Lithologic Characteristics of Pliocene Rocks Cored at Elk Hills, Kern County, California

GEOLOGICAL SURVEY BULLETIN 1332-D

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By WILLIAM M. BERRYMAN

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A complete sequence of Pliocene rocks cored in Naval Petroleum Reserve No. 1 well 324-19R is established as a reference section for subsurface Pliocene rocks in the Elk Hills oil field

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LITHOLOGIC CHARACTERISTICS OF PLIOCENE ROCKS CORED AT ELK HILLS, KERN COUNTY, CALIFORNIA

By WILLIAM M. BERRYMAN

ABSTRACT

A complete sequence of rocks of Pliocene age cored in Unit Operation Naval Petroleum Reserve No. 1 well 324–19R was examined and described in order to establish a reference section for subsurface Pliocene rocks in the Elk Hills oil field. The lithology and electric-log characteristics of the sequence were compared and many fossils identified.

The Pliocene rocks overlie the Reef Ridge Shale of Miocene age and include, in upward order, the Etchegoin Formation and the San Joaquin Formation. The Etchegoin Formation, 2,622 feet thick, is divisible into two distinct lithologic units of nearly equal thickness. The lower unit, 1,330 feet thick, consists mostly of light-olive-gray to olive-gray silty shale; the upper unit, 1,292 feet thick, consists mostly of interbedded light-olive-gray to greenish-gray sandstone and siltstone. The terms "Tupman Shale Member" and "Carman Sandstone Member" are herein proposed for the lower and upper units, respectively. The overlying San Joaquin Formation, 1,085 feet thick, is composed chiefly of light-olive-gray to greenish-gray shale containing some beds of siltstone and sandstone. It is overlain by the Tulare Formation of Pliocene and Pleistocene age. Fossils indicate that shallow-water marine conditions dominated during Etchegoin deposition, alternating brackish-water and fresh-water conditions during San Joaquin deposition, and fresh-water conditions during Tulare deposition.

INTRODUCTION

The Elk Hills oil field is about 20 miles southwest of the city of Bakersfield in the southern San Joaquin Valley of California (fig. 1). The field, which constitutes a large part of Naval Petroleum Reserve No. 1, extends over most of a large anticline whose surface expression is a line of hills about 17 miles long and 7 miles wide. The hills rise to an altitude of 1,551 feet, or about 1,200 feet above the west edge of the San Joaquin Valley. Wells at Elk Hills have penetrated rocks ranging in age from Pleistocene to Oligocene, including important petroleum reservoirs in rocks of Pliocene and Miocene age. The recoverable oil reserves in these rocks are estimated to exceed 1.3 billion barrels, of which less than 300 million barrels have been produced.

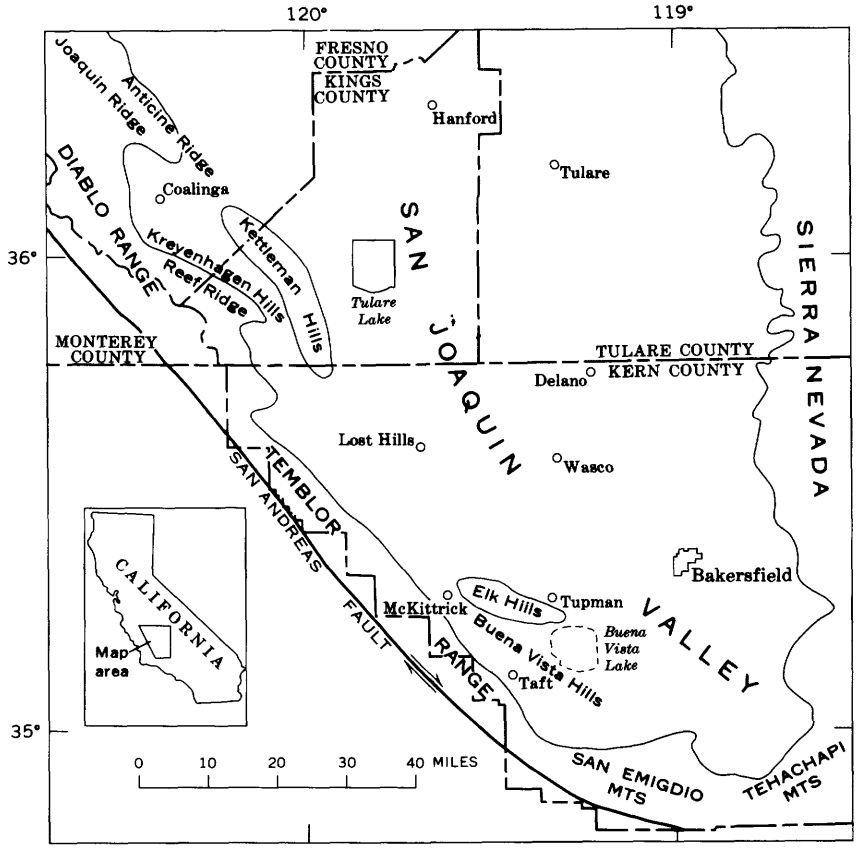


FIGURE 1.—Southern San Joaquin Valley showing location of Elk Hills oil field and other areas discussed in this report.

PURPOSE OF REPORT

The purpose of this report is to establish a reference section for subsurface Pliocene rocks in the Elk Hills oil field for use in a detailed stratigraphic analysis of the field. A reference section is necessary because of difficulties in correlating these rocks between Elk Hills and the Coalinga region, 60 miles to the north, where Pliocene formations present at Elk Hills are defined. The section described here should have value not only in standardizing the nomenclature at Elk Hills but also in relating stratigraphic studies at Elk Hills to stratigraphic work in nearby oil fields in this important oil and gas producing region.

The reference section is established in Unit Operation Naval Petroleum Reserve No. 1 (NPR–1) well 324–19R, in the NW¼ sec. 19, T. 30 S., R. 23 E., in the western part of the Elk Hills oil field (fig. 2). Well 324–19R was cored almost continuously through the San

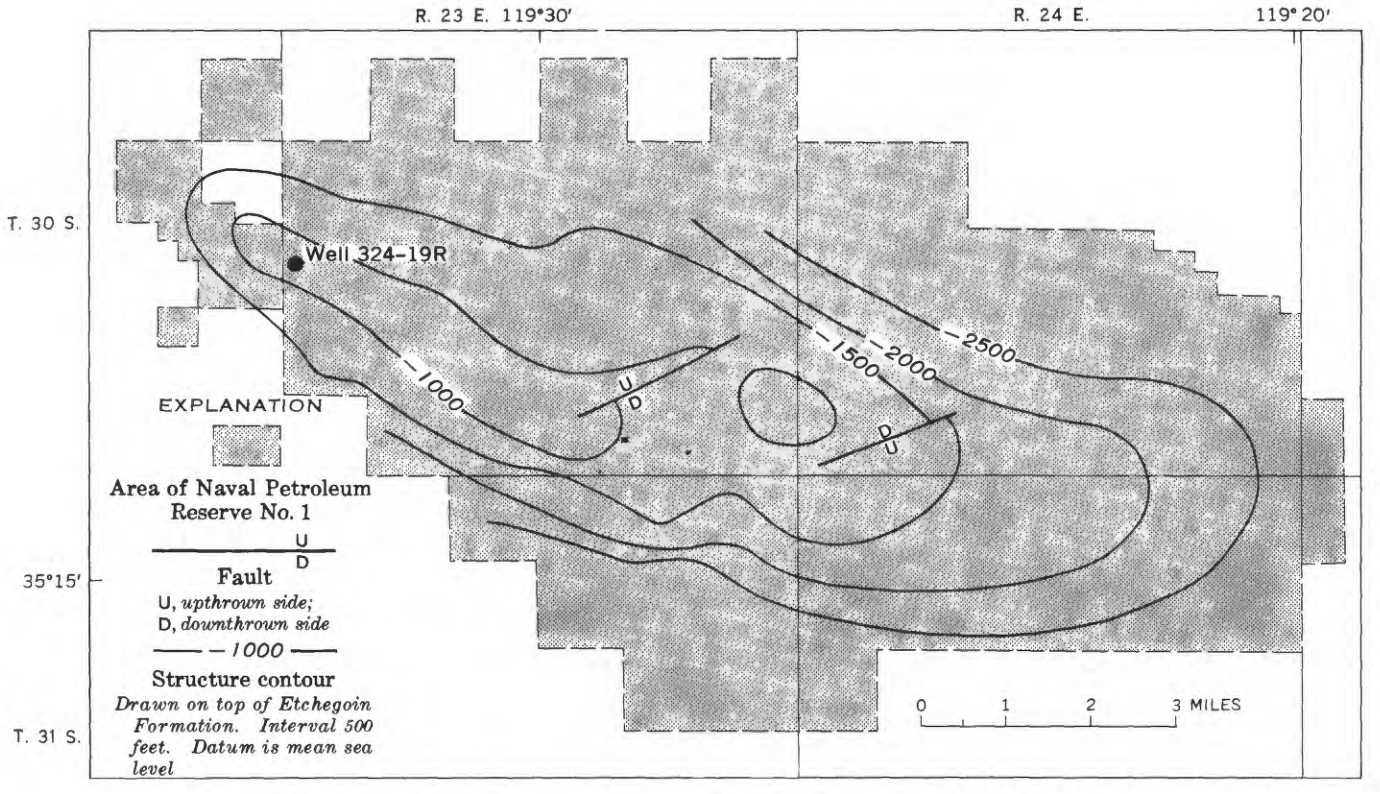


FIGURE 2.—Location of well 324–19R, Elk Hills oil field, Kern County, Calif.

Joaquin and Etchegoin Formations of Pliocene age. The cores, nearly 4,000 feet long, were originally described by Standard Oil Co. of California at the time the well was drilled. The core samples on file at the U.S. Navy office at Elk Hills were reexamined by the writer and are described in detail in this report. Microfossil identifications were made by R. S. Beck and James Burrow. Megafossil identifications are from the Unit Operator.

The detailed study of Pliocene rocks in well 324–19R is part of a geologic investigation of Naval Petroleum Reserve No. 1 conducted by the U.S. Geological Survey at the request of the Director of Naval Petroleum and Oil Shale Reserves, U.S. Navy.

DRILLING SUMMARY

Well 324–19R was started in the Tulare Formation, of Pliocene and Pleistocene age, and drilled with rotary tools to a total depth of 6,469 feet in the Monterey Shale of Miocene age. Drilling began on September 18, 1941 and ceased on January 19, 1942. The altitude of the derrick floor, from which all measurements were made, was 1,215 feet above mean sea level. Nearly continuous cores, about 1½ inches in diameter, were taken from the interval 989 to 4,890 feet. Core recovery was approximately 90 percent. Additional cores were taken between 5,980 and 6,469 feet. Dip measurements (from the Unit Operator) from oriented cores range from 20° to 29° NE in Pliocene beds between 4,398 and 4,683 feet, and from 61° to 75° NE in Miocene beds between 5,990 and 6,467 feet.

Drill-stem tests of the intervals 2,113–2,190 feet, 2,400–2,481 feet, and 5,850–5,987 feet recovered small amounts of gas. Salt water and a trace of oil also were recovered from the second and third intervals, respectively. After a total depth of 6,469 feet was reached and Miocene rocks were found to be nonproductive, the well was plugged back to 2,250 feet and tested through perforations from 2,110 to 2,150 feet and 2,225 to 2,245 feet. The perforations are opposite sandstone beds, known locally as the Bittium sand and the Submulinia sand, present in the upper part of the Etchegoin Formation. The well was reported to have tested 12 million cubic feet of gas a day.

METHODS OF INVESTIGATION

Rock cores from well 324–19R were broken into 3-foot segments and placed in metal trays at the time the well was drilled. During the 28-year period between the completion of the well and the start of this study, some cores were lost and many had weathered to rubble. In order to preserve the samples for future study and to facilitate examination with a binocular microscope, each 3-foot segment of core was put through a jaw-type rock crusher and a representative sample was retained. The crushing, which was done prior to this study, produced

rock fragments slightly larger than average well cuttings. Because of the small size of the rock fragments, accurate description of bedding and other megafeatures was not possible in this study.

The crushed core samples were examined under a binocular microscope with concurrent reference to the electric log, following the procedure described by Maher (1959). The lithology was plotted on a log strip, using colored pencils to designate different rock types. Symbols were used to indicate details of lithology, and detailed descriptions of the rocks were lettered along the right side of the log at the corresponding depth. A vertical scale of 1 inch=100 feet was used; this scale permits the illustration of beds 1–2 feet in thickness. Conversion to a single-color lithologic log (pl. 1) required some generalization of lithology and exaggeration of the thickness of some beds. Thin carbonate beds less than 3 feet thick, for example, could not be illustrated without exaggeration. At some places a single 3-foot bed is shown to represent several closely spaced beds of similar lithology, each only a few inches thick. Stratigraphic thicknesses shown on plate 1 and those indicated in "Stratigraphic Section of Well 324–19R" are drilled (apparent) thicknesses that have not been corrected for measured dips that range from 0° to 29°.

A magnification of $\times$ 7 was used to examine mass lithologic character, and magnifications of $\times$ 10 and $\times$ 40 were used for detail and minute features. Rock color was determined by comparing core samples with the Rock Color Chart of Goddard and others (1948). The grain-size terminology is in accordance with the Wentworth grade scale. Clastic rocks composed mostly of clay-size particles and minor amounts of silt are termed "shale," regardless of bedding characteristics. The term "siltstone" is used for clastic rocks composed of more than 50 percent silt. Rocks composed of more than 50 percent sand are termed "sandstone," regardless of mineral composition. Carbonate rocks were tentatively identified as limestone or dolomite. Limestone was distinguished from dolomite by the speed of reaction in hydrochloric acid 6 *N* at room temperature; limestone effervesces immediately, whereas dolomite exhibits no immediate reaction. The term "dense" is used to describe carbonate rocks composed of particles too small to be seen under $\times$ 7 magnification.

R. S. Beck and James Burrow, micropaleontologists in Bakersfield, Calif., studied the microfauna from 224 core samples that represented the entire sequence of Pliocene rocks. Most were 10- to 30-foot composite samples made up of small quantities of rock taken from 3-foot segments of crushed cores; other samples represented a single 3-foot segment.

ACKNOWLEDGMENTS

Stratigraphic correlations of Pliocene rocks, including tentative identification of informal oil-field sand zones, are adapted from work

done for the U.S. Navy by J. C. Maher, R. J. Lantz, and R. D. Carter of the U.S. Geological Survey. All megafossil identifications, except for a few listed in "Stratigraphic Section of Well 324–19R," are from the well files of the Unit Operator, the Standard Oil Co. of California. Core descriptions made by the Company are used for intervals for which cores were not available. Core-analysis data determined by Core Laboratories, Inc., are from the well files of the Unit Operator.

STRATIGRAPHY

Rocks of Pliocene age crop out in the foothill and mountain areas along the west and southwest sides of the southern San Joaquin Valley. The rocks consist mostly of sandstones and shales that change greatly in thickness, lithologic composition, and faunal content from one locality to another. The best exposures are in the vicinity of Coalinga, about 75 miles northwest of Elk Hills; the rocks there have been described in numerous published reports including, but not restricted to, those by F. M. Anderson (1905, 1908), Arnold and Anderson (1908, 1910), Anderson and Pack (1915), Nomland (1917), English (1921), Reed (1933), Gester and Galloway (1933), Barbat and Galloway (1934), Woodring, Stewart, and Richards (1940), Adegoke (1969), and Dibblee (1972). From the Diablo and Temblor Ranges the Pliocene rocks dip eastward beneath Pleistocene and younger rocks that fill the San Joaquin Valley; they reappear as predominantly continental facies along the west flanks of the Sierra Nevada Mountains.

Several differing stratigraphic classifications have been proposed for the Pliocene rocks along the west side of the southern San Joaquin Valley. The differences in these classifications result from the difficulties in correlating rocks in which lithologic marker beds are absent and rapid changes in facies occur. Some of these classifications, based on exposures and subsurface sections near Coalinga, are compared with those used at Elk Hills and vicinity in figure 3. The Pliocene rocks along the west side of the San Joaquin Valley are generally divided, in upward order, into the Etchegoin Formation and the San Joaquin Formation. In many areas the Pliocene rocks overlie the Reef Ridge Shale of Miocene age and are overlain by the Tulare Formation of Pliocene and Pleistocene age. In the Kreyenhagen Hills, Arnold and Anderson (1908, p. 40) applied the name Jacalitos Formation to a thick sandstone sequence underlying the Etchegoin Formation as defined by them. Most later geologists, however, include the Jacalitos with the Etchegoin Formation because of lithologic and faunal similarities, and several geologists have abandoned the term Jacalitos (Nomland, 1917, p. 195–196; Adegoke, 1969, p. 27), a usage herein followed.

	Coalinga region								Elk Hills region					
Report	Anderson (1905, 1908)	Arnold and Anderson (1908, 1910)	Nomland (1917)	Reed (1933)	Gester and Galloway (1933), Barhat and Galloway (1934)	Goudkoff (1934)	Woodring, Stewart, and Richards (1940)	Adegoke (1969)	*Arnold and* Johnson (1910)	Pack (1920)	Woodring, Roundy, and Farnsworth (1932)	Woodward (1945)	Dibblee (1972)	*This report*
Area	Coalinga area	Coalinga area	Coalinga area	Kreyenhagen Hills	Kettleman Hills, Reef Ridge	Kettleman Hills	Kettleman Hills	Reef Ridge	McKittrick, Elk Hills	McKittrick	Elk Hills	Midway-Sunset	Temblor Range	Elk Hills
NOMENCLATURE	Tulare Formation	Tulare Formation[1]	Tulare Formation	Tulare Formation	Tulare Formation	Tulare Formation	Tulare Formation	Tulare Formation		Paso Robles Formation	Tulare Formation	Tulare Formation	Tulare Formation	Tulare Formation
	Etchegoin Beds: San Joaquin Clays	Etchegoin Formation	Etchegoin Group: Upper Etchegoin	Etchegoin Group: San Joaquin Clay	San Joaquin Clay	San Joaquin Clay	San Joaquin Formation	San Joaquin Formation				San Joaquin Formation	San Joaquin Formation (absent)	San Joaquin Formation
	Etchegoin Beds: Etchegoin Sands			Jacalitos Formation	Etchagoin Sand	Etchegoin Formation	Etchegoin and Jacalitos Formations, undifferentiated	Etchegoin Formation	McKittrick Formation	Etchegoin Formation	Etchegoin Formation	Etchegoin Formation	Etchegoin Formation	Carman Sandstone Member; Tupman Shale Member; Etchegoin Formation
		Jacalitos Formation	Etchegoin Group: Lower Etchegoin	Reef Ridge Formation		Jacalitos Formation								
	Coalinga Beds	Santa Margarita Formation	Santa Margarita Formation	Santa Margarita Formation	Reef Ridge Shale	McLure Shale	Reef Ridge Shale	Reef Ridge Shale	Santa Margarita(?) Formation	Maricopa Shale	Maricopa Shale	Monterey Shale	Reef Ridge Shale	Reef Ridge Shale

[1]Mapped as Paso Robles Formation in 1908 report.

FIGURE 3.—Stratigraphic classifications of upper Miocene, Pliocene, and Pleistocene rocks along the west side of the southern San Joaquin Valley, Calif.

The Tulare Formation of Pliocene and Pleistocene age is the only formation exposed at Elk Hills, but rocks as old as Oligocene have been penetrated by wells. Two formations, the Etchegoin and the San Joaquin, make up the Pliocene Series and have a total thickness of 3,707 feet in well 324–19R. The Pliocene rocks overlie the Reef Ridge Shale of Miocene age and may be conformable with it in this well.

The Jacalitos Formation, recognized by some geologists in the Kreyenhagen Hills and vicinity, has not been identified at Elk Hills. If rocks equivalent to the Jacalitos are present, they are included in the lower part of the Etchegoin Formation in this report.

The Pliocene sequence cored in well 324–19R is used as a reference section for the Elk Hills oil field; its stratigraphic units are discussed in ascending order in the immediately following pages. Detailed lithologic descriptions of the cores from the land surface downward follow the general discussion.

MIOCENE SERIES, REEF RIDGE SHALE

The term "Reef Ridge Shale" was proposed by Barbat and Johnson (1933; 1934, p. 3–6) for a "soft, blue (brown weathering) clay shale with minor beds of sandy shale" that is typically exposed along the northeast side of Reef Ridge, about 10 miles south of Coalinga. The formation has since been recognized in the subsurface and at other outcrop areas along the west side of the San Joaquin Valley. According to Barbat and Johnson (1934, p. 7), the Reef Ridge Shale forms a conspicuous unit of caving blue shale in wells at Kettleman Hills and is late Miocene in age. Goudkoff (1934, p. 438–439) considered the upper part of the caving blue shale to be closely related to the overlying Jacalitos Formation of Pliocene age on the basis of microfossils; he abandoned the term "Reef Ridge Shale" and assigned the upper part to the Jacalitos and the lower part to the McLure Shale of Miocene age. Siegfus (1939, p. 24) revived the term "Reef Ridge" and restricted it to a sequence of rocks exposed along Reef Ridge that corresponds to the caving blue shale of Kettleman Hills. The type Reef Ridge Shale is considered late Miocene in age on the basis of its Foraminifera (Kleinpell, 1938, p. 165).

Only the upper 173 feet of the Reef Ridge Shale at Elk Hills was cored in well 324–19R, but the cores were lost prior to this study. The drilled thickness of the Reef Ridge Shale in well 324–19R is 633 feet. Core descriptions made at the time the well was drilled indicate that the upper part of the Reef Ridge Shale consists of hard brownish-gray to grayish-brown claystone with scattered limy streaks and beds of tan limestone, 1–3 inches thick. Laminae of fine-grained sandstone and silty gray claystone are present in some parts. The claystone, termed "shale" in this report, appeared slightly banded in part and is reported to exhibit a "diatomite" fracture. Fossils are sparse in the

cores but included fish remains, pyritized diatoms, diatom molds, plant fragments, crustacean fragments, and Foraminifera identified as *Buliminella elegantissima.* A pelecypod cast was found near the top of the formation. Apparent dips ranging from 21° to 30° were recorded from the cores. Measurements from a single oriented core taken at 4,725 feet indicated a dip of 22° NE. and strike of N. 46° W.

The relation of the Reef Ridge Shale to the overlying Etchegoin Formation is not clearly understood. According to Barbat and Johnson (1934, p. 7), the Etchegoin rests with "distinct unconformity upon the Reef Ridge shale along the northeast side of Reef Ridge." Siegfus (1939, p. 31), however, reports that the upper contact of the Reef Ridge Shale is gradational with the Jacalitos [Etchegoin] at most places along Reef Ridge. Mapping along Reef Ridge by Adegoke (1969, p. 21) led him to conclude that the upper part of the Reef Ridge Shale grades almost imperceptibly into the overlying Etchegoin.

The upper contact of the Reef Ridge Shale at Elk Hills is difficult to determine except at the west end of the field where the shale is overlain directly by a thick sequence of sandstone, known locally as the Olig sand. In well sections where the Olig is missing, the top of the Reef Ridge Shale is determined by electric-log correlations with wells where the Olig is present. This procedure, supported by lithologic and paleontologic data when available, has been useful for subsurface mapping at Elk Hills. In well 324–19R, the upper contact closely coincides with an upward change in the dominant color from brownish gray to olive gray.

PLIOCENE SERIES

ETCHEGOIN FORMATION

The term "Etchegoin Beds" was first applied by F. M. Anderson (1905, p. 178–181) to a thick sequence of dominantly marine sands, gravels, and clays, that is typically exposed in the vicinity of the old Etchegoin ranch, about 20 miles northeast of Coalinga. The sequence was divided into the "Etchegoin Sands", composed chiefly of bluish-gray sands, and the overlying "San Joaquin Clays" (fig. 3), but no type section was designated. The Etchegoin Beds were reported to overlie a thick sequence composed mostly of sandstone, which F. M. Anderson (1905, p. 174) termed the "Coalinga Beds", and to underlie the fresh-water Tulare Formation. Arnold and Anderson (1908, p. 46–47; 1910, p. 113–117) later applied the term "Etchegoin Formation" to the upper part of Anderson's (1905) Etchegoin Beds (fig. 3) and suggested that a section on Anticline Ridge, 9 miles north of Coalinga (fig. 1), be taken as the type section. As thus defined, the formation included the rocks above the base of the *Glycymeris* zone, a hill-forming sandstone containing a distinctive fossil assemblage

and below the base of the Tulare Formation. Rocks below the Etchegoin Formation and above the Miocene siliceous shales were termed the "Jacalitos Formation" by Arnold and Anderson (1908, p. 40–46). Nomland (1917, p. 195–197) raised the Etchegoin to group rank and divided it into the upper and lower Etchegoin, which he considered equivalent to the Etchegoin and Jacalitos Formations, respectively, of Arnold and Anderson (1908). According to Nomland (1917, p. 197), the term "Jacalitos" should be abandoned because a division between the Jacalitos and Etchegoin on faunal and lithologic grounds is unmerited. Reed (1933, p. 235–236) also used the term "Etchegoin Group," but unlike Nomland he divided it into the Reef Ridge Formation, the Jacalitos Formation, and the San Joaquin Clay (in ascending order).

At Kettleman Hills, Gester and Galloway (1933, p. 1169, 1172) and Barbat and Galloway (1934, p. 477) reverted in part to the original terminology of F. M. Anderson, and they separated the stratigraphic section between the Reef Ridge Shale and the Tulare Formation into the Etchegoin Sand, which included the Jacalitos, and the San Joaquin Clay (fig. 3). Goudkoff (1934, p. 438–443) retained the Etchegoin and Jacalitos Formations in the subsurface at Kettleman Hills on the basis of lithology and foraminiferal assemblages. In a later study of Kettleman Hills, Woodring, Stewart, and Richards (1940, p. 114–117) stated that "There is no economic incentive to distinguish these two formations [Etchegoin and Jacalitos]—if, indeed, their differentiation is practicable in subsurface work." More recently, Adegoke (1969, p. 26–27) mapped these rocks in the vicinity of Coalinga and noted that "No consistent lithologic basis for separating the Jacalitos Formation from the Etchegoin could be found ***." He concluded that the name, "Jacalitos Formation," should be abandoned.

The name "McKittrick Formation" was applied by Arnold and Johnson (1910, p. 74–90) to a sequence of sands, gravels, and clays exposed along the flanks of the Temblor Range and in the adjacent Elk Hills and Buena Vista Hills. The McKittrick included beds of Miocene, Pliocene, and Pleistocene age that had been correlated, in part, with the Jacalitos, Etchegoin, and Tulare Formations of the Coalinga area. According to Arnold and Johnson (1910, p. 75), differentiation of those formations was not practical at that time. A few years later Gester (1917) divided the McKittrick Formation in the vicinity of McKittrick into the Etchegoin and Tulare Formations on the basis of megafossils. In the Sunset-Midway region, including the McKittrick area, the term "McKittrick Group" as used by Pack (1920, p. 43–51) included the Etchegoin and Paso Robles (Tulare) Formations. Pack (1920, p. 43–47) reported that the Etchegoin For-

mation rests unconformably on rocks he called Maricopa Shale in the Temblor Range just west of Elk Hills.

In 1932, Woodring, Roundy, and Farnsworth (1932, p. 31) used the name "Etchegoin Formation" for strata lying between the Maricopa Shale and Tulare Formation in the subsurface at Elk Hills. The San Joaquin Formation was later differentiated from the Etchegoin and was first mentioned by Wells (1951, p. 2634), although it was probably recognized and used informally by oilfield geologists following the work of Barbat and Galloway (1934) at Kettleman Hills. In the Buena Vista Hills, about 2 miles south of Elk Hills, McMasters (1943) recognized the Etchegoin and San Joaquin Formations and defined the top of the Etchegoin as "the first [youngest] occurrence of *Mulinia densata* Conrad***."

The age of the Etchegoin Formation was first determined as Pliocene by F. M. Anderson (1905, p. 180, 184); Arnold (1909, p. 45) considered the formation as latest Miocene by applying Lyell's method of age classification. According to Merriam (1915, p. 41) the "invertebrate faunas, interpreted in terms of the Lyellian percentage method***suggests Pliocene age" for the Etchegoin Formation. Merriam (1915, p. 33) also cites vertebrate faunas from the Etchegoin just north of Coalinga as evidence for a Pliocene age but notes that these faunas "were not found in place, but appeared on exposures which seemed to consist solely of Etchegoin material." According to Woodring, Stewart, and Richards (1940, p. 103), "The assignment of the Jacalitos, Etchegoin, and San Joaquin formations to the Pliocene is now generally accepted." Adegoke (1969, p. 44–48) summarizes faunal evidence for assigning the Etchegoin Formation of the Coalinga area to the Pliocene. The Etchegoin Formation at Elk Hills is considered Pliocene in age on the basis of its stratigraphic position and faunal content.

The Etchegoin Formation in well 324–19R at Elk Hills, which is 2,622 feet thick, is divisible into two distinct lithologic units of nearly equal thickness. The lower unit consists mainly of shale, the upper unit mainly of interbedded sandstone and siltstone. Electric-log correlation studies by J. C. Maher, R. J. Lantz, and R. D. Carter indicate that these rock units maintain their lithologic character and identity over most of the Elk Hills field, but their extent outside the field is unknown. They are here named and designated as members within the Etchegoin Formation at Elk Hills. The terms "Tupman Shale Member" and "Carman Sandstone Member" are proposed for the lower and upper units, respectively. Both terms were originally used informally in unpublished reports by J. C. Maher, R. J. Lantz, and R. D. Carter. The name "Tupman" is derived from the community of Tupman (fig. 1), which lies at the east end of Elk Hills within the

boundary of Naval Petroleum Reserve No. 1. The name "Carman" is derived from the old Hay-Carman lease in sec. 36, T. 30 S., R. 23 E., where the discovery well of the Elk Hills oil field was drilled in 1919 by the Standard Oil Co. (California). Well 324–19R is designated the type section for these two new members.

The Olig sand, which marks the base of the Etchegoin Formation in the southwestern part of the Elk Hills oil field, is not present in well 324–19R. The sandstone is more than 700 feet thick in the Asphalto oil field, about 1½ miles southwest of well 324–19R, but thins rapidly in a northeasterly direction and is absent in most wells at Elk Hills. In the McKittrick area, Zulberti (1956, p. 52) considers the Olig sand as conformable with and part of the Reef Ridge Shale; he considers the top of the sandstone to be an erosional surface, progressively overlain in a westerly direction by the Etchegoin and San Joaquin Formations. Foss and Blaisdell (1968, p. 37) also include the Olig in the Reef Ridge Shale and report that the sandstone becomes increasingly coarse toward the top. These views, however, are inconsistent with lithologic data at Elk Hills. According to W. L. Adkison (oral commun., 1970), cuttings from well 526–30R, about 1 mile south of well 324–19R, indicate that the Olig becomes coarser toward the bottom. In addition, other wells have shown beds of conglomerate near the base of the sandstone. Because of the downward increase in grain size, the Olig sand is included in the Etchegoin Formation in this report.

TUPMAN SHALE MEMBER

The Tupman Shale Member is 1,330 feet thick in well 324–19R and is present between the depths of 4,717 and 3,387 feet. These strata have also been informally termed the "Buliminella silt" by oil-company geologists because of the general abundance of the foraminifer *Buliminella elegantissima.* In many wells in the western part of Elk Hills, the lower or basal part of the Tupman also includes thick beds of sandstone which are informally named the "Olig sand," and in these wells the member is divided into the Olig sand zone and the overlying Buliminella silt zone (Adkison, 1973). In well 324–19R, however, the Olig sand zone is not recognizable, so the term "Buliminella silt zone" is applied to all the Tupman Shale Member. The member in this well consists mainly of silty shale which is divided informally into two parts that differ slightly in color, mineralogy, and degree of induration.

The lower part of the Tupman Shale Member, 517 feet thick, consists mostly of slightly siliceous olive-gray silty shale. Most of the silty component, except for scattered laminae of siltstone, is dispersed in the shale as mainly angular grains of detrital quartz, but the remains of diatoms and other siliceous organisms may be present in

amounts of several percent. Laminae of very fine grained sandstone are present in some parts of the shale. The shale is generally tough to brittle and does not swell or break down when wet as does much of the shale in the overlying strata. The amount of silica cement in the shale is small, but it is noticeably greater in the lower 200 feet, where Foraminifera have been completely replaced by silica. Thin beds of microcrystalline carbonate rocks, generally 1–3 inches thick, are common in the shale. These beds are shades of olive gray or yellowish gray and contain appreciable amounts (unmeasured) of silt and clay. The carbonate rocks were tentatively identified as dolomite, but samples from some of the beds were determined by X-ray analysis to be siderite (K. J. Murata, written commun., 1968).

Cores from the lower 49 feet of the Tupman, which includes beds equivalent to the Olig sand, were lost prior to this study. They had been described as gray to brownish-gray shale with scattered streaks of hard tan limestone. The lowermost core, 9 feet long, reportedly contained spots of redeposited silica(?) and a few scattered well-rounded gray quartz pebbles as much as half an inch in diameter that are isolated in a shale matrix. The base of this pebbly shale interval is easily correlated by electric logs with the base of the Olig sand in nearby wells, and it is considered to mark the base of the Etchegoin Formation in well 324–19R.

The upper part of the Tupman Shale Member, 813 feet thick, consists mostly of light-olive-gray silty shale with scattered laminae and thin beds of sandstone and siltstone. This part of the Tupman is characterized by relatively abundant phosphate pellets, most commonly found in laminae or thin beds of clayey, generally limy sandstone and siltstone, especially in the lower 250 feet; phosphate pellets also occur disseminated in some shale beds. The pellets range in size from coarse silt to coarse sand and generally appear as well-rounded pale-brown translucent grains or black opaque grains. These pellets are known locally as "sporbo," an acronym for "smooth-polished-round-black (blue or brown)-objects," which Galliher (1931) described as an impure form of collophane. In addition to sporbo, phosphate occurs in the form of small rounded dull microcrystalline dark-brown limy pebbles and black to amber-colored fish remains. Some phosphate pebbles show a black mineral coating that may be manganese. Thin beds of dense light-olive-gray dolomite or siderite(?) are scattered throughout the upper part but are most abundant in the lower 250 feet.

The Tupman Shale Member includes, near the middle, three sandstone beds between depths of 4,062 and 4,017 feet. These beds are readily identified on electric logs and are traced over most of the western part of the Elk Hills oil field. The top of the uppermost sand-

stone as shown on electric logs is locally termed the "O horizon" (pl. 1). The sandstones, 3–14 feet thick, are composed of as much as 40 percent fine-grained sporbc and up to 50 percent limy silt and clay. The other constituent grains consist of clear angular very fine quartz and some feldspar; phosphatic fish remains are present in parts of the sandstones. Nearby wells have penetrated three similar sandstone beds at equivalent stratigraphic positions; thus, these beds may be useful as local lithologic marker beds, as well as electric-log markers. Another sandstone bed is indicated on the electric log between 3,810 and 3,792 feet, but only 1 foot of partly oil stained sandy shale was recovered from this interval. Porosities of the sandstones near the middle of the member range from 23.7 to 32.4 percent; permeabilities, which are relatively low, range from 0.0 to 68 millidarcys (table 1). Chloride content of the pore water ranges from 4,250 to 5,550 ppm; residual oil saturation is as much as 6.0 percent.

The upper 200 feet of the Tupman Shale Member includes several sandy siltstone beds as much as 16 feet thick. The siltstones are slightly lighter in color than the shale, and some contain a few thin beds or laminae of very fine to very coarse grained sandstone. Thin beds of carbonate rocks are present near the base of the siltstone beds.

Microfossils, mainly benthonic Foraminifera, are common to abundant in parts of the Tupman Shale Member, but they are generally poorly preserved. Most Foraminifera appear leached and iron stained;

TABLE 1.—*Core-analysis data from NPR–1 Unit well 324–19R, Elk Hills, Kern County, Calif.*

[Calculations made by Core Laboratories, Inc.]

Formation	Sand or silt zone	Key No. (See pl. 1)	Sample depth, in ft	Porosity (percent)	Permeability (millidarcys)	Pore-water chloride content (ppm)	Residual oil saturation (percent pore space)
Tulare Formation		1	993–1,005	33.5–39.8	1,410–8,150	2,820	0.0
San Joaquin Formation	Mya Sand zone	2	1,021	35.9	324	.....	0.0
		3	1,049	38.1	4.420	.....	0.0
		4	1,060–64	27.8	249–6,810	5,650	0.0
		5	1,099	35.3	64	.....	0.0
		6	1,351	45.4	33	.....	0.0
		7	1,668	38.5	2,970	.....	0.0
	Scalez Sand zone	8	2,074	44.3	124	.....	0.0
Etchegoin Formation	Mulinia Sand zone	9	2,140–44	41.9–45.9	322–826	.....	0.0
		10	2,236	34.5	140	.....	4.1
Carman Sandstone Member	Wilhelm Sand zone	11	2,281	37	35	.....	1.1
		12	2,300	33.6	15	.....	3.3
		13	2,362	36.6	52	.....	1.9
		14	2,444–51	34.0–36.7	74–836	3,660	1.7–5.1
		15	2,523–36	29.1–32.1	80–88	.....	0.0
	Gusher Sand zone	16	2,584	31.6	7.6	.....	0.0
		17	2,592–2,609	26.8–36.8	3.2–172	5,650–5,870	0.0–1.4
		18	2,887–98	31.9–35.7	0.0–112	2,500	0.0
	Calitroleum Sand zone	19	3,246–54	31.5–35.3	17–41	.....	0.0–6.5
		20	3,365–72	29.1–32.5	10–25	5,570	7.2–11.0
		21	3,386	30.5	0.0	.....	9.5
Tupman Shale Member	Buliminella Silt zone	22	4,018–43	23.7–32.4	0.0–68	4,250–5,550	0.0–6.0

according to R. S. Beck (oral commun., 1970), this is typical of specimens found in early Pliocene rocks at Elk Hills and vicinity; some specimens in the lower part of the Tupman are silicified. The stratigraphic distribution of the Foraminifera and other microfossils identified in well 324–19R is shown in figure 4. The most abundant species of Foraminifera is *Buliminella elegantissima;* hence the name "Buliminella silt zone". Next in abundance is *Eponides exigua.* Both species range throughout the Etchegoin Formation in well 324–19R and probably extend downward into rocks of Miocene age. These species, in the absence of deeper water Foraminifera, are generally indicative of a neritic or shelf environment. Less common species include *Haplophragmoides* sp. and *Cassidella* (formerly *Virgulina*) cf. *C. subplana.* Other microfossils occur sparsely in most parts of the Tupman Shale Member; they include sponge spicules, radiolarians, diatoms, fish remains, and ostracodes.

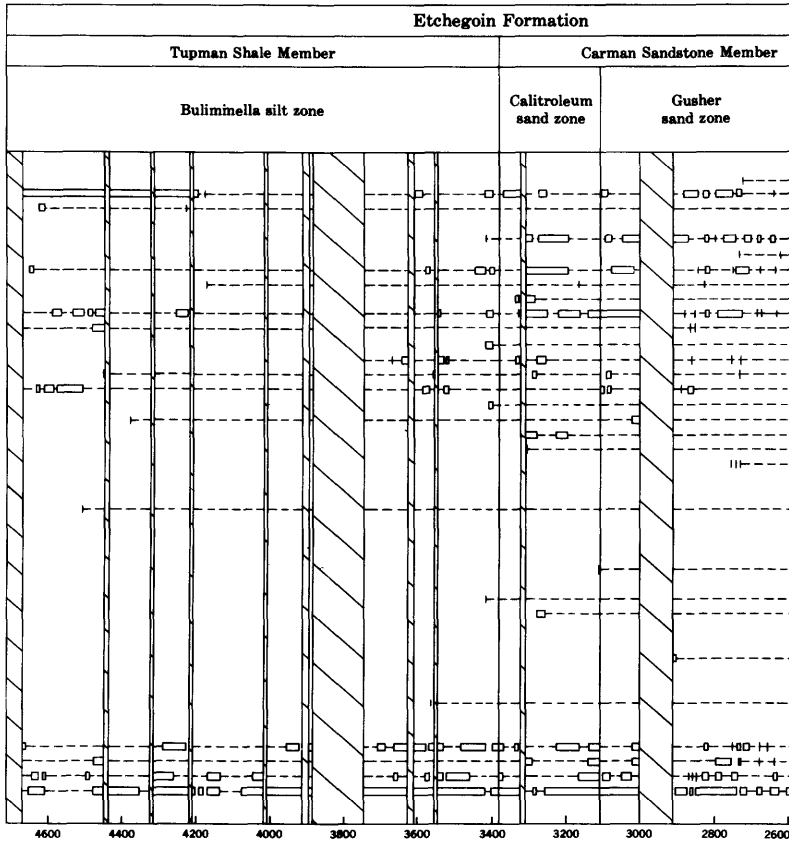
Cores taken between 4,170 and 3,675 feet, near the middle of the member, contain very few Foraminifera. Phosphate pellets (sporbo) are most abundant in this interval, which may indicate that conditions suitable for the formation of phosphate may be unsuitable for the growth of benthonic Foraminifera. Sponge spicules, diatoms, radiolarians, and fish remains are present in this part of the Tupman Shale Member.

Megafossils are conspicuously rare in the Tupman Shale Member. Fragments of unidentified mollusks were found in several cores by R. S. Beck; a few pelecypod fragments and pelecypod molds were observed by the author. In the original core description, crab claws and molds of *Yoldia* and *Macoma* were reported near the base of the shale, and casts of *Macoma* and *Arca* were reported near the middle; *Pecten terminus* was reported near the top. The stratigraphic distribution of the megafossils in well 324–19R is shown in table 2 and also on plate 1. The presence of casts and molds of pelecypods in the Tupman Shale Member suggests that leaching may be responsible for the paucity of megafossils and foraminifers in this part of the Etchegoin Formation.

The contact between the Tupman Shale Member and the overlying Carman Sandstone Member lies at a depth of 3,387 feet in well 324–19R. This horizon marks an upward lithologic change in the Etchegoin Formation from predominantly shale to predominantly siltstone and interbedded sandstone. It also marks an abrupt upward change in strata mainly devoid of megafossils to strata rich in megafossils.

CARMAN SANDSTONE MEMBER

The Carman Sandstone Member, 1,292 feet thick in well 324–19R, forms a conspicuous lithologic unit between the depths of 3,387 and 2,095 feet. The member is composed chiefly of interbedded siltstone



[1]Identified as *Virgulina* cf. *V. subplana* by R. S. Beck
[2]Identified as *Elphidium hannai* by R. S. Beck
[3]Identified as *Elphidium* cf. *E. hannai* by R. S. Beck
[4]Identified as *Nonion* cf. *N. belridgensis* by R. S. Beck
[5]Identified as *Nonionella cushmani* by R. S. Beck
[6]Identified as *Nonionella* cf. *N. cushmani* by R. S. Beck
[7]Identified as *Pulvinulinella gyroidinaformis* by R. S. Beck
[8]Identified as *Virgulina californiensis grandis* by R. S. Beck

and sandstone; some sandstone beds, especially those near the top, are important petroleum reservoirs in the Elk Hills oil field.

The Carman Sandstone Member is divided into four informally named sand zones, in upward order, the Calitroleum, Gusher, Wilhelm, and Mulinia sand zones. Names for the lower three zones are adapted from nomenclature used in engineering reports of very limited distribution by the Elk Hills Engineering Committee. The origin of the terms is uncertain, although they were probably derived many years ago from the Sunset-Midway oil field, about 10 miles south of Elk Hills. As early as 1932, the name "Calitroleum oil sand"

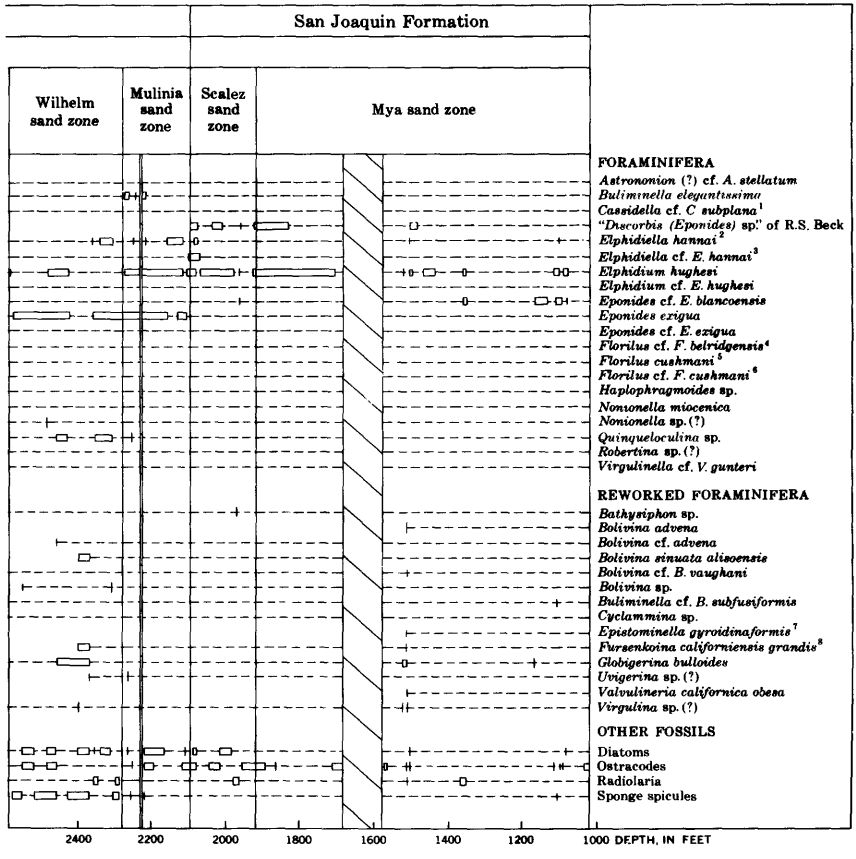


FIGURE 4.—Stratigraphic distribution of microfossils in Pliocene rocks cored in well 324–19R, Elk Hills oil field, Kern County, Calif.

was used in the Midway oil field (Woodring and others, 1932, p. 48, fig. 4). In a report on the southeastern part of the Sunset-Midway area, Woodward (1945) noted that the names Calitroleum, Gusher, and Wilhelm were applied to beds of sandstone in the Etchegoin Formation. The sequence of rocks above the Wilhelm sand zone and below the top of the Etchegoin Formation at Elk Hills is called the Mulinia sand zone in this report. In some parts of the Elk Hills oil field, the Mulinia sand zone includes, in upward order, the Bittium, Submulinia, and Mulinia sands of the Elk Hills Engineering Committee, but of these three only two, the Bittium and Submulinia sands, are present in well 324–19R (pl. 1). The four sand zones that make up the Carman Sandstone Member are shown on plate 1 and are described below.

TABLE 2.—*Stratigraphic distribution of megafossils in Pliocene rocks cored in well 324–19R, Elk Hills oil field, Kern County, Calif.*

[From files of Unit Operator]

Megafossils	Etchegoin Formation					San Joaquin Formation	
	Tupman Shale Member	Carman Sandstone Member					
	Buliminella Silt Zone	Calitroleum Sand Zone	Gusher Sand Zone	Wilhelm Sand Zone	Mulinia Sand Zone	Scalez Sand Zone	Mya Sand Zone
Barnacles:							
Balanus sp		×					
Gastropods:							
Amnicola sp						×	
Bittium sp					×		
Brannerillus (?) sp			×				
Calipyrgula sp							×
Calliostoma sp				×			
Calyptraea sp					×		
Forreria sp		?	×				
Fluminicola sp					×		×
Goniobasis (?) sp			×				
Mitrella sp		×			×		
Nassarius sp		×	×	×	×	×	
Natica sp		×	×	×	?		
Odostomia sp		×					
Physa sp							×
Planorbis sp							×
Polinices sp		×	×				
Scalez petrolla						×	
Turris sp		?	×				
Turritella sp		×					
Valvata humerosa							×
Pelecypods:							
Anodonta sp						×	×
Arca trilineata	×		×	×			
Cryptomya sp		×	×		×	×	
Macoma affinis							×
Macoma sp	×		?	?	×	?	
Mactra (?) sp			×				
Mya intermedia							×
Mya sp					×	×	×
Mytilus sp		×	×			×	
Ostrea lurida							×
Ostrea sp			×		?		
Pandora (?) sp					×		
Pecten oweni		×	×	×			
Pecten terminus	×	×					
Psephidia sp			×	×	×	×	
Pseudocardium [*Mulinia*]					×		
Siliqua sp			×	×	×		
Solen sp		?		×			
Sphaerium sp							×
Tellina (?) sp			×				
Tivela (?) sp			×				
Transenella sp			×				×
Vitrinnella sp				×			
Volsella sp		×	×	×	×		
Yoldia sp	×						
Zirfaca sp			×				

CALITROLEUM SAND ZONE

The Calitroleum sand zone, 273 feet thick, is present between the depths of 3,387 feet and 3,114 feet in well 324–19R. The lower one-third consists mostly of interbedded light-olive-gray silty shale and sandy siltstone. Two siltstone beds, each about 10 feet thick, are present near the base of the zone and are readily identified on the electric log (pl. 1). These beds are composed chiefly of well-sorted coarse silt with scattered laminae of very fine grained sandstone; the upper bed grades downward into a 2-foot thick bed of very fine grained sandstone. A few coarse angular grains of quartz and very coarse subangular grains of gray feldspar are scattered in the siltstone. Sporbo (phosphate pellets) generally compose about 1 percent of the siltstone, but may compose as much as 25 percent of some laminae or stringers. Analyses of cores near the base of the zone show that the porosity of the siltstone ranges from 29.1 to 32.5 percent, and the permeability ranges from 0 to 25 millidarcys (table 1). The residual oil saturation is as much as 11 percent. The chloride content of pore water in one siltstone bed near the base is 5,570 ppm (parts per million). Another siltstone bed is indicated on the electric log between 3,330 and 3,320 feet, but cores were not recovered from this interval. Silty shale with scattered laminae or thin beds of carbonate rocks makes up the remainder of the lower part. Some shale shows disturbed bedding and contains silt-filled borings, questionably identified as worm tubes. Pelecypod fragments, mostly leached, are abundant in some of the shale.

The upper two-thirds of the Calitroleum sand zone consists predominantly of light-olive-gray siltstone with abundant irregular laminae of very fine grained silty sandstone. Most of the siltstone is friable, except for a few thin carbonate-cemented beds. The siltstone generally contains finely disseminated biotite, appreciable amounts of clay, and scattered shale laminae. Fractures filled with calcite were found in one bed near the base of the siltstone. A sandstone bed, about 11 feet thick, is present near the middle of the siltstone interval. The sandstone is light olive gray, very fine grained, friable, silty, and clayey; the lower half is interbedded with siltstone and shale; the upper half is oil stained and contains abundant pelecypod and gastropod fragments. A similar sandstone bed lies about 10 feet below this bed but only a small part of the core was recovered. Siltstone near the middle of the Calitroleum has a porosity of 31.5–35.3 percent and a maximum permeability of only 41 millidarcys (table 1).

Megafossils, mainly marine gastropods and pelecypods, are relatively abundant in the Calitroleum sand zone, in marked contrast to the underlying strata. Eight genera of gastropods and six genera of pelecypods were identified in the original core description (table 2;

pl. 1). One gastropod, *Odostomia* sp., and the barnacle, *Balanus* sp., were found only in this part of the Etchegoin Formation. A single "black cap brachiopod" was reported near the base of the zone. Foraminifera are also relatively abundant and are slightly more diversified than in the Tupman Shale Member (fig. 4). The more common species of Foraminifera include *Buliminella elegantissima, Elphidiella* (formerly *Elphidium*) *hannai, Elphidium hughesi, Eponides exigua, Eponides* cf. *E. blancoensis, Florilus* (formerly *Nonionella*) *cushmani,* and *Quinqueloculina* spp. A few specimens of reworked Foraminifera, identified as *Bolivina* cf. *B. vaughani* and *Cyclammina* sp., were found in the upper half. Other fossils present in the Calitroleum sand zone include fish remains, sponge spicules, plant fragments, diatoms, ostracodes, and radiolarians.

The upper contact of the Calitroleum sand zone is drawn at a depth of 3,114 feet, where a slight change in lithology occurs. Beds of siltstone immediately above the Calitroleum contain a greater amount of clay and more shale laminae than the underlying beds. The contact is well defined on the electric log (pl. 1).

Gusher Sand Zone

The Gusher sand zone encompasses a 534-foot sequence of mostly interbedded siltstone and sandstone between the depths of 3,114 and 2,580 feet. The siltstone, which is composed chiefly of coarse silt, is described as light olive gray, slightly micaceous, very finely sandy, and mostly friable. Laminae of well-sorted, generally glauconitic, very fine grained standstone are scattered in the siltstone. Scattered laminae and very thin beds of shale generally constitute only a small part of the Gusher sand zone, but one shale bed, about 25 feet thick, lies near the middle of the zone.

Several relatively thick beds of sandstone are present in the middle and upper parts of the Gusher sand zone. The sandstone is light olive gray, mostly fine to medium grained, moderately sorted, and mostly friable. The constituent grains consist mainly of light-gray subrounded feldspar and clear subangular quartz. Fine- to coarse-grained pellets of glauconite are present in most of the sandstone and, in some laminae or thin beds, compose as much as 15 percent of the rock. The sandstone has a silt and clay matrix, and some beds are partly cemented by carbonate or silica. Phosphate, which occurs as sporbo, brown to black dolomitic nodules, and phosphatized pelecypods and fish remains, is present in some beds of sandstone and siltstone. Porosities of some of the sandstones range from 26.8 to 36.8 percent, and permeabilities range from 0.0 to 172 millidarcys (table 1). Chloride content of the pore water is as much as 5,870 ppm (parts per million) in beds at the top of the sand zone but is only 2,500 ppm in sandstone near the middle.

Marine megafossils are common in the Gusher sand zone and are more diversified than in any other part of the Etchegoin Formation. Eight genera of gastropods and thirteen genera of pelecypods were identified in the original core description (table 2). One of the more common pelecypods reported is *Pecten oweni*. Three pelecypods, including *Tellina*(?) sp., *Tivela*(?) sp., and *Transenella* sp., and the gastropod *Brannerillus*(?) sp. were found only in the Gusher sand zone.

Microfossils, mainly Foraminifera, are common in many parts of the Gusher, but they are rare or absent in the beds of glauconitic sandstone. The more common species of Foraminifera include *Elphidiella* (formerly *Elphidium*) *hannai*, *Eponides exigua*, *Elphidium hughesi*, and *Buliminella elegantissima*. The species *Florilus* (formerly *Nonionella*) *cushmani* is sparse in the zone and does not range above it in well 324–19R. The stratigraphic distribution of the Foraminifera and other microfossils identified is shown in figure 4. Sponge spicules and fish remains are common in the zone, and Radiolaria, diatoms, and ostracodes are sparse. Plant fragments are conspicuously absent. The Gusher sand zone is probably conformable and gradational with the overlying Wilhelm sand zone in well 324–19R.

Wilhelm Sand Zone

The Wilhelm sand zone, 305 feet thick, is present between the depths of 2,580 and 2,275 feet. It is composed mainly of sandy siltstone, similar to that of the Gusher sand zone, interbedded with sandstone and shale. The siltstone is greenish gray to light olive gray, very sandy, clayey, biotitic, and mostly friable. Thin beds of greenish-gray silty shale are common. Sandstone beds, most less than 15 feet thick, make up nearly one-third of the Wilhelm sand zone. These beds consist of fine- or medium-grained moderately to well-sorted feldspathic sandstone. Some beds are slightly oil stained. The sandstone has a silt and clay matrix, and contains biotite and abundant glauconite. Carbonate rocks are rare in the Wilhelm sand zone, but several sandstone beds near the top of the zone are cemented in part by dense dolomite or calcite. Porosities of the sandstones range from 29.1 to 37 percent, and permeabilities from 15 to 836 millidarcys (table 1). The chloride content of pore water in a sandstone bed near the middle of the zone is 3,660 ppm. Residual oil saturation of sandstones in the upper half is as much as 5.1 percent of the effective pore space.

The most abundant fossils in the Wilhelm sand zone consist of marine mollusks and Foraminifera. The mollusks listed in the original core description include three genera of gastropods and eight genera of pelecypods (table 2). The Foraminifera include *Eponides exigua*, *Buliminella elegantissima*, *Elphidiella* (formerly *Elphidium*) *hannai*, *Elphidium hughesi*, *Quinqueloculina* sp., and several species reworked

from older Tertiary rocks (fig. 4). Other fossils are sparse but diverse and include sponge spicules, echinoid spines, fish remains, oval and spherical Radiolaria, diatoms, and carbonaceous plant fragments.

The contact between the Wilhelm sand zone and the overlying Mulinia sand zone marks a significant lithologic change from mainly siltstone and sandstone to shale. This contact is easily recognized on electric logs and can be traced across most of the Elk Hills oil field. Rocks of the Wilhelm sand zone and the underlying sand zones generally appear more resistive on electric logs and show a greater negative self-potential than the rocks above. Electric-log correlations across the field suggest the possibility of an unconformity at the top of the Wilhelm sand zone.

Mulinia Sand Zone

The Mulinia sand zone, 180 feet thick, is present between the depths of 2,275 and 2,095 feet and is the uppermost rock unit of the Carman Sandstone Member. This zone consists of soft greenish-gray shale and some sandstone and siltstone. The zone includes three sandstone beds, which are as much as 11 feet thick, that are important petroleum reservoirs in the Elk Hills oil field. The lowermost sandstone, known locally as the Bittium sand, was cored, but only the lower 4 feet was recovered. The sandstone is described as greenish gray, medium grained, well sorted, clayey, glauconitic, friable, and slightly oil stained in parts. The Bittium sand marks the highest stratigraphic occurrence of glauconite in well 324–19R. The sandstone has a porosity of 34.5 percent and a permeability of 140 millidarcys (table 1). The residual oil saturation is 4.1 percent. Two sandstone beds, and an intervening shale bed, known locally as the Submulinia sand, lie about 25 feet below the top of the Mulinia sand zone. The lower bed of the Submulinia sand, 6 feet thick, is separated from the upper bed, 11 feet thick, by 10 feet of shale. The sandstone is very fine to fine grained, well sorted, and poorly consolidated. The porosity of the lower bed of the Submulinia sand is very high and ranges from 41.9 to 45.9 percent; the permeability ranges from 322 to 826 millidarcys. According to well records of the Unit Operator, both the Bittium and Submulinia sands are capable of producing gas in well 324–19R.

The sequence of rocks between the Bittium and Submulinia sands includes several thin beds and laminae of siltstone and a thin conglomeratic shale bed. The conglomeratic shale, reportedly about 6 inches thick, contains scattered sand grains, abundant carbonaceous plant fragments, and numerous rounded and polished yellowish-brown dolomite or phosphate pebbles. The pebbles, as large as 1 inch in diameter, are the largest clastic fragments found in well 324–19R.

Beds of carbonate rocks are absent in the Mulinia sand zone.

Fossils are abundant in parts of the Mulinia sand zone and include both marine and nonmarine species (fig. 4; table 2). The marine fossils consist chiefly of pelecypods and Foraminifera; the nonmarine fossils are mainly gastropods. The pelecypod *Pseudocardium* [*Mulinia*] is diagnostic of the zone and is present only in the upper 45 feet in beds of sandstone and shale. Fresh-water gastropods, identified as *Fluminicola*, are abundant in the shale bed that separates the lower and upper parts of the Submulinia sand and occur with *Pseudocardium* [*Mulinia*]. These gastropods mark the lowest stratigraphic occurrence of fossils of definite fresh-water origin in well 324–19R. Five species of Foraminifera are present and include, approximately in order of decreasing abundance, *Elphidium hughesi, Eponides exigua, Buliminella elegantissima, Elphidiella* (formerly *Elphidium*) *hannai*, and *Quinqueloculina*(?) sp. Two species, *Buliminella elegantissima and Eponides exigua*, do not range above the Mulinia sand zone in well 324–19R. Other fossils present in the Mulinia sand zone include fish remains, ostracodes, pyritized diatoms, and a few echinoid spines, sponge spicules, and carbonaceous plant fragments.

The upper contact of the Carman Sandstone Member (top of the Etchegoin Formation) is drawn at a depth of 2,095 feet, which marks the highest stratigraphic occurrence of the fossil *Pseudocardium* [*Mulinia*]. Specimens of *Pseudocardium* [*Mulinia*] were found only between the depths of 2,140 and 2,095 feet in well 324–19R. This relatively thin *Pseudocardium* [*Mulinia*]-bearing interval is widespread and has long been recognized in the Elk Hills oil field and in other nearby oil fields. The interval was informally termed the "*Mulinia* zone" many years ago and was correlated by Woodring, Roundy, and Farnsworth (1932, p. 39) with the upper *Mulinia* zone at Kettleman Hills. The contact at Elk Hills is drawn in accordance with Barbat and Galloway (1934, p. 482), who designated the top of the upper *Mulinia* zone at Kettleman Hills as the contact between the Etchegoin Formation and the type San Joaquin Formation. This usage has been commonplace for many years at other oil fields in the vicinity of Elk Hills. At Kettleman Hills, Woodring, Stewart, and Richards (1940, p. 49–50) placed the top of the Etchegoin Formation at the base of conglomerate beds that are as much as 250 feet above the upper *Mulinia* zone. In well 324–19R, no conglomerate is present at a similar stratigraphic position above the *Pseudocardium* [*Mulinia*]-bearing rocks. The contact in well 324–19R also coincides approximately with the upper range limit of *Eponides exigua*, which, according to R. S. Beck (oral commun., 1970), marks the top of the Etchegoin Formation at Elk Hills and vicinity.

SAN JOAQUIN FORMATION

The name "San Joaquin Clays" was first used by F. M. Anderson (1905, p. 181) to designate a sequence of banded clays, about 1,500 feet thick, that overlies his "Etchegoin Sands" in the Diablo Range. Together the two lithologic units formed the "Etchegoin Beds" and were considered Pliocene in age (fig. 3). Many geologists did not differentiate the San Joaquin from the underlying strata until Barbat and Galloway (1934, p. 478–481) redescribed the sequence as the San Joaquin Clay and specified a type section in section 23, T. 22 S., R. 18 E. on North Dome, Kettleman Hills (fig. 1), about 60 miles north of Elk Hills. Woodring, Stewart, and Richards (1940, p. 27) changed the name "San Joaquin Clay" to "San Joaquin Formation" because a predominant type of lithology was lacking. They suggested that a section exposed along Arroyo Hondo in sec. 8, T. 22 S., R. 18 E. on the east side of North Dome, Kettleman Hills, would be a more suitable standard section, regarded herein as a reference section. More recent field investigations led Dibblee (1972) to conclude that the San Joaquin Formation is lithologically indistinct from the Etchegoin Formation where exposed in the Diablo and Temblor Ranges. In the Kettleman Hills, Dibblee (1972) retained the name, San Joaquin Formation, for a predominantly siltstone sequence, 1,200–1,800 feet thick, which he considers "the basinward facies of the upper part of the Etchegoin Formation of the Diablo Range to the southwest."

The San Joaquin Formation is generally considered to be Pliocene in age, although Barbat and Galloway (1934, p. 495–496) considered the upper part at Kettleman Hills as transitional between the Pliocene and Pleistocene. According to Woodring, Stewart, and Richards (1940, p. 102–103), vertebrate and marine invertebrate fossils indicate a Pliocene age for the formation at Kettleman Hills.

At Elk Hills, the San Joaquin Formation is 1,085 feet thick in well 324–19R. The formation is divided in this report into two informally named sand zones that were used in unpublished geologic reports by J. C. Maher, R. J. Lantz, and R. D. Carter of the U.S. Geological Survey (written commun., 1969). The lower zone is called the Scalez sand zone. The name is derived from the distinctive fossil *Scalez petrolia*, a gastropod operculum present near the base of the formation in many wells at Elk Hills. The fossil was first discovered in 1921 in wells at the east end of Elk Hills (Hanna and Gaylord, 1924). It generally occurs abundantly in a thin bed of brittle brown shale, known locally as the *Scalez* marker bed. According to Woodring, Roundy, and Farnsworth (1932, p. 36–38), *Scalez* is locally present is as many as four beds in the western San Joaquin Valley, but the lowermost of these is clearly the *Scalez* marker bed at Elk Hills. Specimens of *Scalez* have not been reported from exposures of the

San Joaquin Formation with the exception of a single specimen found near the base of the formation at Kettleman Hills, about 50 miles north of Elk Hills (Woodring and others, 1940, p. 40). In some parts of the Elk Hills oil field, the Scalez sand zone includes as many as four important oil-bearing sandstones, known locally, in upward order, as the Second Subscalez sand, the First Subscalez sand, the Above Scalez sand, and the E-laminated sand. These sandstones are not present in well 324–19R.

The upper zone of the San Joaquin Formation, informally called the Mya sand zone, makes up about nine-tenths of the formation. The name is derived from the pelecypod *Mya*, present in many beds in the formation. The fossil is not restricted to the zone but ranges in well 324–19R from the uppermost part of the Mulinia sand zone to within 81 feet of the top of the San Joaquin Formation. As many as five sandstone beds in the formation are locally called Mya sand and are differentiated by numbering in downward order. These sandstones are not identified in this report because of their lenticular nature and the uncertainty of their correlation. *Mya*-bearing beds have long been known in outcrops and other well sections of the San Joaquin Formation along the west side of the southern San Joaquin Valley. The two sand zones that make up the San Joaquin Formation in well 324–19R are described below.

Scalez Sand Zone

The Scalez sand zone, 181 feet thick, is present between the depths of 2,095 feet and 1,914 feet in well 324–19R. Greenish-gray to light-olive-gray shale makes up most of the zone, but laminae and beds of siltstone as much as 10 feet thick are present in the upper half. The shale is composed mostly of clay. It has a smooth texture, slightly waxy luster, and a blocky to hackly fracture. Slickensides were observed on many core samples. Carbonate rocks are absent except for one thin bed of yellowish-brown vuggy dolomite near the middle of the zone. Apparent dips of 8°–12° were recorded from cores taken at 1,944 feet.

Fossils are abundant in the lower half of the zone but sparse in the upper half. According to the original core description, *Scalez* are present in the middle of a brown shale bed, 5 feet thick, which lies 10 feet above the base of the formation. Specimens of *Scalez* were not found in this study, except for a single specimen near the middle of the overlying Mya sand zone. It is probable that the *Scalez*-bearing interval was removed from the cores prior to this study. A thin bed of coquina, known locally as Amnicolite, lies about 20 feet above the base of the San Joaquin Formation. This bed, about 1 foot thick, consists predominately of minute fresh-water gastropods of the genus *Amnicola* and contains abundant black ostracodes. The coquina has

a clay matrix and is very friable. A similar bed has long been recognized at approximately the same stratigraphic position at the east end of Elk Hills (Roberts, 1927, p. 6–7) and as far north as Kettleman Hills (Barbat and Galloway, 1934, p. 479). Other fossils in the Scalez sand zone include fish fragments, pyritized diatoms, Radiolaria, Foraminifera, and both marine and nonmarine mollusks (fig. 4; table 2). The chief Foraminifera were identified by R. S. Beck as "*Discorbis (Eponides)* sp." and *Elphidium hughesi*, which, in addition to the megafauna, strongly indicate that brackish-water conditions dominated during deposition of the Scalez sand zone. Carbonaceous plant fragments are present in the upper half of the zone, and some are pyritized.

The contact between the Scalez sand zone and the overlying Mya sand zone is drawn at a depth of 1,194 feet at the base of a thin sandstone or siltstone bed. This bed is easily recognized on the electric log, but cores from it were not recovered.

Mya Sand Zone

The Mya sand zone, 904 feet thick in well 324–19R, consists of interbedded marine and nonmarine rocks between the depths of 1,914 feet and 1,010 feet. The lower half of the zone is mostly greenish-gray to light-olive-gray shale. The shale is composed chiefly of clay that readily breaks down when wet. It has a smooth dense texture, slightly waxy luster, and is soft enough to be scratched by a fingernail. Slickensides are present in many parts. A siltstone bed, 45 feet thick, is present near the middle of the shale. The siltstone contains scattered shale laminae and, near the top, a few very coarse subangular quartz grains and granules. These granules are the largest clastic fragments found in the San Joaquin Formation in well 324–19R. The siltstone shows crossbedding in parts and apparent dips as much as 18°, according to the original core description. A thin bed of greenish-gray silty limestone is present near the middle of the siltstone. According to the original core description, a 5-foot sequence of fine-grained sandstone with an intervening bed of siltstone lies approximately 50 feet above the thick siltstone bed, but the core was lost prior to this study. The sandstone is reportedly well sorted in the upper part and contains the fossil *Mya*. The bed causes a sharp negative self-potential deflection on the electric log and can be traced eastward across much of the Elk Hills field.

The upper half of the Mya sand zone consists of nearly equal portions of shale and interbedded sandstone and siltstone. The shale is similar to that in the lower half except that it is generally slightly lighter in color. Three thick rock units composed of interlaminated to thinly interbedded shale, siltstone, and very fine grained sandstone are present in this part of the zone between the depths of 1,460 feet

and 1,201 feet (pl. 1). The sandstone and siltstone are generally well sorted and very friable; carbonaceous plant fragments and biotite are present on most bedding planes. Apparent dips recorded in the original core description are 2°–4° in the middle unit and 4°–13° in the upper unit. These rock units, especially the upper two, show prominent negative self-potential deflections on the electric log. Thick shale beds containing scattered siltstone laminae and a few laminae or very thin beds of dense limestone or dolomite separate the coarser clastic units described above. The upper 100 feet of the Mya sand zone includes several thin beds of sandstone and siltstone that are readily identified on the electric log by their high negative self-potential and relatively high resistivity (pl. 1). The sandstones are very fine to fine grained, silty, clayey, slightly micaceous, and mostly friable to poorly consolidated; one is cemented in part with dense dolomite, another is very limy. Porosities of the sandstone or siltstone beds in the Mya sand zone range from 27.8 to 45.4 percent, permeabilities from 33 to 6,810 millidarcys (table 1). A chloride content of 5,650 ppm was found in the pore water from a sandstone bed near the top of the formation. No residual oil was found in any of the beds sampled.

Megafossils found in the Mya sand zone and identified in the original core description include both marine and nonmarine mollusks (table 2). The chief marine mollusk is the pelecypod *Mya*, which, except for one species, does not range higher than the lower one-third of the zone. Another marine pelecypod, *Ostrea lurida*, is abundant in a sandstone and shale interval, 9 feet thick, near the top of the zone. About 10 feet above the *Ostrea lurida*-bearing strata, or 72 feet below the top of the San Joaquin Formation, *Mya* is found in a shale bed 2 feet thick. This bed probably marks the last marine deposition during Neogene time at Elk Hills. Fresh-water mollusks, mainly *Anodonta* sp. and *Valvata humerosa*, are most abundant in the lower-middle part of the zone. Fresh-water mollusks are also present in a thin bed just below the top of the formation. The upper half of the Mya sand zone, excluding the upper 90 feet, is devoid of megafossils with the exception of carbonaceous or pyritized plant fragments. The plant fragments are present in most parts of the zone.

Microfossils, mainly Foraminifera and ostracodes, range through the Mya sand zone (fig. 4). The Foraminifera include "*Discorbis (Eponides)* sp.", *Elphidiella* (formerly *Elphidium*) *hannai*, and *Eponides* cf. *E. blancoensis*. The species "*Discorbis (Eponides)* sp." occur chiefly in the lower half of the zone, and *Eponides* cf. *E. blancoensis* occur mainly in the upper half; *Elphidiella* (formerly *Elphidium*) *hannai* range through the zone. Foraminifera were found in beds containing marine megafossils and those devoid of megafossils, but they were not found in beds containing fresh-water megafossils. Sev-

eral species of recycled Miocene Foraminifera were found near the middle of the zone, just above fresh-water mollusk-bearing strata. Ostracodes are present mainly in the lower half and make up very thin beds of laminae of coquina in some parts. Other microfossils include fish remains, pyritized diatoms, and reworked Radiolaria. The fossils in the Mya sand zone indicate that the rocks were deposited in an environment characterized by alternating brackish-water and fresh-water conditions.

The contact with the overlying Tulare Formation is placed at a depth of 1,010 feet at the base of a relatively thick sandstone bed. The upper part of the sandstone is much coarser than any sandstone in the San Joaquin Formation. The sandstone lies 72 feet above the uppermost occurrence of the fossil *Mya* and marks the beginning of a significant change in the depositional history at Elk Hills. The electric log suggests that strata above the contact, in contrast to the predominately shale section below, consists mainly of sandstone or sand. The upper contact of the San Joaquin Formation at the type locality (North Dome, Kettleman Hills) was placed at the base of a massive sand, 152 feet above the "uppermost '*Mya*' zone" (Barbat and Galloway, 1934, p. 480). Woodring, Stewart, and Richards (1940, p. 13–15, 28–32), however, chose the top of the "upper *Mya* zone" as the contact at Kettleman Hills.

PLIOCENE AND PLEISTOCENE SERIES, TULARE FORMATION

The name Tulare Formation was applied by F. M. Anderson (1905, p. 181–182) to a thick sequence of fresh-water sands and clays that are exposed along the western border of the San Joaquin Valley. The strata had previously been described briefly by Watts (1894, p. 55, 67), who collected fossils of fresh-water mollusks from some of the beds exposed at Kettleman Hills and near McKittrick. According to F. M. Anderson (1905, p. 181), the Tulare Formation is at least 1,000 feet thick in the northern part of the Kettleman Hills, where it lies conformably above his "San Joaquin Clays".

In a preliminary report on the Coalinga area, Arnold and Anderson (1908, p. 56–61) on the basis of lithology and stratigraphic position, considered the Tulare Formation to be the same unit mapped as the Paso Robles Formation in the Salinas Valley. For this reason, Arnold and Anderson (1908, p. 56–57) used the name Paso Robles Formation in the Coalinga area. In a later report (Arnold and Anderson, 1910, p. 142), they considered the lower part of the Paso Robles Formation of the Salinas Valley to be equivalent to parts of the Etchegoin and Jacalitos Formations in the Coalinga area, and they reverted to the name Tulare Formation in the Coalinga area. They noted that the Tulare is best exposed at Kettleman Hills and suggested that that area be taken as the type locality (Arnold and Anderson, 1910, p. 143).

According to English (1918, p. 231–232), the Paso Robles Formation in the vicinity of Parkfield, about 18 miles southwest of Coalinga, occupies the same stratigraphic position as the Tulare Formation in the Coalinga area. English retained the older name Paso Robles Formation in the Parkfield area and stated that the name Tulare Formation had been abandoned by the U.S. Geological Survey.

In the southwestern part of the San Joaquin Valley, including Elk Hills and vicinity, Arnold and Johnson (1910, p. 74–90) mapped beds equivalent to the Tulare Formation as the upper part of the "McKittrick Formation". The Tulare Formation was later differentiated in the McKittrick area by Gester (1917, p. 210–216). Pack (1920, p. 43–51) mapped the formation in much of the southwestern part of the valley, but he used the term "Paso Robles ('Tulare')" in accordance with English (1918). In a later report on the southern border of the San Joaquin Valley, Hoots (1930, p. 288) stated that on the basis of fossils "the Tulare Formation of the Coalinga and McKittrick region can not be correlated with all those beds of the Salinas Valley originally described as Paso Robles. Proper usage demands that the name Tulare be retained, as originally proposed, for the beds, mainly of fresh-water origin, that overlie the marine Etchegoin strata in the Coalinga region." Woodring, Stewart, and Richards (1940, p. 13–14) later mapped and described the Tulare Formation at Kettleman Hills and suggested that exposures on the northeast side of North Dome be considered as the type section.

The age of the Tulare Formation is not satisfactorily known, but it is generally considered as late Pliocene and Pleistocene on the basis of its stratigraphic position and fossil content. Some of the problems in determining the age of the Tulare were discussed by Woodring, Stewart, and Richards (1940, p. 103–104). Foss and Blaisdell (1968, p. 35) report that the Tulare is considered Pleistocene in age because of its stratigraphic position and molluscan fauna. According to Croft (1969, p. 16), faunal and potassium-argon dating has established that the upper part of the Tulare Formation is of Pleistocene age. In the present report, the Tulare Formation is regarded as late Pliocene and Pleistocene age.

The Tulare Formation blankets the Elk Hills anticline, where it was mapped and described by Woodring, Roundy, and Farnsworth (1932, p. 16–30). These writers report that the exposed beds consist of interbedded nonmarine mudstones and pebbly sands that may total 850 feet in thickness. The exposed beds were divided on the basis of color into two parts—olive-gray mudstone characterizes the lower part, buff-colored rock the upper. Two thin limestone beds, designated Limestones A and B, were described and found useful as local marker beds. Woodring, Roundy, and Farnsworth (1932, p. 25)

could not establish the lower boundary of the Tulare in the subsurface at Elk Hills.

Well 324–19R drilled through 1,010 feet of the Tulare Formation (0–1,010 ft. depth) but cored only the lower 21 feet. Cores from the lower 18 feet include two beds of sandstone separated by a 3-foot bed of siltstone. The basal sandstone bed, about 4 feet thick, is very fine to fine grained, contains scattered medium grains, and is silty. The sandstone is cemented with dense limy dolomite in the upper half; near the middle is a thin bed of medium-gray hard dense sandy clastic dolomite. The dolomite appears in thin section to be composed of elongate coarse-grain size microcrystalline clasts that are filled with algal material. The siltstone, which overlies the lower sandstone, grades into very fine grained sandstone in part; some is interbedded or interlaminated with silty shale. Biotite is generally abundant on bedding planes of the siltstone. The upper sandstone bed, about 11 feet thick, is very fine to very coarse grained and poorly consolidated. The matrix of the sandstone, which makes up as much as 50 percent of the rock, is composed of very limy silt and clay. Granules and small pebbles of light-gray feldspar and light-gray quartz are scattered in the sandstone; some of the feldspar contains inclusions of biotite or hornblende. Biotite and very fine grained hornblende also occur disseminated in the sandstone, giving it a speckled appearance. Siltstone and silty shale laminae are scattered in the sandstone, and a few laminae composed chiefly of biotite are present in some parts. Overlying the sandstone is a 3-foot bed of soft slightly waxy light-olive-gray shale.

The porosity of the pebbly sandstone near the base of the Tulare Formation ranges from 33.5 to 39.8 percent, and the permeability ranges from 1,410 to 8,150 millidarcys (table 1). The pore water has a chloride content of 2,820 ppm.

Fossils from the basal part of the Tulare Formation in well 324–19R are most abundant in the upper sandstone bed. The sandstone contains leached thin-shelled pelecypod fragments, ostracodes, fish remains, and fresh-water gastropods that are tentatively identified as *Amnicola*. The lower standstone bed appeared nonfossiliferous, but sponge spicules, algal material, and fish vertebrae were seen in a thin section of the rock.

Samples above the basal part of the Tulare Formation in well 324–19R were not available, but rotary samples were collected during the drilling of well 526–30R, about a mile to the south. These samples were collected at 10- or 15-foot intervals below a depth of 117 feet. The samples were described by Adkison (1973), who divided the Tulare into three members in accordance with unpublished stratigraphic studies by J. C. Maher, R. J. Lantz, and R. D. Carter

(written commun., 1969). The following description of the Tulare in well 526–30R is based upon the detailed sample descriptions by Adkison (1973).

The Tulare Formation is 1,280 feet thick in well 526–30R, where it is divided into a lower sand and gravel member, a clay member, and an upper sand and gravel member. These members are recognizable on electric logs in the western part of the Elk Hills oil field, according to J. C. Maher, R. J. Lantz, and R. D. Carter (written commun., 1970).

The lower sand and gravel member, 567 feet thick, consists of sandstone interbedded with siltstone and shale. The sandstone is generally light olive gray, poorly consolidated, silty, biotitic, and very fine to very coarse grained; it contains scattered granules. Fragments of white chert are present in some beds of unconsolidated sand near the top of the member. Oil staining is evident in several beds of sandstone and siltstone near the base of the formation.

The clay member, 91 feet thick, is composed mainly of light-olive-gray silty shale that is slightly dolomitic or limy in most parts. The shale includes a few thin beds and stringers of very fine to very coarse grained feldspathic sandstone.

The upper sand and gravel member is 713 feet thick in well 526–30R. The member is composed chiefly of medium to very coarse unconsolidated sand that contains numerous granules and scattered pebbles. Many of the sand grains and larger clastic fragments are feldspar, but fragments of chert, limestone, quartzite, granite, and other igneous rocks are present in some beds. Siltstone and shale beds, most less than 5 feet thick, are present in the upper sand and gravel member but make up only about 5 percent of the total thickness. Samples from the upper 117 feet were not recovered.

According to R. S. Beck (written commun., 1969), the lower sand and gravel member and the clay member of the Tulare Formation in well 526–30R contain scattered fish remains, mollusk fragments, and reworked Foraminifera. The Foraminifera, which were derived from Miocene and Pliocene rocks, include *Elphidiella* (formerly *Elphidium*) *hannai*, *Globigerina bulloides*, *Nonion* cf. *N. costiferum*, *Valvulineria californica obesa*, *V. robusta*, *V. miocenica*, *Valvulineria* cf. *V. ornata*, and *Virgulina*(?) sp. Beck also reports that ostracodes and thin-shelled pelecypods are present near the base of the lower sand and gravel member, and that small gastropods, questionably identified as *Amnicola*, are present in the clay member. Fossils were not found in the upper sand and gravel member of the Tulare Formation in well 526–30R.

Alluvium of Quaternary age overlies the Tulare Formation around the perimeter of the Elk Hills anticline and in the surrounding valley areas. The alluvium has been stripped away by erosion along the crest of the anticline, and it is not present at the site of well 324–19R or

well 526–30R. Both wells began drilling in the upper part of the Tulare Formation as mapped by Woodring, Roundy, and Farnsworth (1932); they reported (p. 15) that the boundary between the Tulare and the overlying alluvium is sharply defined at the east end of Elk Hills and at some places on the west end but cannot be recognized elsewhere.

STRATIGRAPHIC SECTION OF WELL 324–19R

[Reference section in Unit Operation Naval Petroleum Reserve No. 1 (NPR–1), NW¼ sec. 19, T. 30 S., R. 23 E., in the western part of the Elk Hills oil field, San Joaquin Valley, Calif. The well was drilled from September 18, 1941 to January 19, 1942 by the Standard Oil Co. of California. Altitude of the derrick floor was 1,215 feet above mean sea level. The asterisk indicates cores that were lost prior to this study; the description is from the original core description]

Quaternary and Tertiary Systems
Pleistocene and Pliocene Series
Tulare Formation

Feet	
0– 989	No samples.
989– 992	Shale, light-olive-gray, slightly silty, soft, smooth, slightly waxy; rare fish fragments; trace hard yellowish-gray fine- to coarse-grained sandstone with limy silt matrix.
992– 999	Sandstone, light-gray, very fine to very coarse grained, angular to subangular, medium sorted in part, 10–50 percent silty clay matrix, very limy, firm to loose, few subangular to rounded granules and small pebbles (to 6 mm) of light-gray feldspar and quartz, disseminated very fine grained hornblende(?) and mica; few leached thin-shelled pelecypod fragments, *Amnicola*(?), fish fragments; includes thin bed of light-olive-gray shale.
999–1,003	Sandstone, light-olive-gray to light-gray, mostly very fine to medium-grained, well sorted in part, silt matrix, friable to loose, common medium to coarse grains, few subrounded granules and pebbles of light- to dark-gray feldspar, good porosity, few laminae of biotite; few laminae of siltstone and silty to sandy shale containing fish scales, *Amnicola*(?), and ostracodes.
1,003–1,006	Siltstone, light-olive-gray, grades into very fine grained sandstone, friable, thinly interbedded or interlaminated in part with silty shale, abundant biotite on bedding planes.
1,006–1,008	Sandstone, light-olive-gray to medium-gray, very fine to fine-grained, dense limy dolomite cement, very finely disseminated biotite; few fish scales; thin section shows scattered sponge spicules and dolomite fragments with algallike structures.
1,008–1,010	Sandstone, light-olive-gray to yellowish-gray, very fine to fine-grained, few medium grains, very silty, limy, micaceous, friable; 40 percent medium-gray hard dense very sandy dolomite, some dolomite composed of coarse-grain-size dolomite fragments which show algallike structures in thin section.

Tertiary System
Pliocene Series
San Joaquin Formation
Mya sand zone

1,010–1,013	Siltstone, light-olive-gray, clayey, disseminated mica, platy, friable; few *Amnicola,* fish fragments, and thin-shelled pelecypod fragments; reported dip 3°–5°.

Tertiary System—Continued
Pliocene Series—Continued
San Joaquin Formation—Continued
Mya sand zone—Continued

Feet	
1,013–1,016	Shale, light-olive-gray, very silty, very finely micaceous, blocky to platy; few laminae with common to abundant *Amnicola,* few thin-shelled pelecypod fragments, fish fragments, and white ostracodes; trace medium-gray coarse-grained hard clastic dolomite.
1,016–1,019	Shale, light-olive-gray, silty, dolomitic cement, hard, brittle, some parts slightly friable; few *Amnicola* and fish fragments.
1,019–1,026	Siltstone, light-olive-gray, slightly yellowish-gray, clayey, very finely sandy, slightly limy; few thin shale beds.
1,026–1,035	Shale, light-olive-gray, silty, soft, blocky; rare plant fragments; includes thin bed of white clayey fine-grained sandstone near bottom.
1,035–1,038	Shale, light-olive-gray, silty, soft, blocky, slight conchoidal fracture; trace medium-gray very clayey dense dolomite.
1,038–1,044	Shale, medium-gray to dark greenish-gray, bentonitic(?), soft, smooth, slightly waxy; some brittle light-olive-gray silty shale.
1,044–1,048	Shale, light-olive-gray, silty, blocky, slickensides; rare leached shell fragments.
1,048–1,051	Siltstone, light-olive-gray, coarse-grained, clayey, friable, slightly micaceous.
1,051–1,055	Shale, light-olive-gray, silty, blocky; 5 percent composed of well rounded very coarse to fine-grained greenish-gray shale fragments; some clayey siltstone.
1,055–1,058	Shale, greenish-gray, slightly silty, tough, blocky.
1,058–1,064	Sandstone, light-olive-gray, very fine to fine-grained, silty, clayey, loose to friable, slightly micaceous; some very silty shale.
1,064–1,065	Sandstone, as above but cemented with hard dense limy dolomite, very finely micaceous; common to abundant leached Foraminifera or shell fragments in parts; 50 percent interlaminated siltstone and shale.
1,065–1,068	Siltstone, light-olive-gray, coarse silt grading to very fine grained sand, very clayey, slightly friable; few small shell fragments; few shale laminae.
1,068–1,070	Sandstone, light-olive-gray, very fine to fine-grained, silty, clayey, very friable, slightly micaceous; few minute shell fragments—gastropods(?).
1,070–1,085	Shale, greenish-gray to light-olive-gray, slightly silty, blocky, smooth, slickensides, some pyrite; few siltstone laminae and small pelecypods in lower part; includes thin bed of smooth dense dark-greenish-gray bentonite(?) with slickensides.
1,085–1,089	Shale, pale-olive to greenish-gray.
1,089–1,092	Sandstone, very light gray, fine-grained, clay matrix, very limy.
1,092–1,095	Shale, pale-olive, silty; abundant pelecypods—*Ostrea*(?); includes thin bed (1–6 in.) of hard olive-gray vuggy dolomite with abundant gray pelecypod fragments.
1,095–1,105	Shale, as above but pelecypods less common; few laminae or thin beds of angular very fine grained sandstone near bottom.
1,105–1,115	Shale, pale-olive, very silty; abundant pelecypod fragments; trace of brownish-gray siliceous shale.

Tertiary System—Continued
Pliocene Series—Continued
San Joaquin Formation—Continued
Mya sand zone—Continued

Feet	
1,115–1,116	Siltstone, pale-olive, very clayey, micaceous; carbonaceous material; few pelecypods.
1,116–1,119	No sample.
1,119–1,122	Shale, pale-olive, soft, waxy; few pyritized plant fragments.
1,122–1,123	Dolomite, medium-gray to pale-olive, very clayey, hard, dense.
1,123–1,136	Shale, pale-olive to greenish-gray, soft, waxy, slickensides, very slightly silty in parts; single crab claw.
1,136–1,139	No sample.
1,139–1,154	Shale, pale-olive to greenish-gray, soft, waxy, slickensides.
1,154–1,155	Siltstone, pale-olive to yellowish-green, micaceous; scattered plant fragments.
1,155–1,201	Shale, pale-olive to greenish-gray; slightly silty in parts, few slickensides; few pyritized plant fragments and poorly preserved Foraminifera.
1,201–1,210	Siltstone, pale-olive to greenish-gray, micaceous; some shale and very fine grained sandstone laminae; 2-inch bed of slightly vuggy very pale orange to very pale brown siliceous limestone at 1,209 feet; abundant Foraminifera molds; reported dip 4°–8°.
1,210–1,219	Shale, pale-olive to greenish-gray; siltstone laminae; reported dip 11°–13°.
1,219–1,240	Sandstone, pale-olive, very fine grained, angular to subangular, well sorted, biotite; scattered carbonaceous material; interlaminated with siltstone and shale; slightly fissile, very friable; reported dip 11°–13°.
1,240–1,249	Siltstone, greenish-gray; few plant fragments and shale laminae.
1,249–1,270	Shale, greenish-gray; few siltstone laminae; abundant pyritized plant fragments; includes thin bed (probably 2–3 inches thick) of medium-gray limestone at 1,265 feet.
1,270–1,287	Shale, greenish-gray to pale-olive, soft, waxy; abundant pyritized plant fragments in parts; includes 3- to 6-inch bed of mottled light-olive-gray and medium-dark-gray hard dense limestone.
1,287–1,290	No sample.
1,290–1,295	Siltstone, greenish-gray; silty shale and angular very fine grained sandstone laminae; few pyritized plant fragments.
1,295–1,315	Shale, pale-olive, soft, waxy; pyritized plant fragments; few siltstone laminae.
1,315–1,320	Siltstone, greenish-gray, very clayey, slickensides; pyritized plant fragments.
1,320–1,343	Siltstone, greenish-gray, coarse-grained, micaceous, friable, few moderate yellowish-brown spots; few carbonaceous plant fragments; abundant shale and very fine grained sandstone laminae; reported dip 2°–4°.
1,343–1,346	Sandstone, greenish-gray, very fine to fine-grained, fissile, friable; coarse siltstone laminae; reported dip 2°–4°.
1,346–1,368	Siltstone, greenish-gray, micaceous, slightly fissile; carbonaceous material on bedding planes; few light-olive-gray shale laminae with abundant crushed gastropods, few fish fragments; few very fine grained sandstone laminae.

Tertiary System—Continued
Pliocene Series—Continued
San Joaquin Formation—Continued
Mya sand zone—Continued

Feet	
1,368–1,370	No sample.
1,370–1,380	Shale, greenish-gray, very silty, slickensides; thin bed of very silty yellowish-gray limestone at 1,379 feet.
1,380–1,388	Shale, medium-gray to light-olive-gray; pyritized plant fragments.
1,388–1,390	No sample.
1,390–1,398	Shale, light-olive-gray to greenish-gray, soft, smooth, slightly waxy slickensides; some carbonaceous material, pyritized diatoms; few siltstone laminae.
1,398–1,400	No sample.
1,400–1,428	Shale, light-olive-gray to greenish-gray, very silty in parts, blocky; carbonaceous plant fragments; trace greenish-gray and medium-gray limestone at 1,417 feet.
1,428–1,429	Sandstone, light-olive-gray, very fine to fine-grained, subangular, friable.
1,429–1,439	Siltstone and silty shale, interbedded, trace limy cement, micaceous; trace carbonaceous plant fragments.
1,439–1,450	Shale, greenish-gray, silty; thin bed of hard olive-gray dense dolomite at 1,443 feet.
1,450–1,460	Siltstone, light-olive-gray to greenish-gray, slightly sandy, micaceous, slightly limy, slickensides, friable.
1,460–1,468	Shale, greenish-gray, very silty, scattered subrounded coarse quartz grains; trace pyritized diatoms.
1,468–1,475	Shale, pale-yellowish-brown to greenish-gray, smooth, waxy.
1,475–1,487	Shale, greenish-gray, smooth, waxy; few laminae of coarse silt and angular to rounded very fine grained sandstone.
1,487–1,490	No sample.
1,490–1,497	Shale, greenish-gray, slightly silty, trace pyrite; few siltstone laminae.
1,497–1,500	No sample.
1,500–1,505	Shale, pale-olive to greenish-gray, slightly silty; few laminae of angular fine- to medium-grained sandstone with scattered subangular coarse feldspar grains; trace Foraminifera, pyritized diatoms, and thin-shelled pelecypod fragments.
1,505–1,508	No sample.
1,508–1,534	Shale, greenish-gray; few laminae of angular fine-grained sandstone with moderate yellowish-brown oil staining; trace yellowish-brown shale; trace Foraminifera, ostracodes, and pelecypod fragments.
1,534–1,538	No sample.
1,538–1,553	Shale, greenish-gray to light-olive-gray, soft, fissile to blocky; abundant ostracodes and fish fragments in parts; trace olive-gray shale with pyritized plant fragments; reported dip 0°–2°.
1,553–1,558	No sample.
1,558–1,580	Shale, as above; abundant ostracodes with trace of pyrite fillings, trace *Scalez petrolia,* trace fish fragments, gastropods, and pelecypod fragments; reported dip 0°–2°.
1,580–1,608	*Shale, brown, compact; streaks of marl and siltstone at top; common fresh-water gastropods *(Fluminicola kettlemanensis),*

Tertiary System—Continued
Pliocene Series—Continued
San Joaquin Formation—Continued
Mya sand zone—Continued

Feet	
	rare *Anodonta* and *Sphaerium.*
1,608–1,626	*Shale, brown, compact; *Anodonta,* ostracodes.
1,626–1,628	No sample.
1,628–1,634	*Shale, brown, compact; ostracodes, abundant *Valvata humerosa, Anodonta.*
1,634–1,638	No sample.
1,638–1,648	*Shale, brown, compact; fish remains, ostracodes, *Anodonta, Valvata humerosa.*
1,648–1,654	*Shale, green and olive-brown; ostracodes, *Anodonta,* other freshwater shells.
1,654–1,659	No sample.
1,659–1,668	*Shale, brownish-gray.
1,668–1,669	*Sand, gray, fine-grained, well-sorted, very friable; *Mya* shells.
1,669–1,670	No sample.
1,670–1,672	*Siltstone, green, clayey.
1,672–1,673	*Sand, greenish-gray, fine-grained, very clayey.
1,673–1,677	*Shale, gray, silty, micaceous.
1,677–1,680	*Shale, dull gray; common *Mya intermedia.*
1,680–1,686	*Shale, gray, brittle; abundant *Mya,* ostracodes.
1,686–1,690	Shale, dark-greenish-gray, smooth, waxy; abundant ostracodes with trace pyrite filling, abundant pelecypod fragments—*Mya* (?).
1,690–1,700	Shale, pale-olive to greenish-gray, slightly silty; ostracodes; trace medium-gray shale with pelecypod fragments.
1,700–1,710	Shale, greenish-gray to light-olive-gray, trace slickensides; finely disseminated carbonaceous material.
1,710–1,720	Shale, pale-olive to greenish-gray, smooth, waxy; some gray shale with pelecypod fragments.
1,720–1,730	Siltstone, light-olive-gray to greenish-gray, finely disseminated biotite; reported dip 14°–18°.
1,730–1,736	Siltstone, greenish-gray, clayey, scattered shale laminae, trace subangular very coarse to granule-size quartz grains; reported dip 14°–18°.
1,736–1,752	Siltstone, greenish-gray, clayey; carbonaceous plant material, trace pyritized plant fragments; thin bed of brittle greenish-gray silty limestone at 1,747 feet.
1,752–1,765	Siltstone, greenish-gray; interlaminated with shale; pyritized plant fragments, pelecypod fragments; reported dip 12°.
1,765–1,805	Shale, greenish-gray, soft, waxy, slightly silty in parts, slickensides; trace Foraminifera, ostracodes, and pelecypod fragments.
1,805–1,811	No sample.
1,811–1,817	Shale, greenish-gray, smooth, waxy, abundant slickensides; trace pelecypod fragments, fish fragments, and pyritized plant fragments.
1,817–1,821	No sample.
1,821–1,858	Shale, light-olive-gray to greenish-gray, smooth, waxy, slightly silty in lower half, abundant slickensides; trace pyritized plant fragments, thin-shelled pelecypod fragments at 1,850 feet; trace limestone at bottom.

Tertiary System—Continued
Pliocene Series—Continued
San Joaquin Formation—Continued
Mya sand zone—Continued

Feet	
1,858–1,860	No sample.
1,860–1,878	Shale, light-olive-gray, slightly silty; abundant pelecypod fragments near top, trace ostracodes and Foraminifera.
1,878–1,890	Shale, light-olive-gray; abundant black and white ostracodes, few laminae of ostracode coquina, trace pelecypod fragments and fish fragments.
1,890–1,905	Shale, light-olive-gray to yellowish-brown, very silty; trace pelecypod and fish fragments.
1,905–1,910	Shale, light-olive-gray to olive-brown slickensides; few ostracodes with pyrite filling; trace siltstone; trace fish fragments.
1,910–1,914	No sample.
	Scalez sand zone
1,914–1,930	Shale, greenish-gray, slickensides; trace ostracodes; numerous thin beds or laminae of siltstone.
1,930–1,945	Shale, greenish-gray, blocky; trace Foraminifera and plant fragments.
1,945–1,955	Siltstone, greenish-gray, friable; numerous shale laminae; trace carbonaceous plant fragments; trace very fine grained sandstone; reported dip 8°–12°.
1,955–1,965	Shale, greenish-gray to medium-dark-gray, slightly silty.
1,965–1,970	Shale, greenish-gray, smooth, blocky; pyritized plant fragments.
1,970–1,975	Siltstone, greenish-gray; interlaminated with very fine grained sandstone.
1,975–1,999	Shale, greenish-gray, slickensides, trace clay-filled fractures; trace Foraminifera and pyritized plant fragments.
1,999–2,000	Dolomite, yellowish-brown, hard, vuggy; fossil molds(?).
2,000–2,010	Siltstone, light-gray to light-olive-gray, very clayey; Foraminifera, trace ostracodes.
2,010–2,020	Shale, light-olive-gray to greenish-gray, upper part very silty; pelecypod fragments near bottom, trace ostracodes.
2,020–2,040	Shale, greenish-gray; few sandy siltstone laminae near top; abundant pelecypods and pelecypod fragments, abundant pyritized diatoms, few gastropods and Foraminifera.
2,040–2,048	Shale, medium-gray, slightly silty; fish scales, diatoms.
2,048–2,050	No sample.
2,050–2,062	Shale, olive-gray to greenish-gray, slightly silty, blocky to slightly fissile, trace slickensides and pyrite; abundant pelecypod fragments at 2,058; trace gastropods.
2,062–2,070	No sample.
2,070–2,078	Shale, olive-gray; abundant gastropods—*Amnicola*(?), some coquina (Amnicolite) composed of *Amnicola*(?) and black ostracodes, few thick-shelled pelecypods near bottom.
2,078–2,082	Shale, olive-gray to slightly grayish-brown, smooth, slightly micaceous.
2,082–2,091	Shale, olive-gray; thick-shelled pelecypod fragments, few gastropods and ostracodes; *Scalez* reported at 2,082 ft.
2,091–2,095	No sample.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation
Carman Sandstone Member

[Type section of the Carman Sandstone Member, Etchegoin Formation, in well 324–19R at Elk Hills]

Mulinia sand zone

Feet	
2,095–2,097	Shale, greenish-gray; thick- and thin-shelled pelecypod fragments, black and white ostracodes, few gastropods; *Mulinia*(?) reported.
2,097–2,102	No sample.
2,102–2,110	Shale, greenish-gray to medium-dark-gray, slickensides; trace angular fine- to medium-grained limy sandstone; trace pelecypod fragments—*Mulinia*(?), trace gastropods; *Mulinia*(?) reported.
2,110–2,119	Shale, as above; abundant thick- and thin-shelled pelecypods between 2,114 and 2,118 feet; abundant *Mulinia* reported at 2,112 feet.
	Submulinia sand (2,119–2,146 ft.)
2,119–2,130	Sandstone, greenish-gray, very fine to fine-grained, angular to subangular, silty, very clayey; few thick-shelled pelecypod fragments; few brownish-gray shale laminae in lower part; *Mulinia* reported.
2,130–2,140	Shale, greenish-gray; abundant fresh-water gastropods, thick-shelled pelecypod fragments, trace fish fragments; *Mulinia* reported.
2,140–2,146	Sandstone, greenish-gray, fine-grained, angular, well-sorted, clayey, friable; few pelecypod fragments; trace medium-grained sandstone. Base of Submulinia sand.
2,146–2,147	Shale, greenish-gray, scattered subrounded medium- to coarse-grained quartz sand; fish fragments.
2,147–2,162	Siltstone, greenish-gray; interlaminated or thinly interbedded with silty shale; trace fine-grained sandstone; trace pelecypod fragments.
2,162–2,184	Shale, greenish-gray, very clayey to very silty, slickensides; scattered siltstone laminae; trace medium-grained sandstone laminae; pyritized diatoms, trace Foraminifera, fish fragments, and pelecypod fragments.
2,184–2,190	No sample.
2,190–2,196	Shale, greenish-gray, very silty, slickensides; few laminae of fine-grained sandstone with trace oil staining; pyritized diatoms.
2,196–2,200	No sample.
2,200–2,207	Shale, as above; heavy oil in fractures; trace Foraminifera. Includes 6-inch bed of conglomeratic shale at 2,206 feet composed of well-rounded polished dark-yellowish-brown dolomite pebbles up to 1-inch in diameter, scattered fine- to medium-grained sand, abundant carbonaceous plant fragments, few pelecypod fragments and Foraminifera.
2,207–2,225	Shale, greenish-gray, slightly silty, slickensides; scattered gray silt spots—ostracode molds(?).
2,225–2,230	No sample.
	Bittium sand (2,230–2,239 ft.)
2,230–2,235	No sample.
2,235–2,239	Sandstone, greenish-gray, medium-grained, angular to subangular,

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Bittium sand—Continued

Feet	
	clay matrix, glauconite, friable; trace oil staining(?). Base of Bittium sand.
2,239–2,240	Shale, greenish-gray; abundant pelecypod and gastropod fragments, trace *Bittium*(?).
2,240–2,253	Shale, greenish-gray, silty, slightly platy, biotite; fish scales, pyritized diatoms, trace pelecypod fragments and *Bittium*(?).
2,253–2,261	Siltstone, greenish-gray to light-yellowish-brown, very sandy, micaceous; trace subangular fine-grained silty sandstone; trace medium-grained gray feldspar; trace pelecypod fragments.
2,261–2,265	No sample.
2,265–2,272	Shale, light-olive-gray, very silty, platy; trace siltstone; Foraminifera, fish scales.
2,272–2,275	No sample.
	Wilhelm sand zone
2,275–2,289	Siltstone, greenish-gray, clayey, very finely sandy, poorly to well-sorted, micaceous; interlaminated with medium-gray sandy shale and very fine grained sandstone; possible oil staining(?); includes 2- to 3-inch bed of hard dense yellowish-brown to olive-brown silty dolomite at top.
2,289–2,298	Siltstone, greenish-gray, very clayey, partly sandy, micaceous; trace pelecypod fragments and Foraminifera.
2,298–2,305	Sandstone, light-olive-gray, fine- to medium-grained, angular, partly cemented with hard dense dolomite, partly friable; trace dense dolomite with calcite veins; pelecypod fragments.
2,305–2,350	Siltstone, greenish-gray to light-olive-gray, very finely sandy, clayey, micaceous, trace glauconite pellets at 2,340 feet; oil staining(?) in parts; trace angular very fine grained clayey sandstone; trace shale laminae; trace pelecypod fragments and black ostracodes.
2,350–2,358	Shale, greenish-gray, silty; trace gastropods and Foraminifera.
2,258–2,365	Sandstone, light-olive-gray, very fine to coarse-grained, angular to well-rounded, very silty, clayey, abundant fine- to coarse-grained glauconite pellets, micaceous; scattered black phosphatic pelecypod fragments.
2,365–2,370	Sandstone, light-olive-gray, medium-grained, angular to rounded, well-sorted, dense limy cement, abundant feldspar grains, abundant medium-grained glauconite pellets with preferred orientation; pelecypod fragments.
2,370–2,382	Siltstone, greenish-gray, very sandy, clayey, micaceous, trace glauconite pellets, friable; trace pelecypod fragments.
2,382–2,387	Shale, greenish-gray, silty.
2,387–2,395	Sandstone, light-olive-gray, medium-grained, angular to subangular quartz grains, subangular to rounded feldspar grains, silty, clayey, micaceous, abundant glauconite pellets in parts; oil staining.
2,395–2,400	Sandstone, very light gray, fine-grained, angular, silty, slightly limy; oil staining; pelecypod fragments; few greenish-gray shale laminae.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Wilhelm sand zone—Continued

Feet	
2,400–2,411	Siltstone, light-olive-gray, very sandy, micaceous, glauconitic.
2,411–2,418	Shale, greenish-gray, very silty, micaceous; trace fine-grained sandstone laminae.
2,418–2,433	Siltstone, greenish-gray, finely sandy, clayey, micaceous; trace pelecypod fragments; trace shale; some hard light-greenish-gray subangular fine- to medium-grained glauconitic clayey sandstone.
2,433–2,440	Shale, medium-gray and greenish-gray, interbedded, hard, slightly fissile.
2,440–2,453	Sandstone, light-olive-gray to yellowish-brown, fine-grained, subangular, silty, clayey, micaceous, glauconitic, hard to very friable; scattered medium to coarse grains; oil-stained; trace pelecypod fragments.
2,453–2,475	Shale, greenish-gray, slightly silty, slightly fissile to platy; trace siltstone and fine-grained sandstone laminae.
2,475–2,480	Sandstone, light-olive-gray, fine-grained, angular to subangular, silty, very clayey.
2,480–2,489	Siltstone, greenish-gray, very finely sandy, very clayey, micaceous; trace pelecypod fragments.
2,489–2,497	Shale, greenish-gray.
2,497–2,510	Siltstone, greenish-gray, very finely sandy, clayey, micaceous; trace pelecypod fragments and fish scales.
2,510–2,519	Shale, greenish-gray, silty, micaceous; trace glauconitic angular fine-grained sandstone.
2,519–2,521	Siltstone, greenish-gray, very clayey, micaceous; fish scales.
2,521–2,535	Sandstone, light-olive-gray to greenish-gray, fine-grained, angular to subangular, very clayey to silty, micaceous, glauconitic, hard to friable; trace carbonaceous material.
2,535–2,545	Siltstone, greenish-gray, very clayey, very sandy, micaceous, glauconitic; trace shell fragments.
2,545–2,555	Sandstone, light-olive-gray, very fine grained, angular to subangular, very silty, clayey, slightly limy, disseminated biotite, trace glauconite; trace pelecypod fragments.
2,555–2,580	Siltstone, light-olive-gray, finely sandy, clayey; scattered very fine grained glauconitic sandstone and soft waxy shale laminae; trace bluish-white opaline chert; trace fish fragments(?).
	Gusher sand zone
2,580–2,600	Sandstone, greenish-gray to light-olive-gray, fine- to medium-grained, subangular clear quartz grains, abundant subrounded gray feldspar grains, abundant medium- to coarse-grained glauconite pellets, clay matrix, friable; trace rounded polished black fish fragments.
2,600–2,611	Sandstone, light-olive-gray, fine- to medium-grained, angular to subangular, clayey, trace siliceous cement, abundant glauconite pellets, scattered black subrounded coarse phosphate pellets (sporbo); scattered medium- to coarse-grained black organic material.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Gusher sand zone—Continued

Feet	
2,611–2,615	No sample.
2,615–2,618	Sandstone, as above, hard, slightly siliceous, trace black to brown limy phosphate pebbles up to 10 mm in diameter.
2,618–2,642	Siltstone, light-olive-gray to greenish-gray, very finely sandy, clayey; finely disseminated black organic material; trace smooth waxy shale laminae; trace fish scales.
2,642–2,650	Sandstone, light-olive-gray, very fine to fine-grained, angular to subangular, very silty, clayey, hard to friable; trace glauconitic medium-grained sandstone with slightly siliceous clay cement; pelecypod and gastropod fragments.
2,650–2,655	Siltstone, light-olive-gray, very sandy, clayey, scattered medium- to pebble-size black dolomitic phosphate nodules.
2,655–2,656	Shale, medium-dark-gray, slightly silty, bentonitic(?).
2,656–2,675	Siltstone, light-olive-gray, very finely sandy, slightly micaceous, friable; scattered glauconitic fine- to medium-grained sandstone laminae; trace silty sandy limestone at 2,661 feet.
2,675–2,676	Dolomite, light-olive-gray, hard, dense, scattered black spots; some sandy siltstone.
2,676–2,690	Siltstone, light-olive-gray, very sandy; scattered laminae of well-sorted glauconitic subangular medium-grained sandstone; trace pelecypod and fish fragments.
2,690–2,697	Sandstone, light-olive-gray to yellowish-brown, medium-grained, subangular, abundant feldspar, oil-stained, glauconitic, well-sorted, trace white clay matrix.
2,697–2,715	Siltstone, light-olive-gray to yellowish-gray, sandy, clayey, micaceous; few laminae of well-sorted slightly siliceous glauconitic medium-grained sandstone; few shale laminae; trace Foraminifera, shell fragments, and fish fragments.
2,715–2,718	No sample.
2,718–2,724	Siltstone, greenish-gray, very clayey, slightly micaceous; few Foraminifera; trace very silty clayey fine-grained sandstone; 6-inch bed of very silty yellowish-gray limestone at top, contains fish fragments, grades downward into hard dense light-olive-gray dolomite with scattered black spots.
2,724–2,728	No sample.
2,728–2,738	Siltstone, greenish-gray, slightly micaceous; trace medium- to dark-gray bentonite(?).
2,738–2,758	Siltstone, greenish-gray, very finely sandy, very clayey, slightly micaceous; trace very fine grained sandstone laminae; trace Foraminifera.
2,758–2,762	No sample.
2,762–2,770	Siltstone, greenish-gray, very finely sandy, micaceous, slightly fissile, trace irregular spots of gray clay; fish scales.
2,770–2,778	Siltstone, as above; lower 4 feet becomes light-olive-gray; trace medium- to dark-gray clay with finely disseminated black specks.
2,778–2,780	Shale, yellowish-green, soft, smooth, waxy.
2,780–2,788	No sample.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Gusher sand zone—Continued

Feet	
2,788–2,798	Siltstone, light-olive-gray, very finely sandy, clayey, micaceous, finely disseminated black grains; some very fine grained silty sandstone with oil staining on fractures; pelecypod fragments; trace greenish-gray shale.
2,798–2,800	Sandstone, light-olive-gray, very fine grained, very silty, trace siliceous clayey cement; pelecypod and gastropod fragments.
2,800–2,802	No sample.
2,802–2,808	Siltstone, light-olive-gray, very finely sandy, clayey, disseminated very fine to fine black grains.
2,808–2,810	No sample.
2,810–2,818	Siltstone, as above; tough, slightly fissile, finely disseminated carbonaceous(?) material; fish fragments.
2,818–2,819	No sample.
2,819–2,830	Siltstone, light-olive-gray to greenish-gray, very clayey, micaceous, tough, platy to slightly fissile; trace pyritized diatoms.
2,830–2,833	No sample.
2,833–2,846	Siltstone, light-olive-gray, very finely sandy, trace dolomitic cement; trace well-sorted very fine grained clayey sandstone; fish fragments.
2,846–2,850	Shale, light-olive-gray, micaceous, fissile, interbedded with siltstone; Foraminifera, includes thin bed (probably 1–3 inches thick) of yellowish-gray silty dolomite, very finely disseminated black spots, trace cavities with crystal lining.
2,850–2,873	Shale, light-olive-gray, very silty to very clayey, platy to slightly fissile, micaceous, tough, trace slickensides; fish scales.
2,873–2,879	No sample.
2,879–2,890	Siltstone, light-olive-gray, very clayey, slightly sandy, blocky to slightly fissile; few pelecypod fragments including *Pecten*(?), some black phosphatic pelecypod fragments.
2,890–2,900	Siltstone, light-olive-gray, very sandy; laminae of slightly glauconitic slightly limy angular very fine to fine-grained sandstone; scattered fine to medium sand grains; trace small dark-yellowish-brown phosphate pebbles; abundant pelecypod fragments, few gastropod fragments; few medium- to dark-gray shale laminae with finely disseminated black grains.
2,900–2,910	Sandstone, light-olive-gray, fine-grained, subangular, some medium grains, glauconitic, clayey, slightly to very limy; trace yellowish-gray slightly micaceous siltstone; trace shell fragments.
2,910–2,922	*Siltstone, gray, very finely sandy, compact; few shell fragments.
2,922–2,923	*Sandstone, light-gray, silty, hard, limy cemented; few rounded tan cherty shale pebbles up to ½ inch in diameter.
2,923–2,925	*Siltstone, light-gray, firm; few irregular laminae of sandy silt.
2,925–2,928	No sample.
2,928–2,931	*Siltstone, gray, clayey; few sand spots at bottom.
2,931–2,939	No sample.
2,939–2,981	*Siltstone, gray, clayey; scattered irregular laminae of light-gray silt; pelecypods, gastropods, Foraminifera.
2,981–2,991	No sample.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Gusher sand zone—Continued

Feet	
2,991–3,004	*Siltstone, light-gray, clayey; irregular laminae of fine gray silt; pelecypods, gastropods.
3,004–3,005	No sample.
3,005–3,019	Siltstone, light-olive-gray, very clayey, very finely sandy; laminae of olive-gray to medium-dark-gray silty shale and very fine grained sandstone, finely micaceous (biotite); pelecypod fragments and molds, fish fragments.
3,019–3,025	No sample.
3,025–3,032	Siltstone, as above; Foraminifera.
3,032–3,035	No sample.
3,035–3,050	Siltstone, light-olive-gray to greenish-gray, very clayey, very finely sandy, slightly micaceous; laminae of very fine grained clayey sandstone; pelecypod and gastropod fragments; trace dark-yellowish-brown dolomite or phosphate at 3,035 feet.
3,050–3,080	Siltstone, as above; grades to very fine grained angular to subangular sandstone in lower part; trace black phosphatic pelecypod fragments, trace Foraminifera.
3,080–3,085	Siltstone, upper part light-olive-gray to olive-gray, sandy, dense dolomitic cement; pelecypod fragments, Foraminifera(?); some light-olive-gray non-limy siltstone.
3,085–3,095	Siltstone, light-olive-gray to slightly greenish-gray, very clayey, finely disseminated black silt grains (phosphate?), slightly micaceous; trace very silty shale; fish fragments, trace pelecypod fragments.
3,095–3,110	Siltstone, as above; few laminae of light-olive-gray silty shale; trace coarse-grained brownish-gray phosphate pellets; pelecypod fragments.
3,110–3,114	Siltstone, light-olive-gray, very clayey, scattered very fine to medium-grained sand, disseminated biotite; laminae of olive-gray to greenish-gray slightly fissile shale; trace pyritized diatoms.
	Calitroleum sand zone
3,114–3,120	Siltstone, light-olive-gray, coarse-grained, very finely sandy, clayey, mostly friable, some siliceous cemented; trace pelecypod and gastropod fragments; trace greenish-gray shale laminae.
3,120–3,132	Siltstone, as above; thin beds or laminae of very fine grained angular sandstone; trace dolomite and medium- to dark-gray shale laminae.
3,132–3,140	No sample.
3,140–3,150	Siltstone, light-olive-gray, coarse-grained, very finely sandy, clayey, finely micaceous; one barnacle found near middle of core.
3,150–3,152	Sandstone, light-olive-gray to yellowish-brown, very fine grained, angular, silty, clayey, partly friable, slightly oil stained.
3,152–3,158	Siltstone, light-olive-gray, friable.
3,158–3,165	No sample.
3,165–3,180	Siltstone, light-olive-gray; few laminae of hard siliceous cemented clayey very fine grained sandstone; abundant pelecypod and

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Calitroleum sand zone—Continued

Feet	
	gastropod fragments in lower few feet, trace black phosphatic pelecypod fragments.
3,180–3,191	Siltstone, light-olive-gray to yellowish-brown oil stained, very clayey; thinly interbedded or interlaminated with friable clayey biotitic very fine grained sandstone; lower part uniformly oil stained; abundant pelecypod and gastropod fragments and molds, common black phosphatic shell fragments, fish fragments, trace barnacles.
3,191–3,192	Sandstone, light-olive-gray, very fine grained, very silty, clayey, hard, carbonate cement; few sandy siltstone laminae; abundant thick-shelled pelecypods, trace gastropods and black phosphatic shell fragments; trace pinkish-gray limestone with scattered medium to coarse sand grains.
3,192–3,198	Sandstone, light-olive-gray to yellowish-brown oil stained, very fine grained, silty, nonlimy, friable; abundant pelecypod fragments and gastropod fragments, trace barnacles and black phosphatic crab claws.
3,198–3,201	Sandstone, light-olive-gray, very fine grained, silty, clayey; thinly interbedded with very limy to nonlimy light-gray siltstone; few greenish-gray shale laminae; pelecypod fragments; trace small pale yellowish-brown dolomite or phosphate pebbles.
3,201–3,203	Sandstone, light-olive-gray, very fine grained, some fine grained; interbedded with clayey siltstone and silty shale.
3,203–3,213	*Siltstone, oil stained in spots, very clayey to finely sandy; pelecypods, gastropods, barnacles; overlies 1½ feet of very hard cemented light-gray fine-grained sandstone and friable siltstone.
3,213–3,221	No sample.
3,221–3,237	Siltstone, light-olive-gray to yellowish-gray oil stained, friable except for 6-inch bed of hard olive-gray limy siltstone near middle of core; few pelecypods and gastropods, trace fish fragments and shale laminae.
3,237–3,240	No sample.
3,240–3,246	Siltstone, light-olive-gray, firm to friable; few very fine grained silty sandstone laminae; trace shell fragments.
3,246–3,248	Siltstone, as above; slightly more sand, partly limy cemented; abundant shell fragments; trace gastropods in greenish-gray shale laminae.
3,248–3,255	*Siltstone, gray, very finely sandy, clayey, friable.
3,255–3,270	Siltstone, light-olive-gray, coarse-grained, clayey, firm to friable, trace limy cement, trace biotite; few hard dolomitic shale laminae; few very fine grained sandstone laminae; carbonaceous plant fragments; pelecypod fragments, Foraminifera.
3,270–3,280	Siltstone, light-olive-gray, very clayey, blocky to slightly fissile, trace very coarse grains of black phosphatic(?) material, trace dense calcite veins in upper half; trace pelecypod fragments and Foraminifera.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Calitroleum sand zone—Continued

Feet	
3,280–3,285	Shale, olive-gray, very clayey, tough; interbedded with yellowish-gray oil stained(?) slightly sandy friable siltstone; trace carbonaceous plant fragments, Foraminifera, pelecypods, and black ostracodes.
3,285–3,306	Shale, light-olive-gray to olive-gray, silty; few hard dolomitic siltstone and shale laminae; abundant leached shell fragments, few unleached pelecypod fragments.
3,306–3,313	Shale, light-olive-gray, silty, blocky to slightly fissile; few olive-gray shale laminae; trace worm borings(?); trace yellowish-gray limy very fine grained sandstone laminae; pelecypod fragments.
3,313–3,316	No sample.
3,316–3,318	Shale, olive-gray; laminae of light-olive-gray silty shale; thin bed of olive-gray to yellowish-gray clayey dolomite with load casts(?) of coarse siltstone or very fine grained sand; shell fragments.
3,318–3,330	No sample.
3,330–3,345	Shale, light-olive-gray to olive-gray, silty, hard to tough, blocky to slightly fissile; few coarse siltstone laminae; thin bed of yellowish-gray silty dolomite near top of core; trace medium to coarse grains of light-gray feldspar, quartz, and rounded black phosphate pellets (sporbo); trace gastropod fragments and Foraminifera.
3,345–3,359	Shale, light-olive-gray to medium-gray, silty; laminae of light-gray coarse siltstone and well-sorted very fine grained sandstone; fish scales, trace shell fragments.
3,359–3,369	Siltstone, light-olive-gray, very clayey, slightly sandy, trace coarse angular grains of clear quartz, disseminated very fine to fine-grained black phosphate pellets (sporbo); trace dusky-yellow very fine grained dolomitic sandstone that includes up to 25 percent phosphate pellets (sporbo); fish fragments, shell fragments.
3,369–3,371	Siltstone, as above; trace of very fine to very coarse grained angular limy cemented yellowish-gray sandstone, copper-colored mica.
3,371–3,372	Sandstone, moderate-yellowish-brown to yellowish-gray, very fine grained, angular, silty, composed of 10–25 percent fine-grained phosphate pellets (sporbo), few medium-grained sporbo, partly dolomitic.
3,372–3,373	Dolomite, light-olive-gray to greenish-gray, silty, dense, brittle, finely disseminated black spots (sporbo?), in contact with sandstone.
3,373–3,380	Shale, light-olive-gray, silty, tough, scattered phosphate pellets (sporbo); interbedded with smooth waxy clayey olive-gray to medium-dark-gray shale.
3,380–3,382	No sample.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Carman Sandstone Member—Continued
Calitroleum sand zone—Continued

Feet	
3,382–3,387	Siltstone, light-olive-gray, slightly yellowish-gray, clayey, slightly micaceous, firm to friable, few phosphate pellets (sporbo); trace very fine grained sandstone laminae; trace very coarse grains of light-gray subangular feldspar and black phosphatic subrounded fish bones; includes thin bed of very light gray to yellowish-gray silty limestone with finely disseminated sporbo.

Tupman Shale Member

[Type section of the Tupman Shale Member, Etchegoin Formation, in well 324–19R at Elk Hills]

Buliminella silt zone

3,387–3,389	Shale, light-olive-gray, silty; interbedded with olive-gray clayey shale; trace of hard limy cemented very fine to very coarse grained dusky-yellow to yellowish-gray sandstone; trace light-brown mica.
3,389–3,393	No sample.
3,393–3,404	Shale, light-olive-gray, silty, slightly micaceous, tough; trace hard siliceous cemented very fine to very coarse grained sandstone; trace coarse to very coarse grained black phosphate pellets; trace fine to very coarse angular to rounded black fish fragments.
3,404–3,410	Shale, light-olive-gray to olive-gray, very clayey, tough, slightly fissile; abundant *Buliminella elegantissima,* abundant fish fragments; trace brittle sandstone as above.
3,410–3,414	No sample.
3,414–3,419	Shale, light-olive-gray, slightly olive-gray, tough; abundant Foraminifera, fish fragments; trace coarse siltstone laminae.
3,419–3,421	No sample.
3,421–3,423	Shale, light-olive-gray, slightly silty; Foraminifera, few pyritized diatoms.
3,423–3,432	No sample.
3,432–3,437	Shale, light-olive-gray, silty; siltstone laminae; lower few feet slightly sandy and contains disseminated phosphate pellets (sporbo); fish fragments, Foraminifera; trace coarse-grained black phosphate pellets.
3,437–3,442	No sample.
3,442–3,445	Shale, light-olive-gray, very silty, blocky to slightly fissile; scattered very fine grained black carbonaceous material(?).
3,445–3,450	No sample.
3,450–3,453	Shale, light-olive-gray, silty, slightly micaceous, scattered fine-grained black material (sporbo? or carbonaceous material?).
3,453–3,461	No sample.
3,461–3,470	Shale, light-olive-gray, very silty; interbedded with very clayey siltstone, slightly micaceous, tough to friable.
3,470–3,476	Siltstone, light-olive-gray, very clayey, slightly to very sandy, slightly micaceous, firm to friable.
3,476–3,481	No sample.
3,481–3,489	Siltstone, light-olive-gray, very clayey; includes thin bed of

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
	grayish-orange to dark-yellowish-brown very limy silty biotitic very fine grained to pebbly sandstone.
3,489–3,492	Limestone, light-gray to light-olive-gray, very silty, clayey, hard, blocky.
3,492–3,496	No sample.
3,496–3,508	Shale, light-olive-gray, very silty, blocky to platy; 1-inch bed of hard silty dusky-yellow limestone near bottom.
3,508–3,511	No sample.
3,511–3,513	Shale, light-olive-gray, silty; trace Foraminifera.
3,513–3,516	No sample.
3,516–3,525	Shale, light-olive-gray, silty, hard, slightly brittle.
3,525–3,529	Siltstone, light-olive-gray, very clayey, hard; scattered light-brown fine-grained rusty spots (Foraminifera? or diatoms?).
3,529–3,530	No sample.
3,530–3,531	Dolomite, light-olive-gray to yellowish-gray, silty, clayey, hard, dense; some silty shale with light-brown spots.
3,531–3,538	No sample.
3,538–3,551	Shale, light-olive-gray, slightly to very silty, hard, slightly fissile; scattered light-brown spots (Foraminifera?), fish scales and other fish fragments.
3,551–3,562	No sample.
3,562–3,578	Siltstone, light-olive-gray, clayey, partly sandy, firm to friable; light-brown spots (Foraminifera?) and fish fragments in lower part.
3,578–3,580	Shale, medium-dark-gray to olive-gray, slightly silty, fissile; few siltstone laminae; Foraminifera, fish fragments.
3,580–3,583	No sample.
3,583–3,586	Limestone, light-gray, very clayey, silty, some very limy shale; silt size black specks (sporbo?).
3,586–3,590	Shale, olive-gray, silty, blocky to fissile; laminae of light-olive-gray silty shale; fish fragments, plant(?) fragments.
3,590–3,593	Shale, medium-dark-gray to olive-gray, very clayey; few silty shale laminae; includes thin bed of very silty dusky-yellow dolomite with disseminated black silt (sporbo?).
3,593–3,594	No sample.
3,594–3,596	Shale, medium-dark-gray to olive-gray, very clayey.
3,596–3,604	No sample.
3,604–3,605	Shale, light-olive-gray, slightly olive-gray, silty, slightly fissile, slightly micaceous.
3,605–3,614	No sample.
3,614–3,616	Shale, light-olive-gray, slightly olive-gray; very silty, slightly micaceous; few siltstone laminae; fish fragments.
3,616–3,630	No sample.
3,630–3,638	Shale, light-olive-gray to olive-gray, very finely to finely sandy, tough to hard; thin laminae of hard to friable clayey micaceous subangular very fine grained sandstone; fish fragments, microfossils.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
3,638–3,648	Shale, as above but more mica and fish fragments, trace limy cement; scattered very fine grained phosphate pellets (sporbo) near bottom of core.
3,648–3,656	No sample.
3,656–3,665	Shale, light-olive-gray, silty; trace thin laminae of brittle black organic material with brilliant luster on fresh break (coal? or tar?).
3,665–3,669	No sample.
3,669–3,680	Shale, light-olive-gray, slightly to very silty, blocky to fissile, slightly micaceous, abundant light-brown weathered Foraminifera, fish fragments; 1-inch bed of hard very dolomitic dusky-yellow shale at 3,675 feet.
3,680–3,685	No sample.
3,685–3,689	Shale, light-olive-gray, some dark-yellowish-brown, very silty, scattered light-brown fine-grained spots; fish fragments, some with crystal fillings; rare very coarse quartz grains.
3,689–3,696	No sample.
3,696–3,698	Shale, light-olive-gray, some dark-yellowish-brown, very clayey, partly silty; fish fragments, Foraminifera(?).
3,698–3,700	No sample.
3,700–3,701	Shale, as above.
3,701–3,706	No sample.
3,706–3,711	Shale, olive-gray to light-olive-gray, some dark-yellowish-brown, very clayey, slightly fissile; light-brown weathered Foraminifera.
3,711–3,720	No sample.
3,720–3,723	Shale, olive-gray, silty; fish scales.
3,723–3,730	No sample.
3,730–3,731	*Shale, gray to olive-gray, silty, phosphatic nodules at bottom.
3,731–3,732	No sample.
3,732–3,739	Shale, light-olive-gray to yellowish-gray, slightly to very silty; few hard coarse siltstone laminae; includes very thin bed of hard silty light-gray to light-olive-gray dolomite with abundant microfossils and disseminated black silt grains (sporbo?).
3,739–3,747	Shale, medium-dark-gray to olive-gray, silty, tough, slightly fissile and micaceous; yellowish-brown weathered Foraminifera.
3,747–3,772	*Shale, gray, silty to finely sandy, fairly hard; irregular spots and streaks of light-gray finely sandy siltstone; fish fragments; rare phosphatic nodules.
3,772–3,780	No sample.
3,780–3,781	*Shale, dull-gray, silty, firm.
3,781–3,787	No sample.
3,787–3,792	*Shale, gray, silty, becoming finely sandy and partly oil stained in lower part.
3,792–3,798	No sample.
3,798–3,799	*Shale, gray, silty; finely sandy in places; partly oil stained; firm.
3,799–3,810	No sample.
3,810–3,819	*Shale, gray, partly silty, firm; fish fragments; rare phosphatic nodules.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
3,819–3,820	No sample.
3,820–3,821	*Shale, gray, firm.
3,821–3,828	No sample.
3,828–3,857	*Shale, gray, silty; irregular interlaminated with silty very fine grained light-gray sandstone; few irregular 2–3 inch beds of tan limestone; few fish fragments and Foraminifera; dip 21°.
3,857–3,860	*Siltstone, gray, finely sandy; few spots of tight fine-grained sand.
3,860–3,869	*Shale, gray, silty; irregularly interlaminated with light-gray sandy siltstone; few limestone lentils to ½-inch thick; 2-inch bed of silty fine-grained sandstone at top of core.
3,869–3,870	No sample.
3,870–3,881	*Shale, dull-gray, silty; few irregular streaks of light-gray siltstone.
3,881–3,891	Shale, light-olive-gray, silty, slightly fissile and micaceous; disseminated very fine grained black organic material; lower part is very silty and contains few carbonaceous plant fragments and diatoms(?).
3,891–3,894	*Siltstone, light-gray, clayey, finely sandy, firm, oily.
3,894–3,902	*Shale, dull gray, slightly silty; few 2–3 inch streaks of hard silty light-gray limestone.
3,902–3,909	*Shale, dull-gray; few irregular laminae of very silty tight light-gray fine-grained sandstone; 2-inch bed of tan limestone at top; dip 20°–25°.
3,909–3,912	Shale, light-olive-gray, very silty to very sandy, slightly brittle and micaceous; few laminae of silty subangular to subrounded very fine to fine-grained sandstone; trace plant fragments, fish fragments, and phosphate pellets (sporbo).
3,912–3,913	*Shale, dull-gray, silty; few irregular laminae of dark-gray sandy siltstone; abundant sporbo.
3,913–3,917	No sample.
3,917–3,933	Shale, light-olive-gray to slightly olive-gray, silty, slightly fissile and micaceous, hard; scattered irregular laminae of silty sandy phosphate (sporbo)-bearing shale; few laminae of very fine grained phosphate (sporbo)-bearing sandstone; abundant fish fragments, some well rounded black fish bones.
3,933–3,934	No sample.
3,934–3,959	Shale, light-olive-gray to olive-gray, very finely silty, tough to brittle; few laminae of silty clayey very fine grained sandstone with abundant brownish-gray fine-grained phosphate pellets (sporbo); common small grayish-black limy phosphate pebbles; few thin beds of hard dolomitic shale in lower 10 feet.
3,959–3,966	Siltstone, light-olive-gray, very clayey, hard, blocky, sparse to abundant very fine to medium-grained phosphate pellets (sporbo); interbedded with hard slightly dolomitic silty very fine grained sandstone that includes up to 25 percent fine- to medium-grained sporbo.
3,966–3,976	Shale, light-olive-gray, very silty, sandy, abundant phosphate pellets (sporbo), trace small phosphate pebbles; one thin bed of hard silty dolomite near middle; trace Foraminifera.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
3,976–3,979	Sandstone, olive-gray, very fine grained, angular, silty, clayey, slightly dolomitic, hard, fine- to medium-grained phosphate pellets (sporbo) make up as much as 25 percent of rock, few coarse-grained sporbo; fish fragments.
3,979–3,995	Shale, olive-gray to greenish-gray, very clayey, platy to slightly fissile, tough to brittle; few thin beds of light olive-gray dolomite; fish fragments, trace Foraminifera.
3,995–4,005	No sample.
4,005–4,006	*Shale, gray, firm to slightly friable.
4,006–4,011	No sample.
4,011–4,017	*Shale, gray, silty, firm to friable.
4,017–4,031	Sandstone, dark-yellowish-gray to grayish-orange, very fine grained, angular quartz, limy silt and clay matrix, 25–40 percent of rock is composed of fine-grained black phosphate pellets (sporbo), trace small rounded limy yellowish-gray phosphate pebbles; trace fish vertebrae; lower 4 feet contains thin beds of clayey siltstone.
4,031–4,040	Shale, medium-gray to light-olive-gray, silty, hard, blocky to slightly fissile; trace thin dolomite beds; rare phosphate pellets (sporbo).
4,040–4,043	Sandstone, yellowish-gray to light-brown, very fine grained, angular quartz, limy silt and clay matrix, 20–40 percent of rock is composed of fine-grained well-rounded phosphate pellets (sporbo); trace fish vertebrae and small black phosphate pebbles.
4,043–4,047	No sample.
4,047–4,050	Shale, light-olive-gray, very silty, blocky to slightly fissile, few phosphate pellets (sporbo).
4,050–4,055	Sandstone, yellowish-gray to light olive-gray, very fine grained, angular quartz, very silty, clayey, 15–30 percent of rock is composed of fine-grained well-rounded black phosphate pellets (sporbo); some siltstone and shale laminae; trace fish vertebrae; reported dip 16°.
4,055–4,057	No sample.
4,057–4,062	Sandstone, yellowish-gray to light olive-gray, very fine to fine-grained, composed of 30–50 percent limy silt and clay, 20–30 percent well-rounded fine-grained phosphate pellets (sporbo), and 20–30 percent very fine grained angular quartz; fish vertebrae.
4,062–4,067	Shale, olive-gray, some mottled yellowish-gray and light-olive-gray, very silty, scattered yellowish-brown phosphate pellets (sporbo), slightly fissile; trace dense yellowish-gray silty dolomite; fish vertebrae.
4,067–4,077	Shale, light-olive-gray to olive-gray, finely silty slightly brittle, 2 percent disseminated brown and black phosphate pellets (sporbo), trace biotite; trace pyritized plant fragments and fish fragments.
4,077–4,082	Shale, medium-gray to light-olive-gray, finely silty, dolomitic; trace dusky-yellow silty limestone with scattered phosphate

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
	pellets (sporbo).
4,082–4,084	Dolomite, light-olive-gray, hard, dense, brittle, very silty and clayey, few phosphate pellets (sporbo).
4,084–4,097	Shale, light-olive-gray to medium-dark-gray, finely silty, hard; numerous thin beds of hard dense light-olive-gray to dark-yellowish-gray silty dolomite with few phosphate pellets (sporbo); trace small yellowish-gray limy phosphate pebbles; rare fish fragments.
4,097–4,107	Shale, olive-gray, silty, blocky to slightly fissile, oil stains(?); light-brown weathered Foraminifera.
4,107–4,111	No sample.
4,111–4,117	Shale, medium-dark-gray to olive-gray, silty, blocky to slightly fissile; light-brown weathered Foraminifera.
4,117–4,131	Siltstone, light-olive-gray, very clayey, very finely sandy, hard, dolomitic; few laminae as much as 20 percent very finely grained phosphate pellets (sporbo); trace hard yellowish-gray dolomite; fish fragments.
4,131–4,164	Shale, medium-gray to olive-gray, silty, tough to slightly brittle; scattered thin beds of hard dense yellowish-gray silty dolomite; fish fragments, trace carbonaceous plant fragments.
4,164–4,181	Shale, medium-dark-gray to olive-gray, very clayey to very silty, blocky to slightly fissile; trace dense yellowish-gray silty dolomite near bottom; fish fragments, trace Foraminifera.
4,181–4,185	Shale, medium-dark-gray to olive-gray, slightly silty, pelletal texture; scattered laminae 30–35 percent very fine to medium-grained well-rounded phosphate pellets (sporbo); few hard dolomite laminae; trace small grayish-black phosphate pebbles; abundant fish fragments.
4,185–4,188	No sample.
4,188–4,195	Shale, as above.
4,195–4,196	No sample.
4,196–4,206	Shale, olive-gray, silty, slightly brittle; few fish fragments, Foraminifera.
4,206–4,217	*Shale, gray to olive-gray, silty; abundant Foraminifera *(Buliminella elegantissima?)*.
4,217–4,221	No sample.
4,221–4,241	Shale, olive-gray to light-olive-gray, silty, hard, slightly brittle; trace light-gray very fine to fine-grained silty slightly micaceous and glauconitic sandstone; Foraminifera, trace fish scales.
4,241–4,251	No samples.
4,251–4,252	Dolomite, dark-yellowish-gray, silty, hard, dense, brittle, few very fine grained phosphate pellets (sporbo); fish fragments.
4,252–4,268	Shale, olive-gray, silty, hard; laminae of sandy siltstone with phosphate pellets (sporbo); several very thin beds of silty yellowish-gray dolomite; trace oil stains; fish fragments, Foraminifera; reported dip 21°.
4,268–4,278	Shale, light-olive-gray to olive-gray, silty, trace yellowish-gray dolomite; trace oil stains on fractures; Foraminifera.

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
4,278–4,294	Shale, olive-gray, silty, hard, slightly brittle; oil stains on fractures; fish scales, weathered Foraminifera, rare black crab claws.
4,294–4,298	No sample.
4,298–4,310	Shale, olive-gray, very clayey, slightly fissile, brittle; fish scales; trace sand-size shell fragments, trace pelecypod molds, Foraminifera; reported dip 20°–22°.
4,310–4,319	No sample.
4,319–4,324	Shale, olive-gray, finely silty, hard, brittle; includes thin bed of light-olive-gray hard dense silty dolomite; trace Foraminifera and fish fragments; reported dip 24°–26°.
4,324–4,331	No sample.
4,331–4,336	Shale, olive-gray, silty, harder than above, brittle; trace yellowish-gray silty dolomite; Foraminifera.
4,336–4,341	No sample.
4,341–4,367	Shale, olive-gray, finely silty, blocky to platy, brittle; few thin beds of silty dolomite; fish scales, Foraminifera; reported dip 22°–27°.
4,367–4,373	Shale, as above; includes thin bed of hard silty light-olive-gray to yellowish-gray dolomite with gray spots and streaks.
4,373–4,376	No sample.
4,376–4,416	Shale, olive-gray, finely silty, blocky to slightly fissile, slightly brittle; trace yellowish-gray dolomite; trace fish scales and Foraminifera; trace oil stains on fractures in lower 16 feet; reported dip 18°–30°.
4,416–4,420	No sample.
4,420–4,431	Shale, olive-gray, finely silty, hard, brittle, trace dolomitic cement; trace fish fragments and Foraminifera.
4,431–4,441	No sample.
4,441–4,449	Shale, olive-gray, finely silty, hard, brittle; includes thin bed of hard dense silty yellowish-gray dolomite with weathered Foraminifera (?) and pelecypod molds; reported dip 24°.
4,449–4,484	Shale, olive-gray, finely silty, hard, brittle, slightly dolomitic; scattered thin beds of dense silty yellowish-gray dolomite; common to abundant light-brown weathered Foraminifera, fish fragments.
4,484–4,494	Shale, olive-gray, finely silty, hard, brittle, slightly siliceous (?); some shale has very fine to fine-grained pelletal texture (composed of clay pellets?); Foraminifera.
4,494–4,514	Shale, olive-gray; laminated or thinly interbedded with light-olive-gray shale; some shale has brownish tint, hard, slightly siliceous; trace siliceous dolomite; scattered light-brown weathered Foraminifera; reported dip 22°–23°.
4,514–4,534	Shale, olive-gray, slightly brownish in part, hard, slightly siliceous, slightly brittle; trace yellowish-gray silty dolomite; scattered Foraminifera, rare white ostracodes with quartz fillings; trace

Tertiary System—Continued
Pliocene Series—Continued
Etchegoin Formation—Continued
Tupman Shale Member—Continued
Buliminella silt zone—Continued

Feet	
	carbonaceous material or dead oil(?); reported dip 22°–23°.
4,534–4,547	Shale, olive-gray, silty, tough to hard; trace grayish-orange silty dolomite; trace Foraminifera and pelecypod fragments; reported dip 23°.
4,547–4,555	No sample.
4,555–4,562	Shale, olive-gray, finely silty, hard, slightly siliceous and dolomitic; trace carbonaceous material(?); rare ostracodes; reported dip 22°.
4,562–4,585	Shale, light-olive-gray to olive-gray, finely silty; some shale slightly siliceous but most not as hard as above, platy to blocky; several thin beds of dense yellowish-gray silty dolomite: Foraminifera, trace fish fragments, rare ostracodes and pelecypods; reported dip 22°–24°.
4,585–4,594	Shale, olive-gray, finely silty, slightly siliceous; trace Foraminifera; thin bed of dense yellowish-gray siliceous silty dolomite with few round light-gray silty spots; trace fish fragments and Foraminifera.
4,594–4,612	Shale, olive-gray, finely silty, more siliceous than above, hairlike fractures in parts; trace siliceous dolomite with conchoidal fracture; trace fish fragments, Foraminifera and pyritized plant fragments; reported dip 18°–25°.
4,612–4,631	Shale, olive-gray, finely silty, partly siliceous, hard, slightly brittle; few laminae of hard angular very fine grained silty sandstone; trace dense yellowish-gray dolomite with light-gray silty spots; common Foraminifera, trace fish scales.
4,631–4,643	Shale, as above; abundant weathered Foraminifera near top; reported dip 18°–23°.
4,643–4,650	No sample.
4,650–4,668	Shale, olive-gray, partly siliceous; includes thin bed of dense silty yellowish-gray dolomite; common weathered Foraminifera, trace fish scales, rare carbonaceous material and diatoms(?); reported dip 22°.
4,668–4,677	*Shale, brownish-gray; one 3-inch streak of hard tan limestone at 4,675 feet; small pelecypod casts.
4,677–4,687	*Shale, gray, very firm; spots of sandy shale; some redeposited silica; scattered collophane concretions; dip 24°.
4,687–4,696	*Shale, dark-gray, firm to hard, very brittle, scattered sand grains and colophane spots.
4,696–4,703	*Shale, dark-gray, slightly sandy in parts; few pyritized diatoms, trace pelecypod molds.
4,703–4,708	*Shale, gray to tannish-gray, firm to fairly hard, rare scattered sand grains, few colophane spots; fish fragments; dip 22°.
4,708–4,717	*Shale, gray to tannish-gray, firm to fairly hard, spots of redeposited silica(?) in parts, very rare scattered well-rounded gray quartz pebbles up to ½-inch isolated in shale matrix; dip 24°.

Tertiary System—Continued
Miocene Series
Reef Ridge Shale

Feet	
4,717–4,723	*Shale, tan-gray, few thin hard limy streaks; fish scales, very rare Foraminifera; dip 26°.
4,723–4,732	*Shale, gray to tan-gray; 3-inch bed of limy shale at top; fish fragments, few Foraminifera *(Buliminella elegantissima);* dip 24°–26°.
4,732–4,741	*Shale, grayish-brown, slightly banded, hard, fractured; few silty shale laminae; 1-inch bed of limestone at top; dip 26°–28°.
4,741–4,744	*Shale, brownish-gray, hard; thin streaks of limestone showing diatom impressions; rare silty streaks with crustacean fragments.
4,744–4,747	*Nodules, silty gray shale.
4,747–4,750	*Shale, brownish-gray, hard; pyritized diatoms.
4,750–4,759	*Shale, brownish-gray, rarely exhibiting platy fracture and faint banding; 3-inch bed of tan limestone at 4,751 feet; dip 21°–25°.
4,759–4,768	*Shale, brownish-gray, commonly exhibiting diatomite fracture in lower 3 feet; 2-inch bed of tan limestone at 4,767 feet; pelecypod cast at 4,764 feet; dip 21°–24°.
4,768–4,776	No sample.
4,776–4,778	*Shale, gray to brownish-gray, fairly hard, silty and finely sandy in parts with irregular spots and streaks of light-gray fine-grained silty sandstone; dip 26°.
4,778–4,788	*Shale, brownish-gray, fairly hard to hard, rare scattered small green grains in upper 5 feet; very rare scattered diatom impressions; dip 26°.
4,788–4,806	*Shale, grayish-brown, hard, hackly fracture, few thin limy streaks; fish scales.
4,806–4,843	*Shale, grayish-brown, fairly hard, hackly fracture, few thin hard limy streaks; abundant fish fragments, rare plant remains; dip 25°–30°.
4,843–4,844	No sample.
4,844–4,867	*Shale, grayish-brown, hard; abundant fish remains, rare plant remains; dip 25°–30°.
4,867–4,890	*Shale, brownish-gray, hard; arenaceous Foraminifera, fish fragments.
4,890–6,469	Omitted.
6,469	Total depth.

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GEOLOGICAL SURVEY

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