick	41
6. Sandstone, grayish-orange (10*YR* 7/4), fine- to medium-grained, noncalcareous; grains subangular or subrounded; massive units as thick as 20 ft; cavernous weathering; breaks into blocks 10–30 ft in each dimension	143
Total, upper member	1,456
Contact conformable.	
Middle member (part only):	
5. Siltstone, grayish-yellow (5*Y* 7/2), calcareous, massive, hackly fracture; a few interbeds of sandstone 1 ft thick	56
4. Sandstone, arkosic, yellowish-gray (5*Y* 8/1), medium-grained, scattered coarse grains, calcareous; in beds 1–3 ft thick	25
3. Siltstone, like unit 5; partly covered	10
2. Sandstone, yellowish-gray (5*Y* 8/1), medium-grained, well-sorted, calcareous, hard	3
1. Siltstone, like unit 5; base covered	25+
Middle member (part measured)	119+

3. Section east of upper Reliz Canyon in sec. 26, T. 20 S., R. 6 E., Reliz Canyon quadrangle

	Feet
Monterey Shale:	
Sandholdt Member (lower part only):	
20. Siltstone, very pale orange (10*YR* 8/2) and pale yellowish-brown (10*YR* 6/2), calcareous, hackly fracture; contains carbonate beds 1–2 ft thick that are cut by calcite veins as wide as 1½ in.; grades upward into hard platy laminated calcareous shale about 150 ft above base; partly covered	200+

3. Section east of upper Reliz Canyon in sec. 26, T. 20, S., R., 6 E., Reliz Canyon quadrangle—Continued

	Feet
Monterey Shale—Continued	
Upper member—Continued	
19. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), very fine-grained, chiefly calcareous, thin-bedded to massive or poorly bedded; contains lenses or pods of medium-grained sandstone; includes minor amounts of siltstone and medium-grained light olive-gray (5*Y* 6/1) sandstone in beds 1–3 ft thick; scattered calcareous concretions	120
18. Siltstone, moderate yellowish-brown (10*YR* 5/4), noncalcareous, hackly fracture; carcareous concretions and thin sandstone beds in upper part	229
Sandholdt Member (part measured)	549+
Contact gradational.	
Vaqueros Formation:	
Upper member:	
17. Sandstone, arkosic, grayish-orange (10*YR* 7/4), fine-grained, noncalcareous, hard; in beds 1–2 ft thick; partly covered	283
16. Siltstone and very fine-grained sandstone, pale yellowish-brown (10*YR* 6/2), noncalcareous, thin-bedded; a few thin beds of pale yellowish-brown (10*YR* 6/2), porcelanite; partly covered	16
15. Sandstone, yellowish-gray (5*Y* 7/2), fine- to coarse-grained, calcareous, hard; a few scattered granules; in beds about 1 ft thick; upper part covered	89
14. Sandstone, light olive-gray (5*Y* 5/2), fine-grained, noncalcareous, poorly bedded, friable, micaceous	24
13. Sandstone, yellowish-gray (5*Y* 7/2), medium-grained, calcareous, hard, massive; forms bold outcrops; contains lenses of coarse grains, granules, and a few pebbles and small cobbles of basement complex; upper part partly covered	409
12. Covered; forms strike valley; massive friable fine-grained sandstone exposed along strike	87
11. Sandstone, grayish-orange (10*YR* 7/4), fine-grained, well-sorted, noncalcareous; beds about 1 ft thick	105
10. Covered; chips of fine-grained sandstone and siltstone in soil	131
9. Sandstone, light olive-gray (5*Y* 6/1), fine- or medium-grained, calcareous, hard; silty matrix; molds and casts of clam shells locally abundant; partly covered	92
8. Sandstone, yellowish-gray (5*Y* 8/1), coarse-grained and pebbly, calcareous, friable	106
7. Sandstone, dark yellowish-brown (10*YR* 4/2), massive, noncalcareous, friable; laced with tubes one-eighth of an inch in diameter, filled with yellowish-gray (5*Y* 7/2) sand; the tube-filling differs from the surrounding sandstone chiefly in containing fewer dark grains	6

3. Section east of upper Reliz Canyon in sec. 26, T. 20, S., R., 6 E., Reliz Canyon quadrange—Continued

	Feet
Vaqueros Formation—Continued	
Upper member—Continued	
6. Sandstone, yellowish-gray (5*Y* 7/2), speckled with dark yellowish-orange (10*YR* 6/6) spots, fine- to medium-grained, noncalcareous, massive	100
5. Covered	122
4. Sandstone, yellowish-gray (5*Y* 7/2); speckled with dark yellowish-orange (10*YR* 6/6) spots, fine- or medium-grained, calcareous, hard; beds 1–3 ft thick	83
3. Covered; forms strike valley; rock exposed along strike is, in part, mudstone that is light olive gray (5*Y* 6/1) and pale yellowish brown (10*YR* 6/2), noncalcareous, massive; hackly fracture; contains fish scales	215
2. Sandstone, yellowish-gray (5*Y* 7/2), chiefly fine- to medium-grained, scattered granules, calcareous; in beds 6 in. to 2 ft thick; fragments of clam shells in coarser sandstone	118
Total, upper member	1,986
Contact gradational.	
Lower member (upper part only):	
1. Conglomeratic sandstone, arkosic, yellowish-gray (5*Y* 7/2), fine- to coarse-grained, noncalcareous, massive; contains scattered granules, pebbles, and a few cobbles from basement complex as long as 6 in.; cavernous weathering; many of the larger clasts are concentrated in poorly defined lenses; base covered	100+
Lower member (part measured)	100+

4. Section along Reliz Creek in secs. 13 and 14, T. 20 S., R. 6 E., Reliz Canyon quadrangle

[*Age determinations of Foraminifera by Patsy B. Smith*]

	Feet
Monterey Shale (part only):	
42. Porcelaneous mudstone, yellowish-gray (5*Y* 8/1) and light olive-gray (5*Y* 6/1); partly massive and partly in beds 3–6 in. thick; thinner bedded and more porcelaneous above basal 25 ft.	200+
41. Covered	50
Monterey Shale (part measured)	250+
Contact gradational, projected to line of section from west; concealed in Reliz Creek.	
Sandholdt Member:	
40. Shale, interbedded calcareous and noncalcareous, light olive-gray (5*Y* 6/1) and olive-gray (5*Y* 4/1)	14

4. Section along Reliz Creek in secs. 13 and 14, T. 20 S., R. 6 E., Reliz Canyon quadrangle—Continued

	Feet
Monterey Shale (part only)—Continued	
Sandholdt Member—Continued	
39. Mudstone and shale, porcelaneous, light olive-gray (5*Y* 6/1) and pinkish-gray (5*YR* 8/1); irregular bedding; layers of grayish-black (*N* 2) chert ⅛–1 in. thick; contain some porcelanite	5½
38. Siltstone, grayish-orange (10*YR* 7/4), flaky; contains Foraminifera of Mohnian stage	½
37. Mudstone, very pale orange (10*YR* 8/2), massive; sandy in upper 6 in	3
36. Shale, porcelaneous and calcareous, and porcelanite; porcelaneous rocks are light olive gray (5*Y* 6/1), laminated in part, and contain a few layers of grayish-black (*N* 2) chert as thick as a quarter of an inch; calcareous shale is light olive-gray (5*Y* 6/1) and olive-gray (5*Y* 4/1) and contains Foraminifera of Mohnian stage	60
35. Covered	41
34. Shale, light olive-gray (5*Y* 6/1), noncalcareous, laminated; contains interbeds of porcelanite, layers of brownish-black (5*YR* 2/1) chert as thick as half an inch, and Foraminifera of upper Luisian stage	33
33. Covered	164
32. Shale, very pale orange (10*YR* 8/2), calcareous, hard	10
31. Porcelanite, yellowish-gray (5*Y* 7/2); white (*N* 9) on weathered surfaces; contains brownish-black (5*YR* 2/1) chert layers as thick as 3 in	1½
30. Shale, very pale orange (10*YR* 8/2), calcareous, laminated, hard; breaks into platy fragments ⅛–⅜ in. thick; contains Foraminifera characteristic of the lower Luisian stage	93
29. Covered	59
28. Shale, like unit 30	31
27. Carbonate bed, olive-gray (5*Y* 4/1), hard; stained yellowish orange (10*YR* 6/6) on weathered surfaces; cut by calcite veins; laminated in part but not fissile	3
26. Shale, like unit 30	14
25. Covered	324
24. Sandstone, arkosic, very pale orange, fine- to medium-grained, calcareous, hard; clayey matrix	1½
23. Shale, very pale orange (10*YR* 8/2), calcareous, soft, laminated; breaks into plates ⅛–⅜ in. thick; contains fish scales and Foraminifera characteristic of the upper Relizian stage	18
22. Siltstone, grayish-orange (10*YR* 7/4), very hard, calcareous; very pale orange (10*YR* 8/2) on weathered surfaces; breaks into platy fragments 1–2 in. thick; cut by calcite veins	1½
21. Shale, like unit 23	12
20. Siltstone, like unit 22	1
19. Shale, like unit 23	30

4. Section along Reliz Creek in secs. 13 and 14, T. 20 S., R. 6 E., Reliz Canyon quadrangle—Continued

	Feet
Monterey Shale (part only)—Continued	
Sandholdt Member—Continued	
18. Covered	476
17. Siltstone, dark yellowish-brown (10*YR* 4/2), calcareous; hackly fracture; irregular bedding; beds as thick as 1 in.; contains Foraminifera of Saucesian stage	100
16. Carbonate bed, like unit 27	1
15. Siltstone, like unit 22	19
14. Carbonate bed, like unit 27	1
13. Siltstone, like unit 22	53
12. Sandstone, arkosic, yellowish-gray (5*Y* 7/2), fine- to medium-grained, poorly sorted, calcareous, friable	4
11. Siltstone, yellowish-gray (5*Y* 7/2), stained grayish-orange (10*YR* 7/4), calcareous, friable, micaceous; hackly fracture; bedding surfaces irregular; scattered fine sand grains	½
10. Sandstone, like unit 12	2
9. Siltstone, like unit 11	16
8. Covered	100
Total, Sandholdt Member	1,693

Contact gradational, projected to line of section from east of Reliz Creek.

	Feet
Vaqueros Formation:	
Upper member (upper part only):	
7. Covered	47
About 200 ft of section repeated by fault.	
6. Sandstone, arkosic, very pale orange (10*YR* 8/2), chiefly medium-grained, poorly sorted, massive, friable; calcareous concretions 1–2 ft in diameter	20
5. Covered	21
4. Siltstone, pale yellowish-brown (10*YR* 6/2), noncalcareous, friable; hackly fracture; a few sandstone beds as thick as 6 in.; calcareous concretions as long as 4 ft	22
3. Sandstone, very pale orange (10*YR* 8/2), fine- to coarse-grained, micaceous, calcareous; speckled moderate yellowish brown (10*YR* 5/4) and pale yellowish brown (10*YR* 6/2) on weathered surfaces; grains angular to subrounded; alternate massive and laminated beds 2–3 ft thick	7
2. Siltstone, like unit 4	26
1. Sandstone, like unit 3	23
Upper member (part measured)	166

5. Section east of Reliz Creek in secs. 35 and 36, T. 19 S., R. 6 E., Reliz Canyon quadrangle

Unnamed formation (lower part only):	*Feet*
12. Siltstone, yellowish-gray (5*Y* 8/1) and very pale orange (10*YR* 8/2), massive, noncalcareous; hackly fracture	32
11. Sandstone, arkosic, very pale orange (10*YR* 8/2), fine-grained, massive, noncalcareous	7
10. Mudstone, yellowish-gray (5*Y* 7/2), massive, noncalcareous, poorly exposed	13½
9. Sandstone, very pale orange (10*YR* 8/2), mottled yellowish gray (5*Y* 8/1), very fine-grained, massive, noncalcareous, hard, fractured; contains ellipsoidal nodules of pale yellowish-brown (10*YR* 6/2) porcelanite 4–5 in. long; zone of rounded pebbles, half an inch in diameter, of very fine-grained sandstone about 325 ft above base	420
8. Sandstone, grayish-yellow (5*Y* 8/4), fine-grained, friable	½
Unnamed formation (part measured)	473
Contact conformable.	
Monterey Shale (upper part only):	
7. Mudstone, yellowish-gray (5*Y* 8/1), spotted moderate yellowish brown (10*YR* 5/4), noncalcareous; upper part massive; lower part has irregular beds 1–2 in. thick; upper part porcelaneous	80½
6. Mudstone, yellowish-gray (5*Y* 7/2), porcelaneous, hard, fractured; irregular bedding surfaces have "wrinkled" appearance	11
5. Siltstone, yellowish-gray (5*Y* 7/2), massive, conchoidal fracture, noncalcareous	60
4. Mudstone, yellowish-gray (5*YR* 7/2), sandy; contains rounded clasts, ¼–¾ in. in diameter, of very pale orange (10*YR* 8/2) mudstone and—more rarely—basement complex; gradational lower contact; abrupt upper contact; undulations resembling ripple marks on upper surface	½
3. Mudstone, light olive-gray (5*Y* 6/1), massive, noncalcareous, hard, fractured, porcelaneous in part; contains fish scales and molds of Formaminifera	54
2. Mudstone, light olive-gray (5*Y* 6/1), noncalcareous; irregular beds ¼–½ in. thick	1
1. Mudstone, light olive-gray (5*Y* 6/1), mottled grayish orange (10*YR* 7/4); noncalcareous; in beds 2–3 ft thick; irregular bedding surfaces; hackly fracture	7
Monterey Shale (part measured)	214

6. Section northwest of Branstetter Canyon in sec. 11, T. 20 S., R. 7 E., Thompson Canyon quadrangle

	Feet
Paso Robles Formation (lower part only):	
17. Conglomerate, very pale orange (10*YR* 8/2); rounded to subangular pebbles and small cobbles of porcelaneous rock and chert in matrix of calcareous arkosic sandstone and sandy siltstone; poorly consolidated; forms rounded hills covered by pebbly soil; mostly covered	200+
16. Conglomerate, yellowish-gray (5*Y* 8/1); rounded pebbles of porcelaneous rock, chiefly about 1 in. in diameter, in hard sandy opaline matrix; locally very hard and resistant	185
15. Mudstone, white (*N* 9) and yellowish-gray (5*Y* 8/1), soft to hard, porcelaneous, chiefly noncalcareous; porcelanite pebbles near base	27
14. Conglomerate and conglomeratic sandstone, pale yellowish-orange (10*YR* 8/6), noncalcareous; rounded pebbles of porcelanite in sandstone matrix; sandstone fine- to coarse-grained; partly covered	129
Paso Robles Formation (part measured)	541+
Base apparently conformable, but poorly exposed.	
Unnamed formation (upper part only):	
13. Claystone, very pale orange (10*YR* 8/2), spotted dark yellowish-orange (10*YR* 6/6), massive, friable; contains fossil diatoms	65
12. Sandstone, pale-orange (10*YR* 8/2) and pinkish-gray (5*YR* 8/1), very fine-grained, massive, noncalcareous, hard, fractured, micaceous; contains fossil diatoms	13
11. Claystone, like unit 13	52
10. Sandstone, like unit 12	41
9. Claystone, like unit 13; has a few interbeds of fine-grained sandstone and some nodules of light olive-gray (5*Y* 5/2) porcelanite in upper part	33
8. Sandstone, dark yellowish-brown (10YR 4/2), fine- to medium-grained, poorly sorted, massive, noncalcareous, hard; clayey matrix	8
7. Sandstone, like unit 12	118
6. Claystone, like unit 13	13
5. Sandstone, like unit 12	7
4. Claystone, like unit 13	161
3. Sandstone, like unit 12	37
2. Claystone, like unit 13	14
1. Sandstone, like unit 12; base covered	26+
Unnamed formation (part measured)	588+

7. Section south of Bull Canyon in secs. 29 and 32, T. 19 S., R. 9 E., San Lucas quadrangle

	Feet
Paso Robles Formation (lower part only):	
14. Conglomerate, pale yellowish-orange (10*YR* 8/6); rounded pebbles of porcelaneous rock and chert in sandy opaline matrix; locally grades into sandstone	20+
Paso Robles Formation (part measured)	20+
Contact apparently conformable, but poorly exposed.	
Unnamed formation (upper part only):	
13. Sandstone, yellowish-gray (5*Y* 8/1), fine- to medium-grained, poorly sorted, calcareous, friable; scattered coarse grains, granules, and a few pebbles in lower half	10
12. Sandstone, pale greenish-yellow (10*Y* 8/2), fine grained, massive, calcareous	5
11. Covered	5
10. Claystone, yellowish-gray (5*Y* 8/1), massive, friable, noncalcareous	5
9. Sandstone, yellowish-gray (5*Y* 8/1), very fine grained, massive, partly calcareous, abundant casts of small paired clam shells	30
8. Claystone, like unit 10	11
7. Sandstone, like unit 9	2
6. Claystone, yellowish-gray (5*Y* 8/1), massive, friable, noncalcareous; partly covered	55
5. Sandstone, yellowish-gray (5*Y* 8/1), fine-grained, friable; poorly preserved fossil pectens, oysters, and barnacles	3
4. Covered	17
3. Sandstone, yellowish-gray (5*Y* 8/1), fine-grained, massive, friable, fractured, calcareous	5
2. Claystone, like unit 6	33
1. Sandstone, like unit 3	22+
Unnamed formation (part measured)	203+

TABLE 3.—Fossil localities

USGS No.	Location				Formation	Type(s) of fossil(s)						
	Quadrangle	Section	Township South	Range East		Foraminifera	Gastropods	Pelecypods	Brachiopods	Barnacles	Echinoids	Fish and crab remains
M1482	Reliz Canyon	35	20	6	Reliz Canyon	×						
M902	do	35	19	6	Unnamed		×	×	×	×		
M903	San Lucas	5	21	9	do		×	×		×		
M912	do	9	20	9	do		×	×			×	
M913	do	8	20	9	do		×	×		×		×
M915	do	29	19	9	do			×		×		
M918	Thompson Canyon	23	20	7	do			×				
M920	San Lucas	8	20	9	do	×	×	×				×
M952	do	32	19	9	do			×				
M981	Reliz Canyon	26	19	6	do		×	×	×	×		
M987	San Lucas	16	20	9	do			×			×	
M988	do	28	19	9	do			×		×		
M990	do	32	19	9	do		×	×		×		×
M992	do	32	19	9	do		×					

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