OCS Report
MMS 89-0027

# Texaco Hudson Canyon 642-1 Well

## Geological & Operational Summary

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U.S. Department of the Interior
Minerals Management Service
*Atlantic OCS Region*

1990

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# ABSTRACT

The Texaco 642-1 (OCS-A-0038-1) well was drilled near the middle of the northern boundary of block 642 of protraction diagram NJ 18-3 (Hudson Canyon). The well site lies approximately 89 miles east of Atlantic City, New Jersey, and is in 450 feet of water. Block 642 was leased to Tenneco Oil Company and Aminoil Resources Inc. for a high bid of $8,190,000 in Lease Sale 40 in August 1976. The well was spudded on March 23, 1979, then plugged and abandoned as a dry hole 252 days later on December 1, 1979, after a sidetrack hole was drilled and after extensive logging and testing. The lease was relinquished in April 1984. The Ocean Drilling and Exploration Company operated the semi-submersible drilling rig Ocean Victory, which drilled the the well to a total depth of 17,807 feet.

The objectives for drilling the well were to test Lower Cretaceous and Upper Jurassic sandstones expected to occur between 8,000 and 15,000 feet. A highly faulted anticline is the primary trapping mechanism, the same structure in which Texaco discovered gas a year earlier in adjoining block 598. Tertiary claystones, siltstones, and limestones were penetrated to 5,120 feet. Upper Cretaceous shales, siltstones, and dolomites were penetrated to 7,970 feet, and sandstones, siltstones, and coals to 11,870 feet in the Lower Cretaceous section. Sandstones, limestones, siltstones, and coals were logged in the Jurassic section. The 642-1 well encountered significant gas shows from 9,495 feet to total depth. Five conventional cores were obtained between 12,435 and 15,668 feet, and eight formation tests and seven drill stem tests were conducted. Three tests produced gas at rates ranging from 5.5 to 18.7 million cubic feet per day. A total of 119 feet of net pay was calculated by log analysis for zones that tested gas, and 157 additional feet were calculated but not tested.

# ABBREVIATIONS

| | |
|---|---|
| API | American Petroleum Institute |
| bbl | barrels |
| $C_1$, $C_2$, $C_{15}$ | number of carbon atoms in a hydrocarbon chain structure (methane, ethane, etc.) |
| COST | continental offshore stratigraphic test |
| DISFL | dual induction spherically focused log |
| DST | drill stem test |
| FEL | from the east line |
| FNL | from the north line |
| GCM | gas-cut mud |
| GCW | gas-cut water |
| H/C | hydrogen to carbon ratio |
| HEW | hydrocarbon evolution window |
| KB | kelly bushing |
| L, M, U | late, middle, or upper parts of geologic strata |
| MCFGPD | thousand cubic feet of gas per day |
| md | millidarcy |
| MMCFG | million cubic feet of gas |
| MMCFGPD | million cubic feet of gas per day |
| MYBP | million years before the present |
| NSO | nitrogen-sulphur-oxygen |
| OCS | Outer Continental Shelf |
| PBTD | plugged back total depth |
| ppg | pounds per gallon |
| ppm | parts per million |
| psi | pounds per square inch |
| ROP | rate of penetration |
| SP | spontaneous potential |
| STH | sidetrack hole |
| $S_w$ | saturation of water in porous rock |
| TAI | thermal alteration index |
| TD | total depth |
| TIOG | threshold of intense oil generation |
| TOC | total organic content |
| TTI | time-temperature index |
| UTM | universal transverse mercator |
| WD | water depth |
| $\%R_o$ | vitrinite reflectance value |

## INTRODUCTION

The Texaco Hudson Canyon 642-1 was the second well drilled (the first permitted) in block 642 and one of eight holes drilled on a large faulted anticline covering parts of blocks (NJ 18-3) 598, 599, 642, and 643. Although all eight holes were plugged and abandoned, five tested significant amounts of gas with flow rates as high as 18.9 million cubic feet of gas per day (MMCFGPD). Encouraged by these results, the partners in these wells proposed the establishment of a unit operating agreement to extend the lease terms while further evaluation work was undertaken. A suspension of production and a unit agreement were approved in April 1982 for the four-block area. A three-dimensional (3-D) seismic survey was completed, the data were analyzed in 1983 to better understand the complex structure, and additional drilling was proposed. However, falling prices for oil and gas forced cancellation of the project. The leases were relinquished in April 1984, 2 years after the lease extensions were granted. All four blocks are currently unleased.

The 3-D seismic data and all well information were released to the public in 1985 after lease relinquishment. These data show a northwest-trending anticline with a small graben in the crest. Three major northeast-trending faults cut the structure, and numerous other smaller faults have been detected. The faults are deep seated and extend upward only to the Upper Cretaceous section. Reservoir rocks are Late Jurassic sandstones and Middle Jurassic limestones, which are generally not continuous from well to well. The sandstones tend to be poorly developed or pinch out completely over the crest of the structure. Reservoir rock depths range from 11,700 to 17,800 feet.

The five wells that tested gas on this structure and the highest flow rates of the tests are Texaco 598-1 (9.4 MMCFGPD), Exxon 599-1 (7.9 MMCFGPD), Texaco 642-1 (18.9 MMCFGPD), Tenneco 642-2 (18.5 MMCFGPD), and Tenneco 642-3 (5.9 MMCFGPD). The Tenneco 642-2 well also tested oil at the rate of 630 barrels per day from a shallower zone just below 8,300 feet.

The block 598-643 structure lies 12 miles east of the Continental Offshore Stratigraphic Test (COST) B-2, the first well drilled in the Baltimore Canyon Trough, and about 14 miles south of the Hudson Canyon. A similar structure, 8 miles southwest, was drilled by Exxon in 1979-1981 (Exxon 684-1, 684-2, and 728-1 wells), but only slight shows of gas were detected. A number of undrilled oil and gas plays occur within a 25-mile radius of the block 598-643 structure. These plays include Upper Jurassic limestones in other nearby structures (these limestones had gas shows in the Texaco 642-1 well); Upper Jurassic sandstones in other nearby structures; Jurassic sandstones which pinch out against the Great Stone Dome to the west; large anticlines, which occur in a trend just landward of the shelf edge; the carbonate buildup, which includes reef facies to the south and east along the shelf edge; and stratigraphic traps formed by Cretaceous and Jurassic sandstones pinching out against the carbonate buildup beneath the continental rise.

OPERATIONAL SUMMARY

by

Khaliq U. Siddiqui

Block 642 in Mid-Atlantic Official Protraction Diagram NJ 18-3 (Hudson Canyon) was leased to Tenneco Oil Company (65 percent interest) and its bidding partner, Aminoil Resources Inc. (35 percent interest) in Lease Sale 40 on August 17, 1976. Their high bid for this block was $8,190,000. Aminoil assigned a 20 percent interest in the block to Sun Exploration and Production Company in 1979, and Texaco Inc. was designated as unit operator in November 1978 for an 80 acre tract south of and adjoining their block 598 on which the 642-1 well was drilled. The lease was relinquished on April 15, 1984, 3 years after a temporary operating agreement had been established to allow further evaluation of the prospect. Although four drill stem tests produced significant amounts of gas, the 642-1 well was plugged and abandoned on December 1, 1979. The well site lies approximately 89 miles east of Atlantic City, New Jersey. Figures 1 and 2 depict the well's location, and pertinent well information is summarized in table 1.

The 642-1 is the second of three wells that have been drilled in this block to date; four wells have been drilled in block 598, which adjoins on the north (fig. 1). (The Tenneco 642-2 well is summarized by Bielak (1986) and the Texeco 598-3 well by Kobelski (1987).) Texaco Inc. served as the operator, and Ocean Drilling and Exploration Company (ODECO) was the drilling contractor for the 642-1 well. ODECO used the Ocean Victory, self-propelled, semisubmersible drilling rig to drill the well. The drilling vessel is 320 feet long, 266 feet wide, and the main deck is 128 feet above the bottom of the lower hull. It has an eight-point mooring system, a draft of 70 feet, and is capable of drilling in water depths of up to 600 feet.

Davis, Rhode Island (175 statute miles by sea from the drill site), and Atlantic City, New Jersey (90 miles), served as operational bases. Two 200-foot supply vessels transported materials, supplies and personnel. During the drilling operation, ODECO used one standby vessel, normally stationed within a half-mile radius of the well location. ODECO spudded the well on March 23, 1979, in 450 feet of water. Although the rig was on location a total of 252 days, drilling was completed in 100 days, on June 28, 1979, at a total depth of 17,807 feet. However, the well was plugged back to 11,830 feet after the drill pipe became stuck, and a sidetrack hole was drilled to a total depth of 15,786 feet on September 20, 1979. Between September 20 and December 1, 1979, the day the well was plugged and abandoned, Texaco did extensive logging and testing of potential hydrocarbon zones. The daily drilling progress for the well is shown in figure 3.

Drilling Program

Texaco drilled the 642-1 well to a total depth (TD) of 17,807 feet. Drilling rates varied from 0.3 to 54.5 feet per hour. Maximum borehole deviation from vertical is 8 degrees and is generally less than 2 degrees.

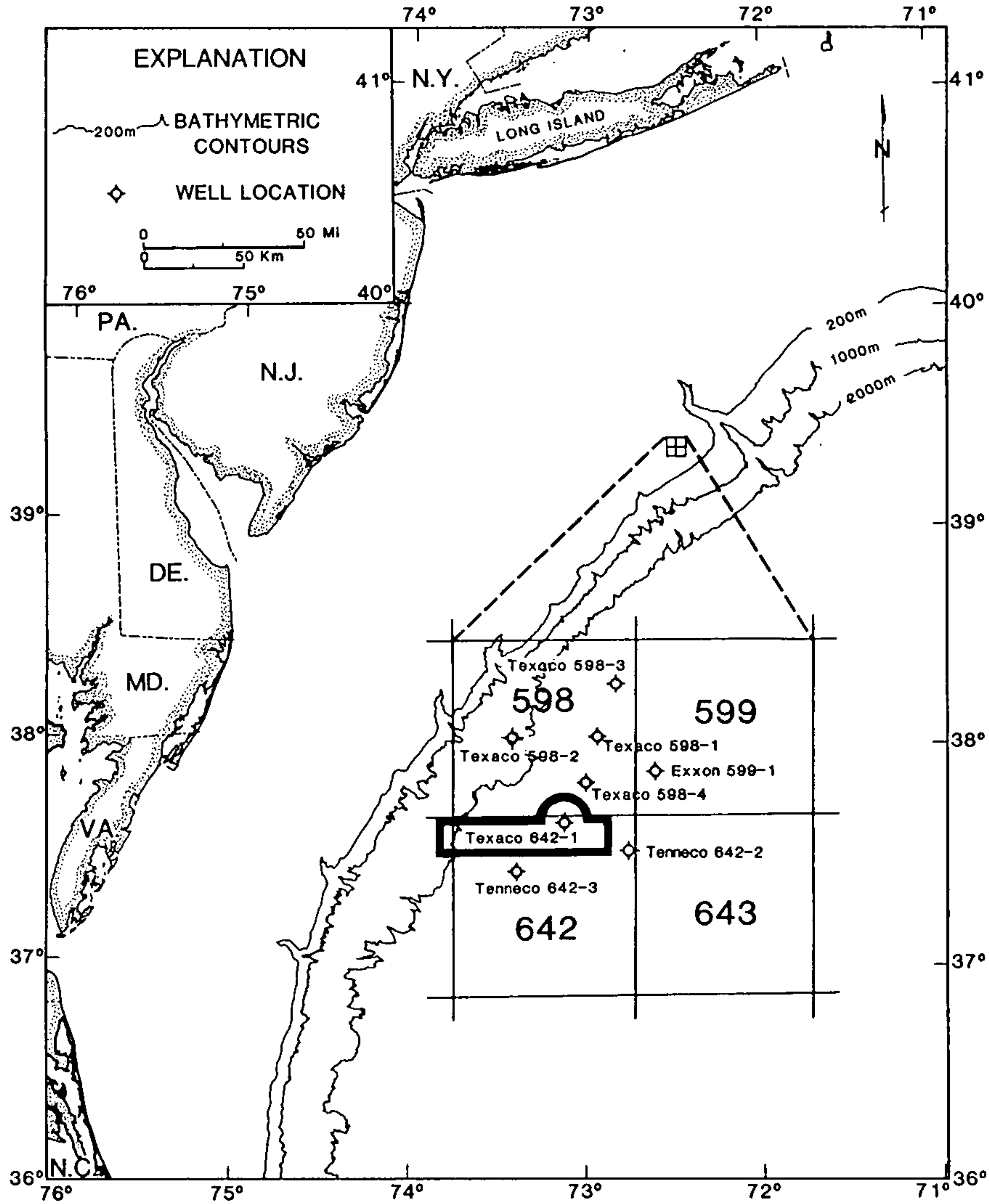



Figure 1.--Portion of the Mid-Atlantic offshore area showing the location of the Texaco 642-1 and surrounding wells.

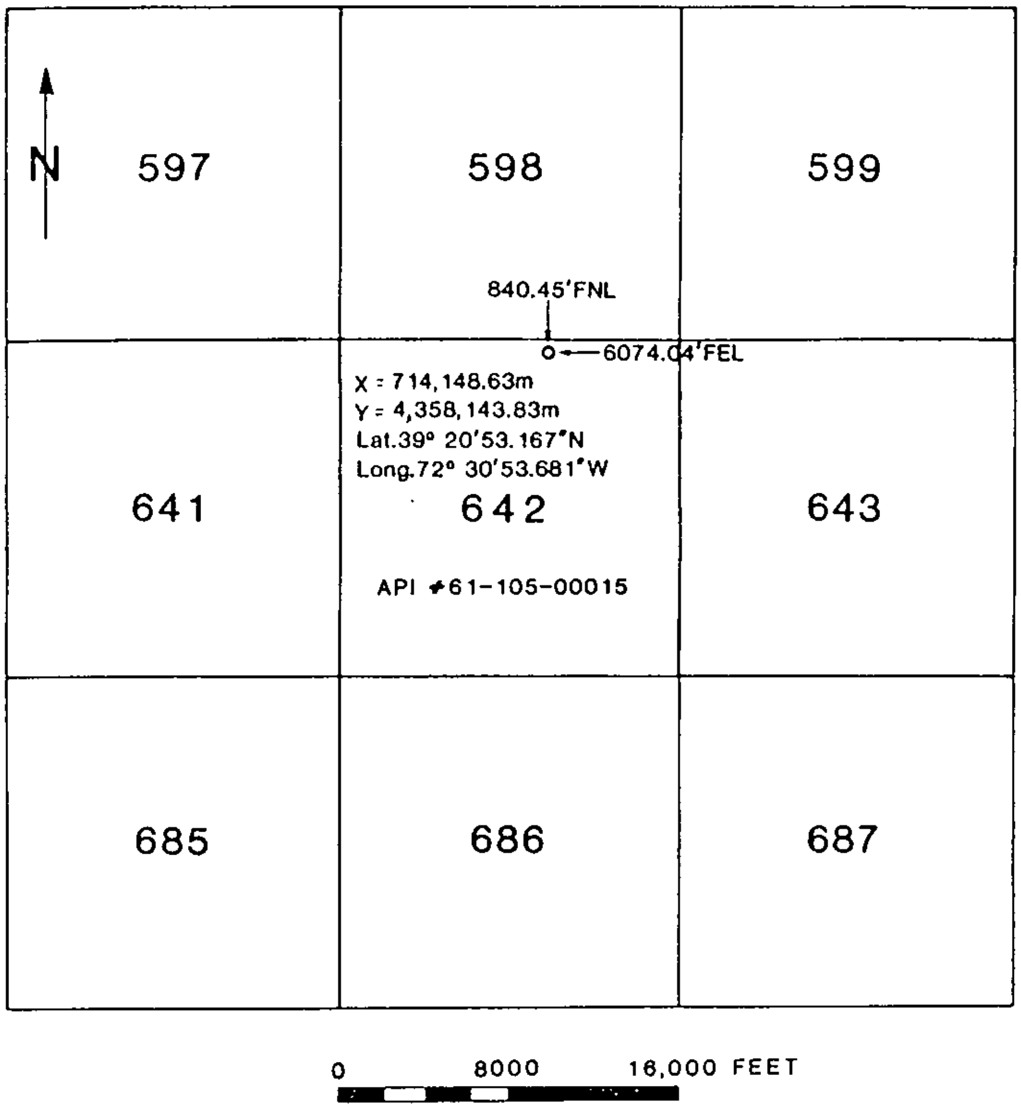



Figure 2.--Location of the Texaco 642-1 well in OCS Protraction Diagram NJ 18-3.

Table 1. -- Pertinent well information for the Texaco 642-1 well

| | |
|---|---|
| Well identification | API No. 61-105-00015 |
| Lease number | OCS-A-0038-1 |
| Protraction diagram | NJ 18-3 (Hudson Canyon) |
| Actual surface location | UTM Coordinates:<br>x = 714,148.63 m<br>y = 4,358,143.83 m<br><br>Latitude: 39°20'53.167" N.<br>Longitude: 72°30'53.681" W. |
| Distance from block lines of block 642 | 840.45 feet FNL<br>6,074.04 feet FEL |
| Actual bottom hole location | Original hole: 559 feet FNL<br>6,116 feet FEL<br><br>Sidetrack hole: 544 feet FNL<br>6,163 feet FEL |
| Proposed total depth | 19,000 feet |
| Actual total depth | Original hole: 17,797 feet<br>Sidetrack hole: 15,776 feet |
| Total measured depth | Original hole: 17,807 feet<br>Sidetrack hole: 15,786 feet |
| Spud date | March 23, 1979 |
| Completion date | December 1, 1979 |
| Kelly bushing elevation | 82 feet above mean sea level |
| Water depth | 450 feet |
| Final well status | Plugged and abandoned |

Note: All depths in this report are measured from the kelly bushing unless otherwise indicated.

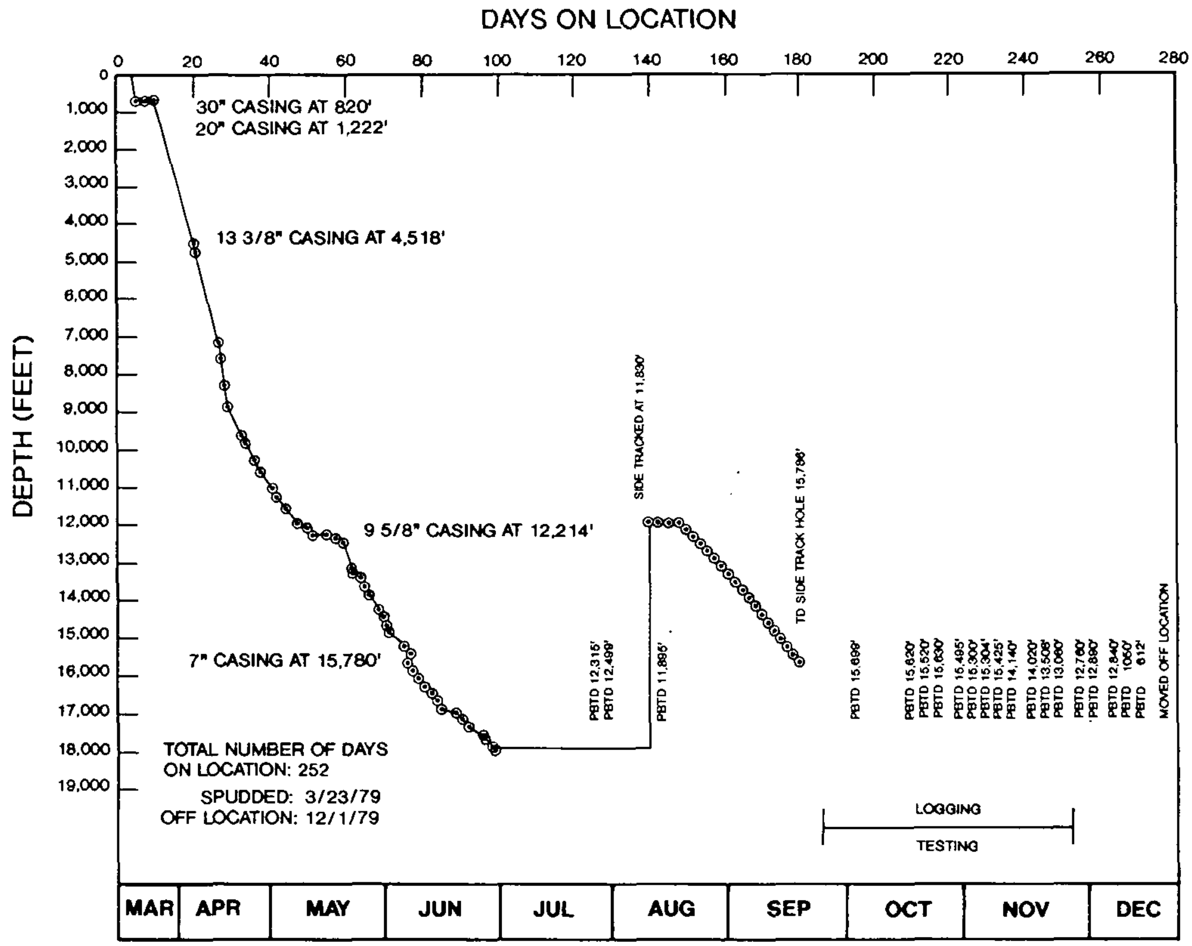



Figure 3.-- Graph showing the daily drilling progress for the Texaco 642-1 well.

Five strings of casing were set in the well as shown in figure 4. The 30-inch casing was set at 820 feet with 1,000 sacks of cement; the 20-inch casing was set at 1,222 feet with 1,200 sacks of cement; the 13 3/8-inch casing was set at 4,518 feet with 1,900 sacks of cement; the 9 5/8-inch casing was set at 12,214 feet with 2,300 sacks of cement; and the 7-inch casing was set at 15,780 feet with 2,150 sacks of cement. Class H cement was used for all casing settings.

The abandonment procedure is also shown in figure 4. Texaco's numerous tests required the setting of a number of retainers and squeeze jobs to isolate the tested zones properly before plugging and abandoning the well.

Mud Program

Seawater with a weight of 8.8 pounds per gallon (ppg) was used as drilling fluid to a depth of 1,270 feet. From 1,270 feet to 7,162 feet, freshwater gel with a weight of 9.6 ppg was used as drilling fluid; seawater and Dextrid Drispac with a weight of 9.8 ppg were used as drilling fluid to a depth of 14,578 feet. Mud weight was raised to 11.5 ppg at 15,503 feet and to 12.8 ppg at 16,940 feet. Soltex was added to the mud system at a rate of 2-4 pounds per barrel to reduce water loss for better control of sloughing shales. At 17,807 feet, drilling was interrupted, due to an 828-unit gas kick, to circulate and condition gas-cut mud using 14.5 ppg mud. While circulating, the drill pipe became stuck at 17,776 feet, and mud weight was increased to 14.8 ppg. A 30-barrel slug of barite mud weighing 21.5 ppg was pumped into the hole; however, it did not reduce the gas flow. The drill collar was cut at 17,766 feet with a jet cutter, and 440 barrels (bbl) of 18 ppg mud followed by 10 bbl of gel spacer and 75 bbl of 17 ppg cement were pumped into the hole. The drill pipe was cut at 16,215 feet and perforated at 15,515 feet. However, circulation could not be maintained and the drill pipe stuck at 12,527 feet. At that point, 175 bbl of 18 ppg mud and 100 sacks of class H cement were pumped in through perforations at 15,515 feet. The drill string again became stuck at 12,499 feet. Mud weight as high as 14.8 ppg was circulated in an attempt to condition the severely gas-cut mud. Efforts to free the drill string failed, and a fishing job followed with the top of the fish positioned at 12,499 feet. The fish was not recovered, and Texaco decided to sidetrack the well. The drill pipe was cut at 12,499 feet, and the well was sidetracked at 11,830 feet and drilled to 15,786 feet (total measured depth).

The viscosity of the mud fluctuated between 60 and 85 seconds (per quart) in the first 1,270 feet and averaged about 49 seconds for the remainder of the well. Mud pH averaged 11.0 with minor fluctuations. Chloride concentrations began at 15,000 parts per million (ppm) and increased to 20,000 ppm at 17,608 feet. Chlorides in the sidetrack hole were highest at 18,000 ppm at 15,786 feet.

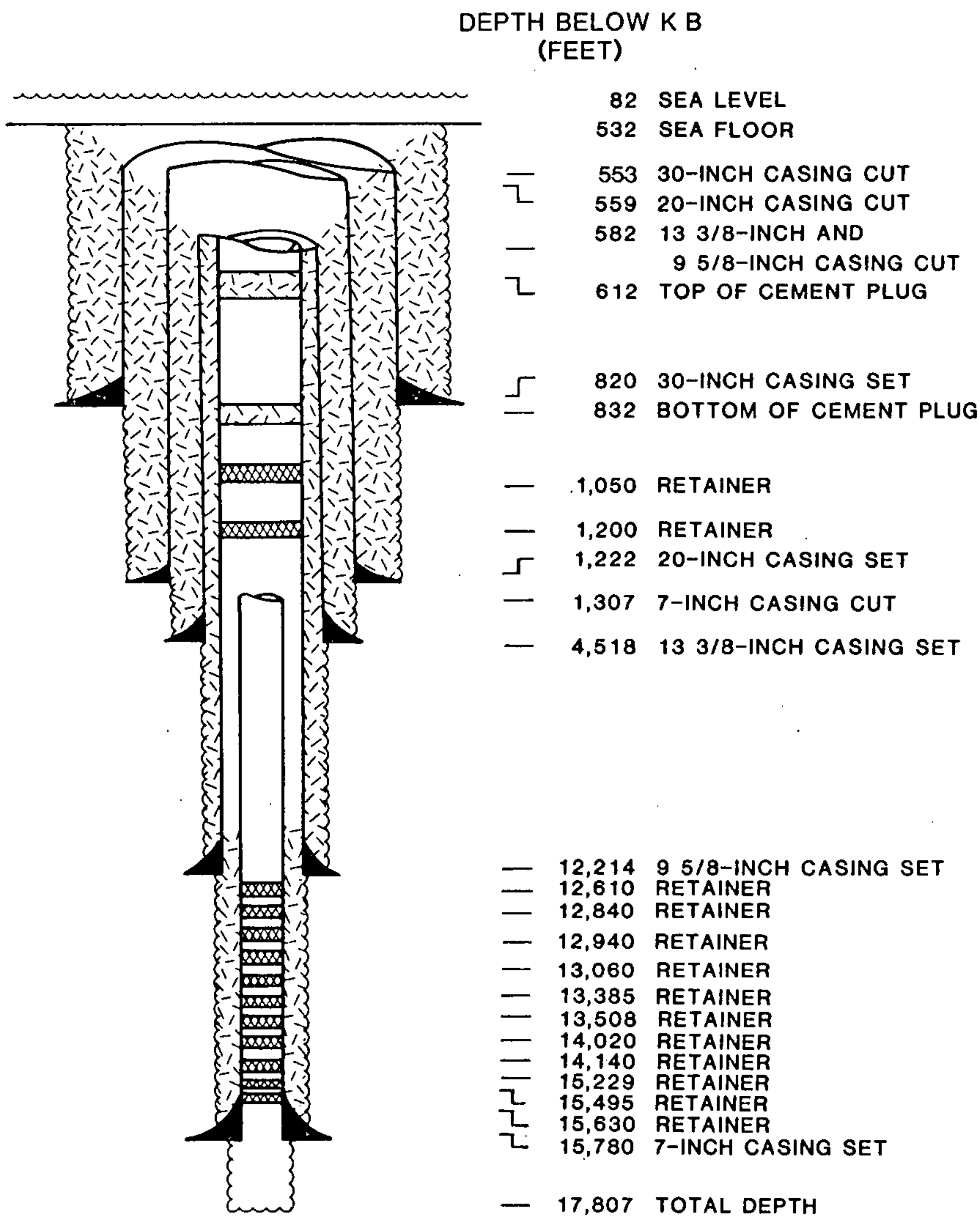



Figure 4.--Casing, cement, and abandonment program for the Texaco 642-1 well.

Samples and Tests

Five conventional cores (table 2) were obtained and analyzed for porosity, permeability, grain density, lithology, paleontology, and hydrocarbon saturation.

Table 2.--Conventional cores recovered from the Texaco 642-1 well

| Core No. | Interval (feet) | Recovery (feet) |
|---|---|---|
| 1 | 12,435 - 12,495 | 59.5 |
| 2 | 14,044 - 14,080.5 | 36.5 |
| 3 | 16,911 - 16,971 | 56.0 |
| 4 (Sidetrack hole) | 15,344 - 15,375 | 31.0 |
| 5 (Sidetrack hole) | 15,608 - 15,668 | 57.4 |

A series of sidewall cores were taken between 7,920 and 15,102 feet, which were analyzed for porosity, permeability, and hydrocarbon saturation. Texaco conducted eight formation tests and seven drill stem tests (DST) in the well. The results of the drill stem tests are given in table 3. Geophysical well logs run in the well are listed and discussed in the Formation Evaluation Chapter of this report.

Table 3. -- Drill stem test results of the Texaco 642-1 well

| Drill Stem Test No. | Interval Tested (feet) | Length of Test (hours) | Choke Size (inches) | Final Flow Press. (psi) | Final Shut-in Press. (psi) | Results/ Recovery |
|---|---|---|---|---|---|---|
| DST-1 | 15,548-15,610 | 4 | 1/4 | 5,017 | 6,276 | 5.5MMCFGPD with 3.3 bbl condensate/ MMCFG (47.5° API) |
| DST-2 | 15,350-15,385 | 4 | 1/4 | 1,651 | 9,617 | 120 MCFGPD (initial flow of 6 MMCFGPD on 48/64 inch choke) well died, tool failed |
| DST-3 | 15,350-15,385 | 4 | 1/4 | 3,259 | 7,730 | Retest of DST-2 zone, 89 MCFGPD, 21 bbl GCM and 17 bbl salt water (9,100 ppm) |
| DST-4 | 14,078-14,115 | 4 | 1/4 | 1,570 | 4,366 | No build-up, slight show of gas; some GCM |
| DST-5 | 13,450-13,487 | 4 | 1/4 | 4,198 | 5,996 | 6.3 MMCFGPD with 0.4 bbl condensate/ MMCFG (46.4° API) |
| DST-6 | 13,003-13,036 | 4 | 1/4 | 1,174 | 5,745 | 750 MCFGPD, Rec. 2 bbl condensate/MMCFG 4 bbl GCW 11 bbl GCM |
| DST-7 | 12,790-12,882 | 4 | 1/4 | 4,780 | 5,719 | 18.9 MMCFGPD with 0.136 bbl condensate/MMCFG |

GCM = gas-cut mud
GCW = gas-cut water

## WELL VELOCITY PROFILE

by

Arnold O. Tanner

Seismic Reference Service Inc. conducted a checkshot survey, as well as sonic logging, for the Texaco 642-1 well to gather data for correlating lithologic and borehole geophysical log data with seismic profiles. The checkshot survey establishes a reference time between the beginning of the sonic log and the top of the well and is used to adjust vertical travel times of the sonic log. The interval velocity profile shown in figure 5, was plotted from the sonic log with all depths below sea level.
Between 1,143 and 16,822 feet (the deepest data), five intervals are indicated on the basis of their relative interval velocities. Most of the velocities in the well are in the the sandstone range. The first downhole indications of limestone velocities occur in Interval III at 11,417 feet. The velocities of the four depth intervals and their inferred lithologies generally agree with the facies units identified from sample and electric log analyses. A noticeable exception is a predominantly limestone section between 4,500 and 5,100 feet, which exhibits siliciclastic velocities.

<u>Interval I</u>: The first interval is identified on the basis of relatively low velocities. These velocities suggest continental clastic lithologies, which fluctuate between sandstone and slower shale velocities.

| | |
|---|---|
| DEPTH RANGE (feet) | 1,143-7,417 |
| INTERVAL VELOCITY RANGE (feet/second) | 5,747-9,901 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 7,623 |

<u>Interval II</u>: The second interval is identified by velocities that suggest a clastic section with a low to moderate calcareous component.

| | |
|---|---|
| DEPTH RANGE (feet) | 7,417-10,917 |
| INTERVAL VELOCITY RANGE (feet/second) | 11,236-13,089 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 12,057 |

<u>Interval III</u>: This section is identified by relatively higher velocities that are intermediate between sandstones and carbonate rocks suggesting a moderate calcareous component. This interval classification is supported by the lithologic description (see the Lithologic Analysis chapter, this report), which identifies a mostly clastic section that becomes very calcareous in the lowermost 300 feet.

| | |
|---|---|
| DEPTH RANGE (feet) | 10,917-15,537 |
| INTERVAL VELOCITY RANGE (feet/second) | 13,661-14,793 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 14,289 |

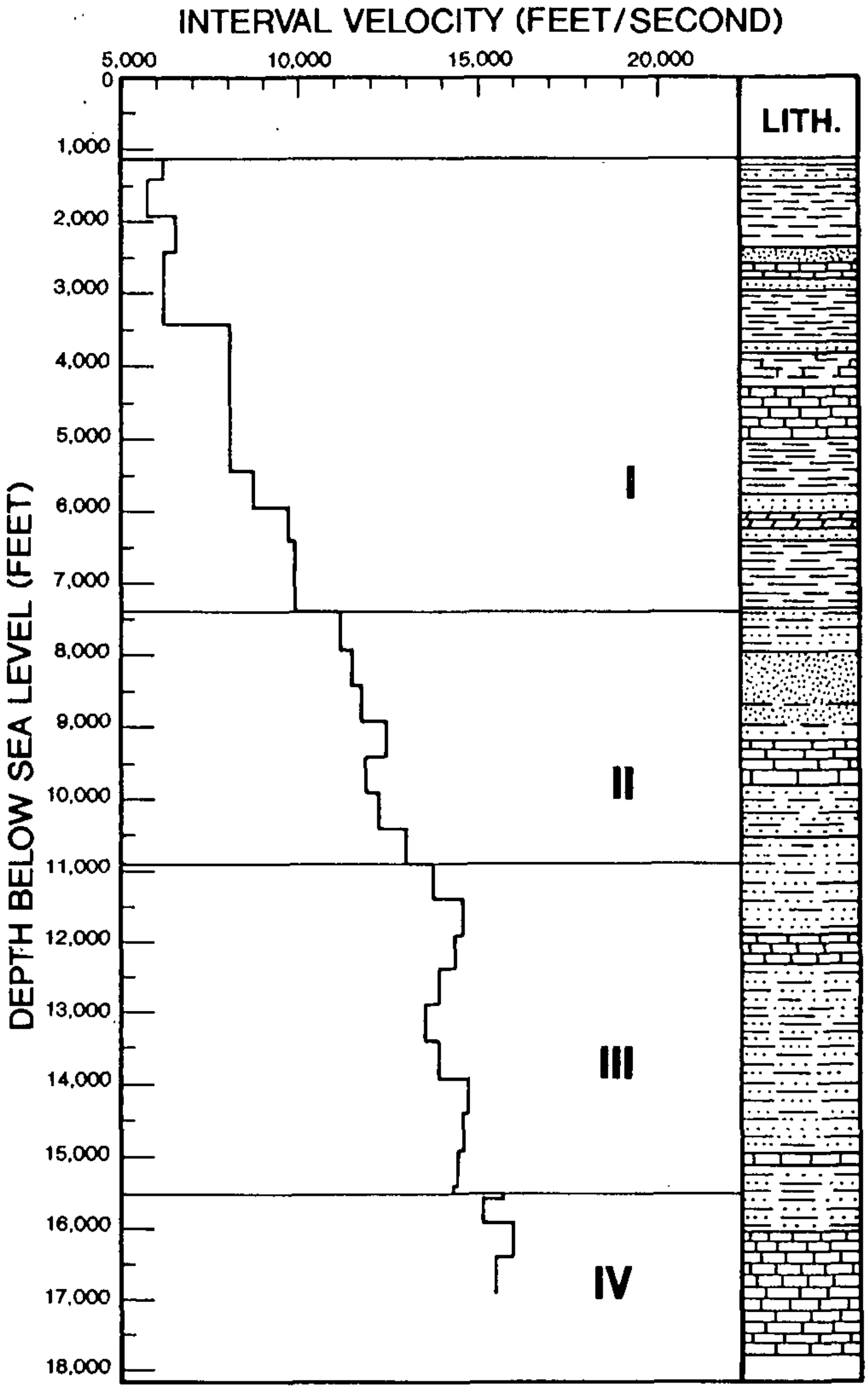



Figure 5.--Interval velocity profile for the Texaco 642-1 well

Interval IV: The deepest interval was determined by its relatively higher velocities.

| | |
|---|---|
| DEPTH RANGE (feet) | 15,537-16,822 |
| INTERVAL VELOCITY RANGE (feet/second) | 15,281-16,129 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 15,728 |

The increased velocities within this interval are consistent with mixed sandstone and carbonate lithologies with limestone predominating from 16,050 to 17,807 feet, the total depth.

# LITHOLOGIC ANALYSIS

by

Robert E. Smith and Frederick Adinolfi

The lithology described in this report is based on a geologic interpretation of electric logs (dual induction, neutron porosity, density and sonic), cuttings samples, the physical formation log, and sidewall and conventional core analyses. Electric logs were used to adjust lithologically distinct contacts to proper depths. Cuttings, taken at 30-foot intervals, varied in quality from fair to good. Visible porosity throughout sampled intervals ranged from good to poor. The best potential reservoir rocks were observed in the Lower Cretaceous and Jurassic sandstone and carbonate sequences. The rocks penetrated by the well have been divided into eight units based on differences in lithologic character. These lithologic units are described below, beginning with the uppermost (youngest) section. Overall sample recovery was adequate from the shallowest samples to the total depth of the well. Sediments recovered from the sidetracked portion of the hole do not differ significantly from the rock types and sequence observed in the original hole. Figure 6 shows the lithologic interpretations and biostratigraphy for the well.

<u>1,270 to 3,850 feet</u>

The first major lithologic unit is an unconsolidated, soft, light- to medium- gray claystone that is slightly calcareous and fossiliferous in the top 80 feet of the interval. The claystone is interrupted by minor interbeds of sand and limestone in the middle and at the base of this section. Among the abundant fossil fauna observed are bivalves, mollusks, and foraminifera. Traces of glauconite, pyrite, and dark mafic minerals are also observed. Most of this section is Pleistocene to Miocene in age with the first Oligocene age sediments occurring at 3,640 feet.

<u>3,850 to 4,300 feet</u>

The second unit consists of a light-gray to grayish-green siltstone that is highly calcareous and soft to moderately firm and contains blocky, fine-grained mineral inclusions exhibiting a metallic sheen. Additionally, minor amounts of glauconite, pyrite, soft clay, and fossil material are present. The sediments in this interval range in age from Oligocene to Eocene and represent a transitional lithology to the underlying section.

<u>4,300 to 5,050 feet</u>

Middle Eocene to Paleocene rocks that constitute this interval are characterized by a light- to medium-gray limestone that is micritic. The rocks are devoid of fossils in the upper 275 feet and become highly glauconitic in the lower 475 feet of the interval. The limestone is further characterized as soft to moderately firm and associated with scattered traces of sand grains, pyrite, and shale.

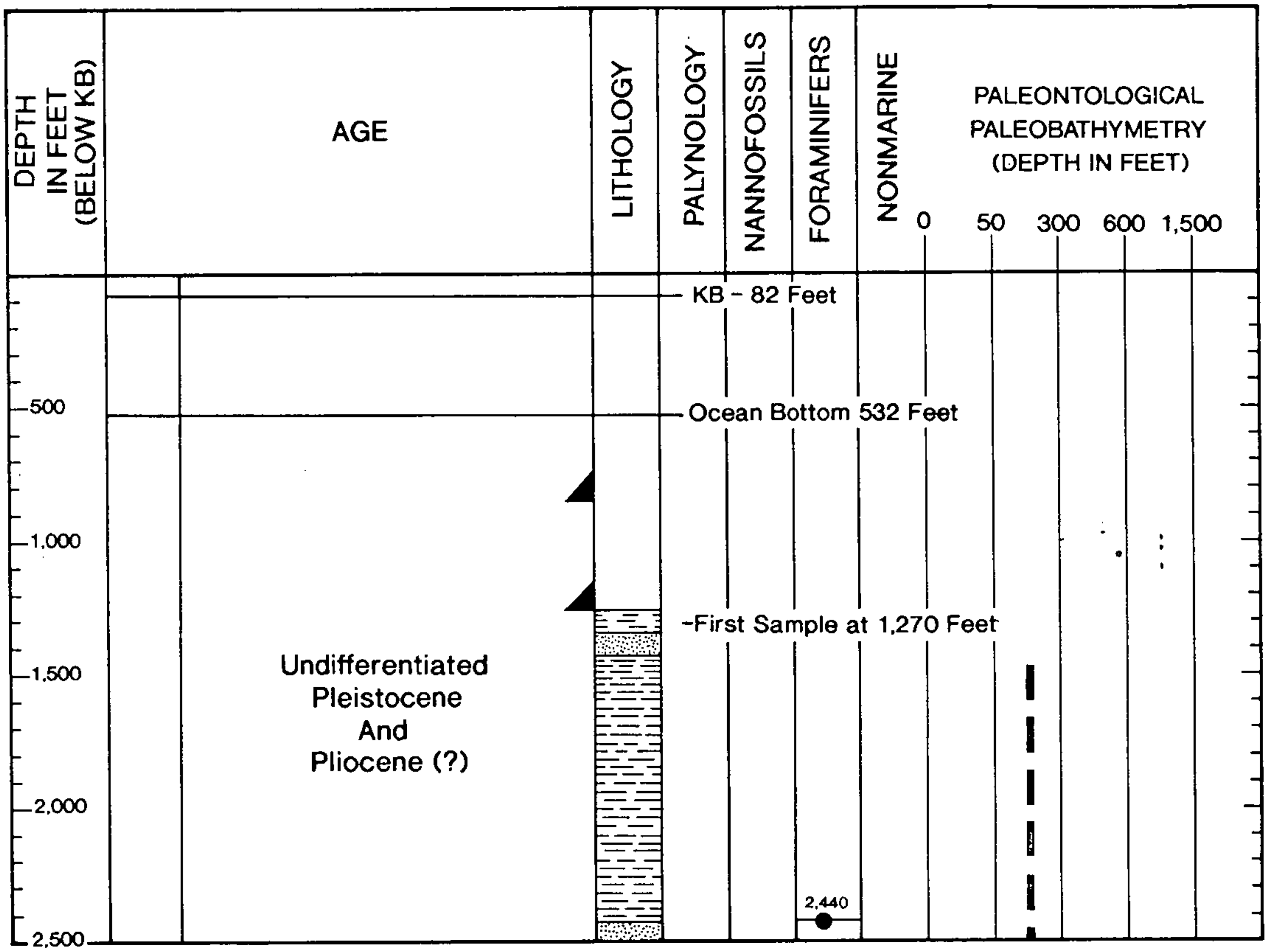



Figure 6.--Lithology, biostratigraphy, and paleobathymetry of the Texaco 642-1 well. Lithologic breaks picked from well logs. Age tops based on paleontology. Within palynology, nannofossil, and foraminifer columns, depths refer to uppermost occurrence of index fossils, listed in biostratigraphy section. Paleobathymetric data become less reliable with increasing depth.

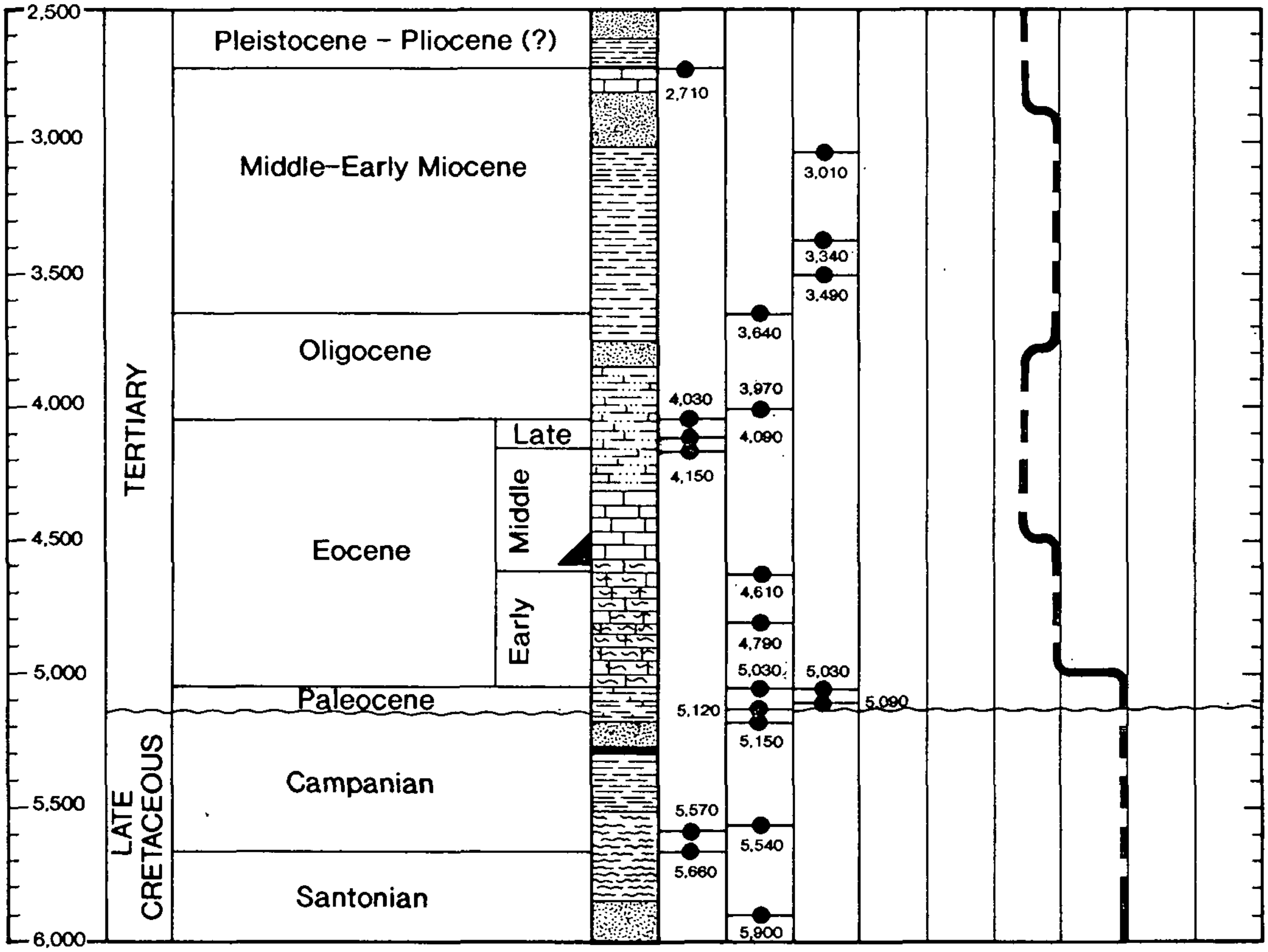



Figure 6.--Lithology, biostratigraphy, and paleobathymetry of the Texaco 642-1 well, continued.

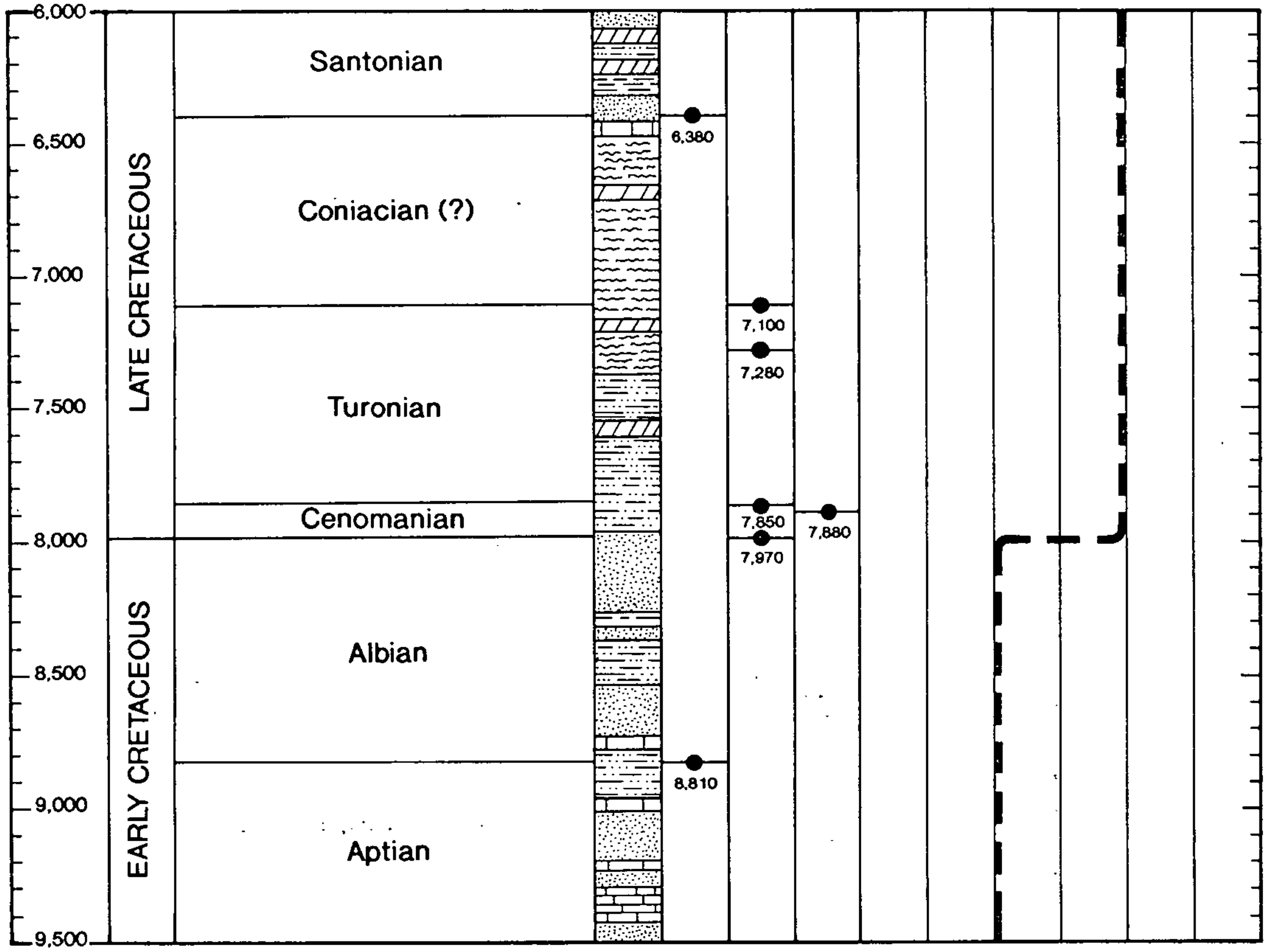
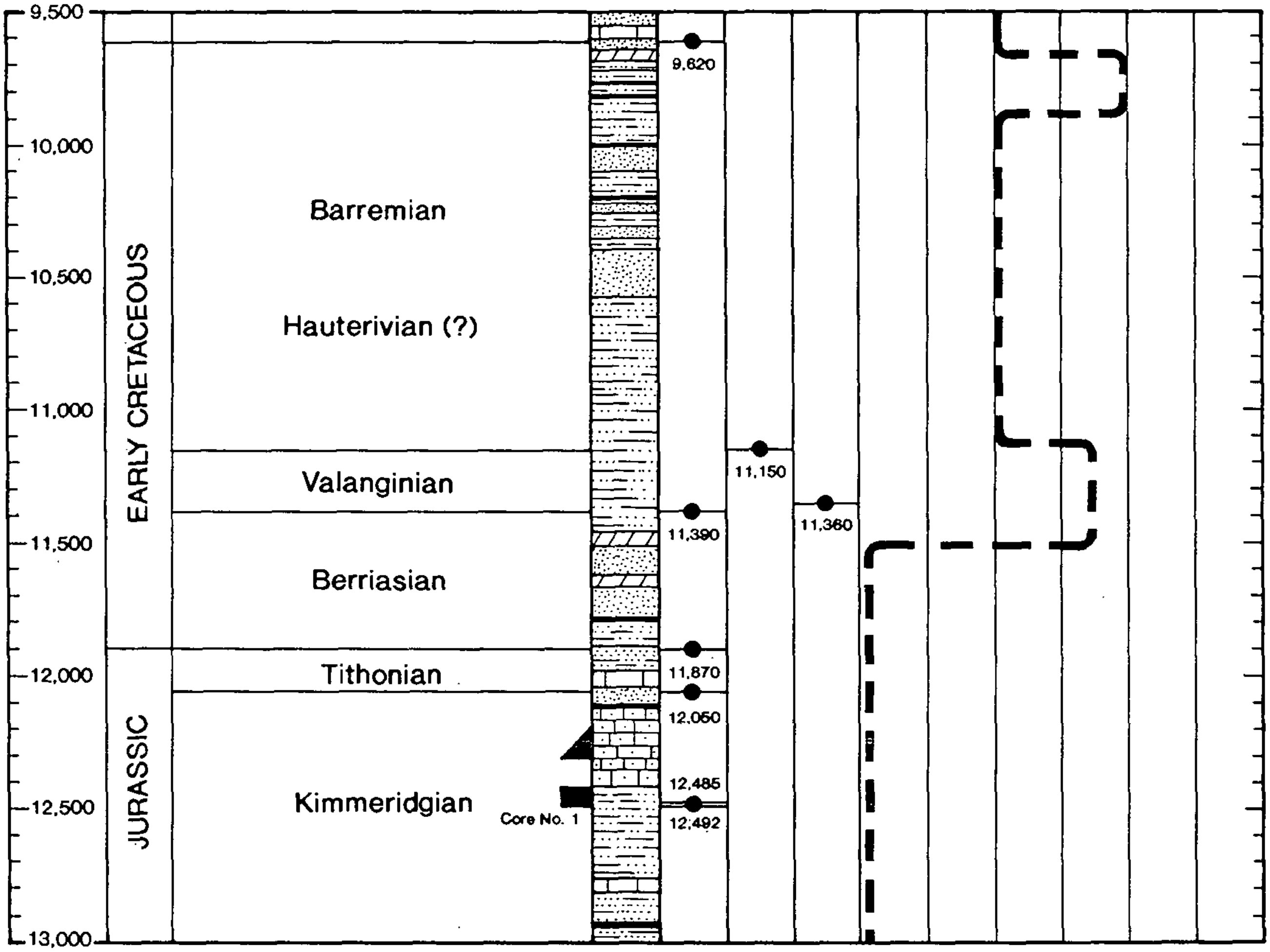



Figure 6.—Lithology, biostratigraphy, and paleobathymetry of the Texaco 642-1 well, continued.

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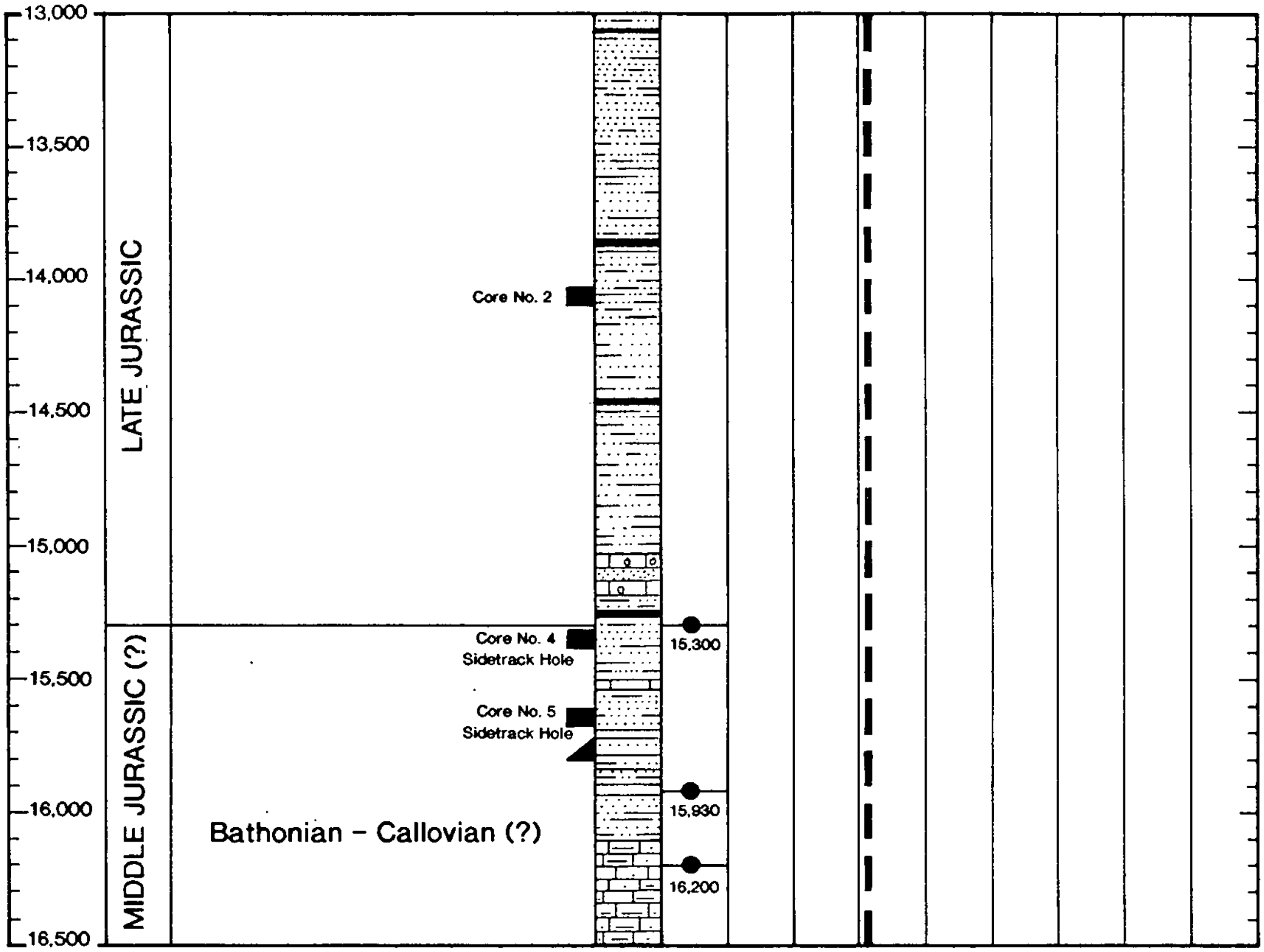


Figure 6.--Lithology, biostratigraphy, and paleobathymetry of the Texaco 642-1 well, continued.

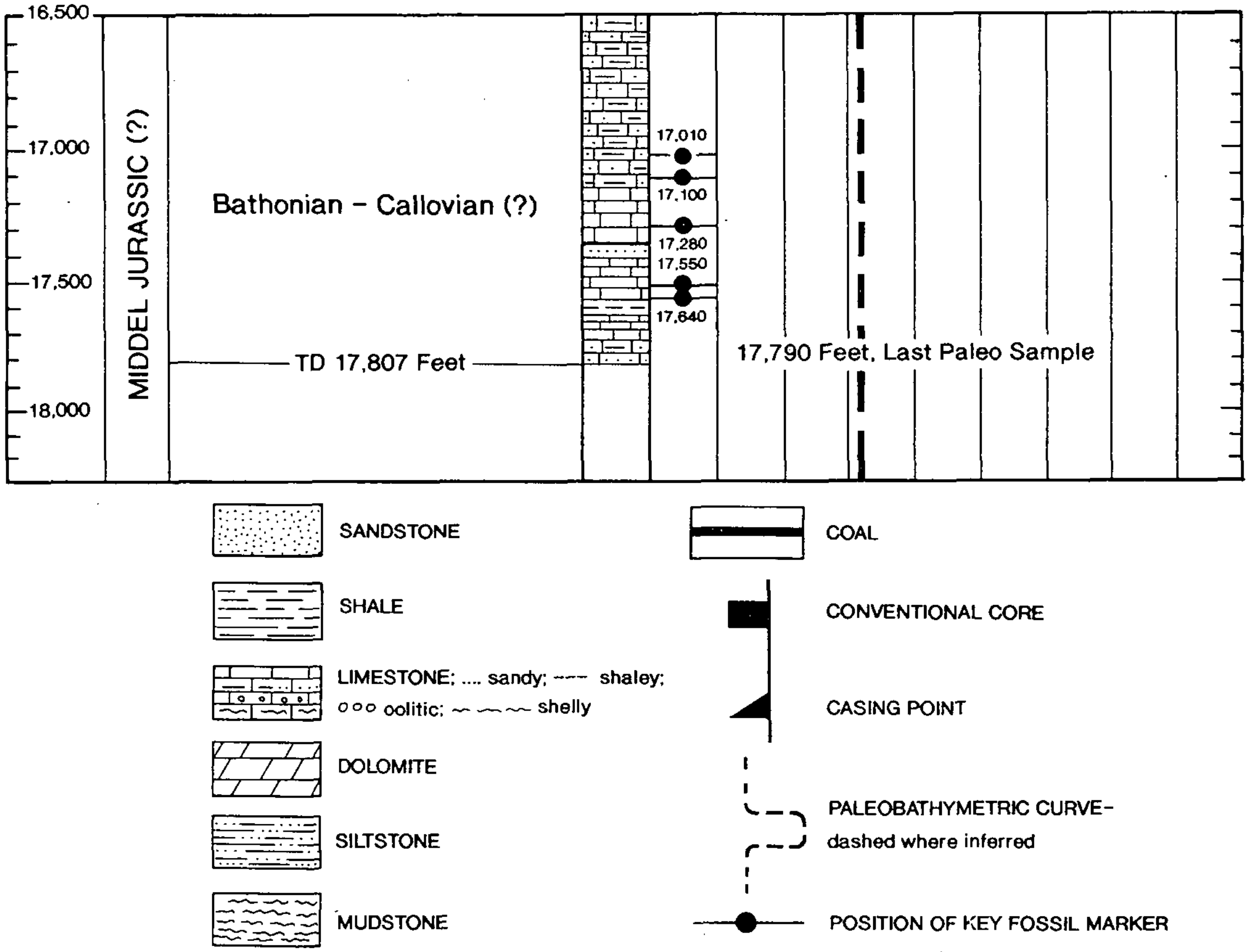


Figure 6.--Lithology, biostratigraphy, and paleobathymetry of the Texaco 642-1 well.

5,050 to 7,350 feet

The top 150 feet of this unit consists of a light- to medium-gray shale that is generally soft, platy, and very calcareous. This interval is followed by a less calcareous lower section containing occasional thin coal stringers and a 100-foot thick sand bed at 5,170 feet. Traces of scattered calcite, pyrite, glauconite, and mafic minerals are also observed. A prominent regional erosional unconformity that was verified both seismically and paleontologically occurs at a depth of about 5,120 feet. Below the unconformity, sediments are dated as Campanian to Turonian in age indicating the loss of the early Paleocene through Maestrichtian section. The section from 5,500 to 7,350 feet consists of a brown, gray, and green, moderately calcareous mudstone with numerous interbeds (thick and thin) of sandstone, limestone, dolomite and shale. Clayey and silty fragments are observed along with assorted traces of pyrite, glauconite, lignite, black coal, mica, and mafic minerals.

7,350 to 10,000 feet

Cenomanian and Barremian rocks are characterized by sandy shale with numerous sand, limestone, dolomite, and coal interbeds of variable thickness ranging from thin stringers to beds over 200 feet thick. The shale is light- to dark-gray, soft to firm, fissile, occasionally blocky and, when bounded by carbonate beds, moderately calcareous. Traces of glauconite, pyrite, lignite, and fossil fragments are also observed.

10,000 to 15,000 feet

This interval contains sandstone with abundant clay, shale, carbonate, and thin coal interbeds. The sands vary greatly ranging from unconsolidated to slightly cemented. The sands are moderately to poorly sorted, soft to friable, subangular to subrounded, fine- to coarse-grained, and micaceous and contain traces of assorted minerals such as glauconite, pyrite, lignite, and mafic minerals. Paleontologic analysis places the top of the Valanginian at 11,150 feet.

15,000 to 17,807 feet

The lowermost unit is Jurassic in age and consists of limestone with abundant interbeds of sand and shale of various thickness. Below 16,100 feet, the limestone is massive. The limestone ranges from an oolitic and nonfossiliferous grainstone in the top 100 feet to wackestones and packstones below, which are occasionally fossiliferous. Many gas shows were recorded by the mud logger through this unit and the overlying unit starting at 11,570 feet. All seven drill stem tests recovered gas ranging from a slight flow to 18.9 MMCFGPD. Figure 7 shows the structural relationships of the Texaco 642-1 well to the other two wells in the block and the zone of gas shows encountered by the wells.

## PALEONTOLOGY AND BIOSTRATIGRAPHY

by

Harold L. Cousminer, William E. Steinkraus, John W. Bebout, Raymond E. Hall, and LeRon E. Bielak

### Paleontological Data

Three factors limit the reliability of paleontologic data from offshore Atlantic wells: (1) most analyses are made from drill cuttings samples, which are often heavily contaminated by cavings from higher in the drill hole. For this reason, only "tops" or the uppermost species appearances are recorded; (2) reworked, older fossil assemblages and individual specimens are commonly reincorporated in detrital sedimentary rocks. The reworked nature of these fossils must be recognized so that misdating can be avoided; (3) biostratigraphic control is poor in pre-Upper Jurassic strata. Calcareous nannofossils and foraminifera are rare to nonexistent. Palynomorphs are more common, but their biostratigraphic distribution is not fully documented with reference to the European-type stage localities. The Jurassic palynostratigraphy of offshore eastern Canada (Bujak and Williams, 1977) has been used for this investigation because many of the palynomorph marker species observed in Canada's Atlantic offshore sediments are also present in the Atlantic offshore sediments of the United States. Although the European stage equivalence of several species is not fully resolved, some species have recently been documented in European-type sections (Woollam and Riding, 1983; Riding, 1984; and Davies, 1985).

The first samples were obtained at a depth of 1,270 feet after 20-inch casing had been set to 1,222 feet. Nannofossil analyses are based on 360 composited samples of cuttings at 30-foot intervals. Palynological studies are based on 168 composited samples of cuttings at 90-foot intervals and core sample splits from the three conventional cores. Foraminifera were spot-checked to verify tenuous age dates or to try to fill in zones where other data were not available.

The paleontologically dated section ranges in age from Pleistocene at 2,440 feet to Middle Jurassic (Bathonian?) below 15,300 feet. A cored interval from 12,485 to 12,492 feet carries abundant marine phytoplankton of late Kimmeridgian age, which is both overlain and underlain by nonmarine to marginal marine shaly intervals that appear to include several shear zones. These carbonized zones, which may be associated with active fault movement, were noted in cored intervals at 12,483 feet, 14,058 to 14,074 feet, 15,355 feet, and 15,370 to 15,374 feet. No Quaternary, Pliocene, or late Miocene fossils were found in the well samples. Paleontological ages are summarized in figure 6 and relationships of the major geologic units are shown in figure 7 for the Texaco 642-1, Tenneco 642-2, and Tenneco 642-3 wells.

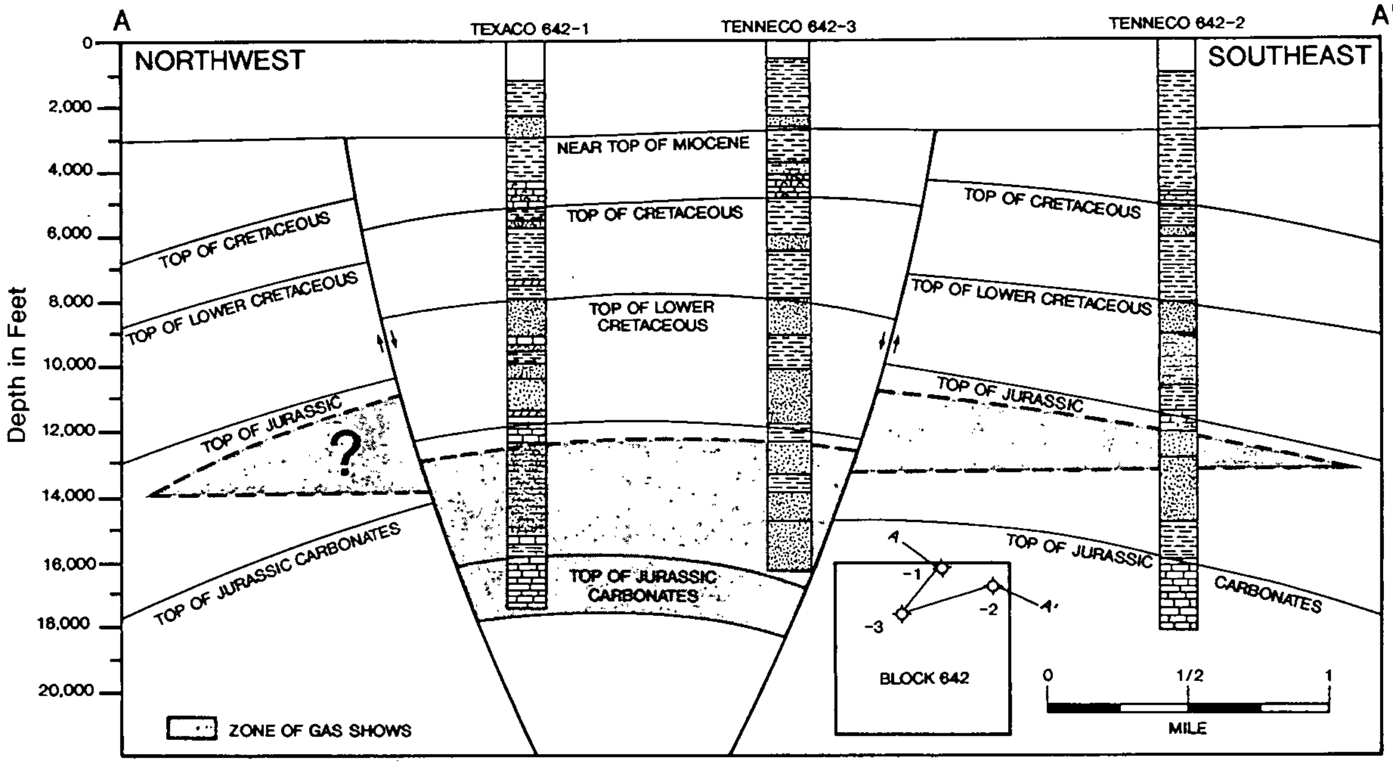


Figure 7.--Schematic cross section through the wells in block 642, showing the relationships of the major geologic units and structures. Shaded area represents the overall zone in which the wells encountered significant shows of gas and tested gas in some of the intervals.

## CENOZOIC

### Quaternary - Tertiary

#### Pleistocene - Pliocene? (1,270-2,710 feet)

Globorotalia truncatulinoides, a Pleistocene planktonic foraminifer, was identified at 2,440 feet. No Pliocene fossils were identified in the Texaco 642-1 well. However, Pliocene foraminifers occur between 1,100 and 2,960 feet in the nearby Tenneco 642-2 well (Bielak, 1986).

#### Middle - Early Miocene (2,710-3,640 feet)

A typical Neogene pollen assemblage is present at 2,710 feet and includes species of Carya (Hickory), Tilia (Basswood), Quercus (Oak). Dinoflagellates include Thalasiphora delicata, Lingulodinium sp., Hystrichosphaeropsis sp., Impletosphaeridium transfodum, and Systematophora ancyrea, all of which indicate a Miocene age. The occurrence of the nannofossil species Discoaster exilis at 3,010 feet and of D. kugleri, D. deflandrei at 3,340 feet confirms a middle Miocene age for this interval. The planktonic foraminifer Globigerinoides altiaperturus indicates an early Miocene section at 3,490 feet.

#### Oligocene (3,640-4,030 feet)

The top of this interval is dated as late Oligocene based on the uppermost occurrence of the nannofossil species Reticulofenestra bisecta and Discoaster obtusus at 3,640 feet. Reticulofenestra umbilica and Isthmolithus recurvus, which occur at 3,970 feet, indicate an early Oligocene age.

#### Late Eocene (4,030-4,150 feet)

A short section of late Eocene sediments is confirmed by the presence of Discoaster saipanensis at 4,030 feet and D. barbadiensis at 4,090 feet. A similarly short late Eocene interval is observed in the Tenneco 642-2 well (Bielak, 1986, p. 16).

#### Middle Eocene (4,150-4,610 feet)

The nannofossil species Chiasmolithus grandis has its highest occurrence at 4,150 feet and indicates a middle Eocene age.

Early Eocene (4,610-5,030 feet)

This interval is dated as early Eocene in age based on the occurrence of the species Discoaster lodoensis at 4,610 feet and Tribrachiatus orthostylus at 4,790 feet.

Late Paleocene (5,030-5,120 feet)

The nannofossil Cruciplacolithus tenuis first occurs at 5,030 feet marking the top of the late Paleocene interval. The late Paleocene age of this interval is reinforced by the occurrence of Heliolithus kleinpelli at 5,090 feet and the planktonic foraminifer Globorotalia angulata at 5,030 feet.

MESOZOIC

Late Cretaceous

No paleontologic evidence of early Paleocene or Maestrichtian sediments was found in the well samples, indicating that a substantial unconformity marks the boundary between Cenozoic and Mesozoic sediments in this well.

Campanian (5,120-5,660 feet)

The recovery of the nannofossil species Broinsonia parca in sediments at 5,120 feet and Tetralithus pyramidus from sediments at 5,150 feet indicates the first occurrence of a Mesozoic section in the well. Eiffellithus eximius, which has its uppermost occurrence at 5,540 feet, establishes an early Campanian age for the base of this interval.

Santonian (5,660-6,380 feet)

The dinoflagellate Deflandrea pirnaensis, which occurs at 5,660 feet, does not range above the Santonian; Cordosphaeridium truncigerum, noted at 5,570 feet, is the nominative species for the Santonian C. truncigerum Zone in the Grand Banks and Scotian Shelf offshore of Canada. Eiffellithus trabeculatus is a nannofossil species of Santonian age that occurs at 5,900 feet.

Coniacian? (6,380-7,100 feet)

The spore species Nevisisporites semiclaris has a topmost Coniacian range in the Mid-Atlantic area (Bebout, 1981). In this well, the highest occurrence of N. semiclaris is 6,380 feet.

Turonian (7,100-7,850 feet)

Two nannofossil occurrences indicate that this interval is of Turonian age: Corollithion cf. C. achylosum at 7,100 feet and C. achylosum at 7,280 feet.

Cenomanian (7,850-7,970 feet)

The nannofossil species Corollithion kennedyi was identified from sediments at 7,850 feet, and the planktonic foraminifer Rotalipora cushmani was identified at 7,880 feet. Both indicate a Cenomanian age.

Early Cretaceous

Albian (7,970-8,810 feet)

The upper limit of the nannofossil species Braarudosphaera africana at 7,970 feet indicates a probable Albian age for the section at this depth.

Aptian (8,810-9,620 feet)

Bebout (1981) indicates that Callialasporites trilobatus has a topmost Aptian age range in the subsurface of the western Atlantic area. The uppermost occurrence of this species in this well is at 8,810 feet.

Barremian (9,620-11,150 feet)

The dinoflagellate species Muderongia simplex and Pseudoceratium pelliferum, which have their highest occurrence at 9,620 feet, represent Barremian sediments.

Valanginian (11,150-11,390 feet)

The nannofossil species Nannoconus colomi occurs at 11,150 feet, indicating a Valanginian age for the section at this depth. The benthic foraminifer Everticyclamina virguliana, seen at 11,360 feet, is also a Valanginian marker.

Berriasian (11,390-11,870 feet)

The Berriasian top is placed at 11,390 feet based on the uppermost occurrence of Polycostella senaria.

## Late Jurassic

### Tithonian (11,870-12,050 feet)

The dinoflagellate species Ctenidodinium culmulum, C. panneum, and Gonyaulacysta cladophora all indicate that the Tithonian top occurs at 11,870 feet.

### Kimmeridgian (12,050-15,300 feet)

The top of the Kimmeridgian is based on the highest range of Gonyaulacysta longicornis, G. globata, and G. nuciformis at 12,050 feet. The dinoflagellate species Ctenidodinium panneum (lowest range, late Kimmeridgian) and Senoniasphaera jurassica occur in both cuttings and core samples between 12,485 and 12,492 feet, supporting a late Kimmeridgian age for this interval.

## Middle Jurassic? (15,300-17,790 feet)

Rare specimens of Gonyaulacysta filapicata occur at 15,300, 15,930, 16,200, 17,100, and 17,640 feet. Valensiella sp. occurs at 17,010 feet, Ctenidodinium combazii at 17,280 feet, and Ctenidodinium sellwoodii at 17,550 feet. These dinoflagellate species indicate a possible Middle Jurassic Bathonian-Callovian age for the section below 15,300 feet. Their rare occurrence at widely separated intervals may indicate the presence of minor marine intercalations in an otherwise dominantly nonmarine to marginal marine sequence.

## PALEOENVIRONMENTAL ANALYSIS

by

Robert E. Smith and Raymond E. Hall

The analysis of depositional environments is derived from paleontologic and lithologic data and from the dual-induction electric log characteristics. Paleoenvironmental and lithologic data from the Tenneco 642-2 well, approximately 1 mile east of the 642-1 well, were also extrapolated to determine lateral extents of rock units and environments of deposition. Paleoenvironments are graphically summarized in figure 6. The paleoenvironment curve is based on limited foraminifer data, lithologic data, and extrapolation of paleoenvironments from the Tenneco 642-2 well (Bielak, 1986). The sediments penetrated by the Texaco 642-1 well have been grouped into four major depositional environments based on vertical and horizontal changes of the lithology and biostratigraphy projected regionally. These environments are as follows: deep marine sediments, marine transgressive sediments, delta complex sediments, and shallow marine carbonate platform sediments.

### Deep Marine Sediments

A series of open marine sediments of middle Miocene to early Eocene age occurs from 1,270 to 5,030 feet. The sediments characterizing this depositional environment are primarily siltstones, claystones, shales, and carbonates with occasional interbeds of sandstone deposited on a middle to outer shelf position. This same sequence of sediments varies greatly in nearby wells, depending on whether observations are made on wells in a landward or seaward direction. The wells landward of the 642-1 well exhibit coarser clastic material, whereas the more seaward wells contain finer grained sediments. The interbedded sands in this well probably represent a regression of the strand line.

Planktonic and benthonic foraminifera indicate that the interval from 1,270 to 5,120 feet is open marine to 2,470 feet and middle to outer neritic (50 to 300 feet of water) to 5,030 feet. Planktonic foraminiferal data indicate an upper bathyal (600 to 1,500 feet of water) from 5,030 to 7,970 feet.

### Marine Transgressive Sediments

Sediments in this sequence occur from 5,030 to 7,970 feet. The age of this sequence of sediments ranges from late Campanian to Cenomanian. A major erosional unconformity occurs near the top of this sequence, accounting for the missing early Paleocene and Maestrichtian age sediments. The sediments characterizing this Upper Cretaceous sequence are fine-grained clastic rocks ranging from calcareous shales to moderately calcareous mudstones with interbeds of sandstone, limestone, and dolomite.

This sequence has been noted in other wells on the shelf and is interpreted to be a major marine transgression. The strata may serve as seals for potential Lower Cretaceous and older reservoir rocks. The sediments in this sequence were deposited in the outer shelf to upper slope position.

The dual-induction electric log curves are characteristic of that of a destructional delta (flat spontaneous potential curve and little resistivity curve deflection). The gamma ray curve through this sequence indicates mostly shale and mudstone; however, where sandstone is penetrated, the gamma ray shows short deflections to the left side of the shale line indicating thin interbeds of sandstone and siltstone. Benthonic and planktonic foraminifera indicate an outer shelf-upper slope (600 feet of water) depositional environment at 7,700 feet.

## Delta Complex Sediments

This sequence ranges in depth from 7,970 to 15,000 feet and is from Cenomanian to late Kimmeridgian in age. These Cretaceous and Upper Jurassic sediments constitute the principal potential gas reservoirs of the well. These sediments are characteristic of a delta setting as they are highly variable, consisting of a complex stratigraphic succession of interfingering marine and nonmarine strata. Correlations to nearby wells are difficult because of lateral variations. Lithologically, the Texaco 642-1 well sediments range from sandy shales to silty sandstones with numerous sandstone, limestone, and dolomite interbeds. Coal beds are numerous and may exceed 50 feet in thickness, indicating lagoonal restricted subenvironments within this massive deltaic sequence.

Self-potential curves of the dual-induction log exhibit blocky, funnel, and serrated shapes depending on the delta facies position. In sharp contrast to the marine transgressive or destructional delta sequence above, the resistivity curve fluctuates greatly, reflecting delta system patterns.

Benthonic and planktonic foraminifera indicate middle neritic to upper slope at 9,650-9,680 feet, and outer neritic (300 to 600 feet of water) at 11,150 - 11,390 feet.

## Shallow Marine Carbonate Platform Sediments

The final sequence of sediments ranges from 15,000 to 17,807 feet (TD) and is of Middle Jurassic age. The sediments characterizing this sequence are mainly limestones with numerous thin interbeds of sandstone and shale. The limestone is micritic with varying amounts of oolitic material and biota. This carbonate platform is positioned in an inner shelf environment landward of the paleoshelfedge. Waters during deposition were shallow and quiet, perhaps occasionally becoming silty over a broad shelf.

More landward wells including the COST B-2, show evidence of sandstone and carbonate interfingering, whereas those seaward verify the more extensive carbonate complex with considerably fewer sandstone beds. Palynological data indicate mostly nonmarine and marginal marine (inner deltaic to outer distributary channel) environments of deposition with minor marine intercalations as evidenced by rare occurrences of dinoflagellates in this deepest interval.

## FORMATION EVALUATION

by

Renny R. Nichols

### Well Logs

Schlumberger Limited ran the following geophysical well logs in the Texaco 642-1 well to provide information for stratigraphic correlation and evaluation of formation fluids, porosity, and lithology:

Table 4.--Geophysical well logs and intervals

| Log Type | Depth Interval (feet) |
|---|---|
| Sonic Log | 1,226-16,938 |
| Dual Induction - Spherically Focused Log (DISFL) | 1,226-16,938 |
| Compensated Neutron Log (CNL)/Formation Density Compensated Log (FDC) | 548-16,910 |
| High-Resolution Dipmeter (HDT) | 4,508-16,910 |

The well was drilled to a depth of 17,807 feet where a gas kick of 828 units was encountered. The drill pipe became stuck and was cut at 12,499 feet. The original hole was logged to 16,938 feet. A sidetrack hole was started at 11,830 feet and drilled to 15,786 feet at which point 1,600 units of gas were encountered and the drilling was terminated.

Exploration Logging Inc., provided a formation evaluation log ("mud log"), which included a rate of penetration curve, sample description, and a graphic presentation of hydrocarbon shows encountered in the original well (1,222 to 17,807 feet) and in the sidetrack (11,830 to 15,786 feet). In addition, drilling data pressure logs (1,222 to 17,807 feet in the original hole and 11,900 to 15,780 feet in the sidetrack hole) were run as well as a pressure analysis log (1,300 to 17,807 feet in the original hole and 11,900 to 15,786 feet in the sidetrack hole).

### Well Log Interpretations

The electric logs from the original hole, together with the mud log and other available data, were analyzed in detail to determine the thickness of potential reservoirs, average porosities, and feet of hydrocarbon-bearing rocks present. Reservoir rocks with porosities of less than 5 percent were disregarded. A combination of logs was used in the analysis, but a detailed lithologic and reservoir property determination from samples, conventional cores, and sidewall cores, in addition to full consideration of any test results, is necessary to substantiate the following estimates as shown in table 5. A total of 119 net feet of hydrocarbon-bearing rocks were calculated for zones that produced gas by DST, and an additional 157 net feet were calculated for zones that were not tested.

Table 5.—Summary of well log interpretations

| Depth Interval (feet) | Feet of Potential Reservoir (a) | Average Porosity (%) | Water Saturation (%) | Potential Hydrocarbon-bearing Zones (feet) (b) |
|---|---|---|---|---|
| 2,473-2,501 | 28 | 35+ | - | - |
| 5,932-5,950 | 18 | 33 | - | - |
| 6,106-6,119 | 13 | 32 | - | - |
| 7,916-7,984 | 54 | 20 | - | - |
| 8,030-8,056 | 26 | 18 | - | - |
| 8,080-8,102 | 22 | 23 | - | - |
| 8,148-8,148 | 26 | 20 | - | - |
| 8,187-8,234 | 19 | 24 | - | - |
| 8,240-8,344 | 94 | 25 | - | - |
| 8,447-8,650 | 167 | 25 | - | - |
| 8,728-8,738 | 10 | 21 | - | - |
| 8,914-8,938 | 14 | 20 | - | - |
| 8,960-8,974 | 14 | 23 | - | - |
| 9,011-9,045 | 28 | 22 | - | - |
| 9,070-9,125 | 26 | 24 | - | - |
| 9,262-9,356 | 30 | 21 | - | - |
| 9,452-9,480 | 25 | 21 | 49 | - (c) |
| 9,510-9,520 | 6 | 19 | 74 | - |
| 9,530-9,552 | 16 | 24 | - | - |
| 9,566-9,602 | 28 | 24 | - | - |
| 9,638-9,696 | 48 | 22 | 89 | - |
| 9,726-9,782 | 36 | 23 | - | - |
| 9,830-9,893 | 46 | 18 | 100 | - |
| 9,948-9,960 | 12 | 21 | 81 | - |
| 9,990-10,048 | 50 | 21 | 100 | - |
| 10,102-10,150 | 35 | 18 | - | - |
| 10,188-10,275 | 66 | 21 | - | - |
| 10,293-10,304 | 11 | 20 | - | - |
| 10,328-10,364 | 17 | 16 | - | - |
| 10,382-10,559 | 63 | 21 | - | - |
| 10,720-10,744 | 22 | 21 | - | - |
| 10,780-10,812 | 32 | 20 | - | - |
| 10,830-10,902 | 34 | 26 | - | - |
| 10,930-10,946 | 14 | 19 | - | - |
| 11,166-11,174 | 8 | 15 | 87 | - |
| 11,542-11,548 | 6(?) | 11 | 65 | - |
| 11,734-11,750 | 14 | 10 | - | - |
| 12,056-12,064 | 8 | 5 | 100 | - |
| 12,208-12,214 | 6 | 6 | 94 | - |
| 12,314-12,330 | 9 | 9 | 36 | - (d) |

Table 5. -- Summary of well log interpretations--Continued

| Depth Interval (feet) | Feet of Potential Reservoir (a) | Average Porosity (%) | Water Saturation (%) | Potential Hydrocarbon-bearing Zones (feet) (b) |
|---|---|---|---|---|
| 12,664-12,674 | 10 | 11 | 53 | - |
| 12,712-12,742 | 30 | 9 | 53 | - |
| 12,814-12,832 | 18 | 9 | 57 | 18 (see DST-7 |
| 12,892-12,904 | 12 | 11 | 47 | - in table 3) |
| 13,026-13,056 | 24 | 8 | - | - |
| 13,222-13,248 | 22 | 15 | 56 | - |
| 13,366-13,384 | 13 | 13 | - | - |
| 13,408-13,428 | 20 | 10 | - | - |
| 13,478-13,510 | 32 | 12 | 29 | 32 (See DST-5) |
| 13,622-13,652 | 24 | 8 | 67 | - |
| 13,784-13,848 | 64 | 9 | - | - |
| 13,938-13,950 | 12 | 12 | - | - |
| 13,970-13,996 | 19 | 10 | - | - |
| 14,000-14,034 | 28 | 7 | 76 | - |
| 14,114-14,129 | 14 | 8 | 51 | - (e) |
| 14,129-14,154 | 22 | 8 | 65 | - |
| 14,230-14,255 | 25 | 9 | - | - |
| 14,442-14,484 | 42 | 8 | - | - |
| 14,616-14,648 | 32 | 12 | 51 | 32 (?) |
| 14,731-14,748 | 17 | 9 | 52 | - |
| 14,822-14,846 | 22 | 10 | - | - |
| 14,878-14,902 | 20 | 8 | - | - |
| 14,920-14,940 | 19 | 9 | 55 | - |
| 15,042-15,054 | 12 | 10 | 49 | 12 |
| 15,082-15,114 | 29 | 11 | 42 | 29 |
| 15,172-15,182 | 10 | 18 | 17 | 10 (?) (f) |
| 15,230-15,240 | 10 | 11 | 39 | 10 (?) (f) |
| 15,270-15,280 | 10 | 11 | 59 | - |
| 15,290-15,314 | 24 | 11 | 44 | 24 (?) |
| 15,314-15,338 | 14 | 11 | 50 | - |
| 15,365-15,384 | 16 | 18 | 65 | - |
| 15,384-15,402 | 16 | 12 | 57 | - |
| 15,522-15,593 | 69 | 19 | 80 | 69 (See DST-1) |
| 15,629-15,702 | 71 | 11 | 72 | |
| 15,740-15,753 | 13 | 8 | 57 | 13 (?) (g) |
| 15,753-15,765 | 12 | 11 | 55 | 12 (?) (g) |
| 15,792-15,813 | 10 | 9 | 66 | - |
| 15,834-15,844 | 10 | 9 | 57 | - |
| 15,850-15,892 | 34 | 8 | 65 | - |
| 15,913-15,396 | 18 | 7 | 82 | - |

Table 5.--Summary of well log interpretations--Continued

| Depth Interval (feet) | Feet of Potential Reservoir (a) | Average Porosity (%) | Water Saturation (%) | Potential Hydrocarbon-bearing Zones (feet) (b) |
|---|---|---|---|---|
| 16,048-16,080 | 24 | 8 | 62 | - |
| 16,199-16,225 | 13 | 8 | 59 | - |
| 16,399-16,412 | 13 | 9 | 100 | - |
| 16,636-16,674 | 20 | 8 | 97 | - |
| 16,858-16,887 | 15 | 8 | 92 | - |
| (From ROP curve on mud log in original hole): | | | | |
| 17,040-17,090 | 35 | *(7-9)? | - | - |
| 17,325-17,360 | 30 | *(7-9)? | - | - |
| 17,040-17,090 | 35 | *(7-9)? | - | - |
| 17,325-17,360 | 30 | *(7-9)? | - | - |
| 17,600-17,660 | 40 | *(7-9)? | - | - |
| 17,790-17,807 | 15+ | *(7-9)? | - | 15+(?) (h) |

*Based on similar rate of penetration (ROP) characteristics with electric log porosity available.

(a) Generally in beds > 10 feet thick and porosity > 5%.
(b) Generally in beds > 10 feet thick, porosity > 5%, and water saturation ($S_w$) < 50%. (c) $S_w$ < 50%, hotwire = 5 units.
(d) $S_w$ < 50%, hotwire ≅ 320 units, chromatograph = $C_{1-2-3}$, no coal seen in samples, no SP on DISFL.
(e) Disproved by DST-4.
(f) Poor SP development, no $C_4$, gas on mud log may actually be recycling from zone at 15,082-15,114 feet.
(g) Hotwire = 1,600 units and presence of $C_{1-2-3-4i}$ for this zone in sidetrack hole.
(h) No logs available, but excellent ROP (11 min/ft to 1 min/ft), hotwire = 828 units, presence of $C_{1-2-3-4i}$.

Sidewall and Conventional Core Analyses

The sidewall core analysis is summarized in table 6.

Table 6.--Summary of sidewall core analyses

| Depth Interval (feet) | Lithology | Porosity Range (%) | Permeability Range (md) | Oil Pore(%) | Oil Bulk(%) | Gas Bulk(%) |
|---|---|---|---|---|---|---|
| 7,920-9,020 | ss/ls | 6.1-24.8 | .4-80 | - | - | 1.6-5.4 |
| 9,457-9,532 | *ss | 19.5-30.9 | .1-525 | 0-1.3 | 0-.3 | 4.8-11.9 |
| 11,545-13,510 | ss | 10.4-22.5 | <.1-14 | - | - | 2.3-7.9 |
| 13,818-15,098 | ss | 14.3-19.3 | .1-5.2 | - | - | 2.0-7.8 |

*The presence of very faint fluorescence was noted by Core Labs in samples at 9,457, 9,460, and 9,463 feet.

Sidewall core porosities compare favorably to electric log porosities as can be seen from table 7.

Table 7.--Comparison of sidewall core and well log porosity data

| Depth (feet) | Sidewall Core Porosity | Neutron Log Porosity | Density Log Porosity | Sonic Log Porosity | $\Delta t$ |
|---|---|---|---|---|---|
| 7,920 | 15 | 24 | 20 | 21 | 84 |
| 8,397 | 15 | 33 | 15 | 23 | 86 |
| 8,422 | 17 | 33 | 21 | 26 | 90 |
| 8,462 | 25 | 31 | 22 | 26 | 90 |
| 8,614 | 21 | 32 | 27 | 26 | 90 |
| 8,620 | 23 | 32 | 27 | 26 | 90 |
| 8,664 | 6 | 12 | 0 | 9 | 60 |
| 8,676 | 11 | 12 | 1 | 9 | 60 |
| 9,020 | 24 | 32 | 24 | 27 | 91 |
| 9,457 | 21 | 20 | 23 | 30 | 95 |
| 9,460 | 31 | 23 | 17 | 24 | 87 |
| 9,470 | 26 | 30 | 22 | 25 | 89 |
| 9,498 | 20 | 34 | 6 | 17 | 78 |
| 9,514 | 21 | 24 | 21 | 13 | 73 |
| 9,516 | 20 | 26 | 18 | 18 | 80 |
| 9,532 | 26 | 31 | 21 | 24 | 87 |
| 11,545 | 18 | 20 | 9 | 15 | 76 |
| 11,582 | 10 | 21 | 4 | 2 | 58 |
| 11,772 | 12 | 21 | -2 | 2 | 58 |
| 12,164 | 14 | 19 | 8 | 12 | 71 |

Table 7. -- Comparison of sidewall core and well log porosity data--
Continued

| Depth (feet) | Sidewall Core Porosity | Neutron Log Porosity | Density Log Porosity | Sonic Log Porosity | $\Delta t$ |
|---|---|---|---|---|---|
| 12,444 | 23 | 45+ | 30 | 35+ | 110 |
| 12,448 | 22 | 45+ | 15 | 26 | 90 |
| 13,486 | 20 | 30 | 3 | 13 | 73 |
| 13,494 | 22 | 15 | 12 | 12 | 72 |
| 13,510 | 20 | 15 | 15 | 11 | 70 |
| 13,818 | 18 | 12 | 8 | 9 | 67 |
| 13,990 | 18 | 13 | 11 | 9 | 67 |
| 14,122 | 19 | 16 | 13 | 10 | 69 |
| 14,252 | 16 | 12 | 9 | 9 | 67 |
| 14,462 | 17 | 11 | 7 | 6 | 63 |
| 14,480 | 16 | 12 | 7 | 6 | 63 |
| 14,620 | 17 | 15 | 15 | 11 | 70 |
| 14,624 | 14 | 15 | 10 | 10 | 68 |
| 14,632 | 14 | 15 | 12 | 12 | 71 |
| 14,640 | 17 | 11 | 11 | 10 | 68 |
| 14,734 | 19 | 13 | 10 | 6 | 64 |
| 14,740 | 16 | 11 | 11 | 7 | 65 |
| 15,098 | 15 | 12 | 9 | 2 | 58 |

The interval 7,920 to 9,020 feet exhibits fair correlation between sidewall porosity and density log porosity which is generally 2-6 percent higher.

From 9,460 to 12,164 feet, there is fair correlation with sonic log porosity which is generally 2-3 percent lower. From 12,444 to 15,098 feet, there is poor to fair correlation with neutron log porosity, which is generally 2-6 percent lower (density porosity is even lower and closely agrees with the sonic log porosity). The sidewall core porosity may be higher for this lower interval (12,444-15,098 feet) because of an increase in siliceous as well as calcareous cement within the sandstones, which may result in fractures within the sidewall cores due to the sampling process.

Table 8.--Summary of conventional core analysis

| Core No. | Depth Interval (ft) | Lith. | Porosity Range (%) | Permeability Range (md) | Oil Pore (%) |
|---|---|---|---|---|---|
| 1 | 12,434-12,495 | ss | 3.4-13.0 | <.1-.1 | - |
| 2 | 14,044-14,078 | ss | 2.6-9.9 | <.1-1.5 | - |
| 3 | 16,911-16,966 | ss/ls | 1.0-10.3 | <.1-.1 | *- |
| 1-STH | 15,344-15,375 | ss | 5.5-13.2 | <.1-.5 | - |
| 2-STH | 15,608-15,668 | ss | 2.2-21.7 | <.1-46.0 | - |

*In original core No. 3, the zones from 16,924 to 16,927, 16,933 to 16,945, and 16,955 to 16,956 feet exhibited dead oil with yellow fluorescence but no cut as reported by Texaco geologists.

For core No. 1 STH=sidetrack hole (table 8), there is fair correlation with sonic porosity, which is higher by 2-3 percent (more in shaley zones), and good correlation with the density porosity. Core No. 2 shows fair correlation with the sonic porosity which is slightly higher and the density porosity, which is generally 15 percent higher. Core No. 3 cannot be compared with the sonic porosity (no reading below 16,900 feet) or the density porosity (no reading below 16,908 feet) due to the stacking configuration of the logging sondes.

Note: Preliminary analysis of core No. 1 by Core Laboratories, Inc., reported oil saturations ranging from 3 to 9 percent on all samples after retorting at 300 °F. On a final check, portions of the same samples were retorted at 1200 °F, and no oil was observed at the completion of the process. Consequently, no oil saturation is shown in the final report (letter from Core Labs to Minerals Management Service of Aug. 22,1979). The mud used during drilling may have contained a substance that contributed to the original inaccurate results.

Dipmeter Survey

Results of the dipmeter survey were recorded on an arrow plot from 4,508 to 15,096 feet. Possible structural anomalies may be present at 5,025, 5,650, 8,490, 10,250, and 10,830 feet. The dip direction and magnitude in the well are shown in table 9.

Table 9.--Dip direction and magnitude from dipmeter

| Interval (feet) | Predominant Direction | Magnitude (degrees) |
|---|---|---|
| 4,500-5,025 | Southward | 1-4 |
| 5,025-5,925 | Northeast-Southward | 1-56 |
| 5,925-7,200 | Southward | 1-11 |
| 7,200-8,200 | Westward | 1-15 |
| 8,200-10,400 | Eastward | 1-30 |
| 10,400-10,850 | Southward | 1-15 |
| 10,850-12,500 | Westward | 1-14 |
| 12,500-14,500 | Southeastward | 1-30 |
| 14,500-15,096 | Southward | 1-20 |

Significant Hydrocarbon Shows

Table 10 lists all shows of hydrocarbons encountered in the Texaco 642-1 well (hotwire readings below 100 units and zones less than 10 feet thick were generally omitted in this list). A summary of the depth intervals of the most significant hydrocarbon shows follows:

| | | |
|---|---|---|
| 9,495-9,505 feet | 15,105-15,140 feet | 17,040-17,090 feet |
| 12,840-12,860 feet | 15,200-15,210 feet | 17,325-17,360 feet |
| 13,495-13,535 feet | 15,255-15,265 feet | 17,600-17,660 feet |
| 15,065-15,080 feet | 15,315-15,335 feet | 17,795-17,807 feet |

Table 10.--Summary of hydrocarbon shows

| Depth Interval (feet) | Drilling Break min/ft | Sample Description (mud log) | Gas (Mud log units) b.g. | Gas (Mud log units) total | Chromatograph | Cuttings Gas | Conventional Cores Interval | Conventional Cores Ø | Conventional Cores K | Conventional Cores $O_p$ | Conventional Cores $O_b$ | Conventional Cores $G_b$ | Sidewall Cores Depth | Sidewall Cores Ø | Sidewall Cores K* | Sidewall Cores $O_p$ | Sidewall Cores $O_b$ | Sidewall Cores $G_b$ | Well Log Interpretation Interval (feet) | Well Log Interpretation Ø | Well Log Interpretation $S_w$ | Tests |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9,495-9,505 | 3-1 | ss, calc. | 3 | 850 | $C_{1-2-3}$ | 12 | | | | | | | 9,457-<br>9,532 | 20-<br>31 | .1-<br>525 | 0-<br>1.3 | 0-<br>.3 | 2.8-<br>11.9 | 9,510-9,520 | 19 | 74 | |
| 9,615-9,635 | 4-1 | ss, coal | 3 | 45 | $C_{1-2-3}$ | 5 | | | | | | | | | | | | | 9,638-9,696 | 22 | 89 | |
| 9,825-9,835 | 8-1 | ss, hd., coarse | 4 | 85 | $C_{1-2-3}$ | 10 | | | | | | | | | | | | | 9,830-9,893 | 18 | 100 | |
| 9,960-9,970 | 5-2 | siltstn, fri. | 5 | 80 | $C_{1-2-3}$ | 8 | | | | | | | | | | | | | 9,948-9,960 | 21 | 81 | |
| 9,990-10,005 | 4-1 | ss, congl. | 15 | 160 | $C_{1-2-3}$ | 8 | | | | | | | | | | | | | 9,990-10,048 | 21 | 100 | |
| 11,170-11,190 | 7-2 | ss, coarse calc.,<br>dull org. flu.,<br>no cut | 3 | 40 | $C_{1-2}$ | 10 | | | | | | | | | | | | | 11,166-11,174 | 15 | 87 | |
| 11,570-11,580 | 6-4 | ss, firm, calc. | 10 | 600 | $C_{1-2-3}$ | 20 | | | | | | | 11,582 | 10.4 | <.1 | - | - | 2.3 | 11,542-11,548 | 11 | 65 | |
| 12,060-12,070 | 8-2 | ls, hd., sandy | 5 | 100 | $C_{1-2}$ | 20 | | | | | | | | | | | | | 12,056-12,060 | 5 | 100 | |
| 12,205-12,215 | 16-4 | ls, hd., sandy | 5 | 80 | $C_1$ | 85 | | | | | | | | | | | | | 12,208-12,214 | 6 | 94 | |
| 12,330-12,350 | 8-2 | ss, coal | 5 | 320 | $C_{1-2-3}$ | 38 | | | | | | | | | | | | | 12,314-12,330 | 9 | 36 | |
| 12,840-12,860 | 5-2 | ss, calc. | 10 | 120 | $C_{1-2-3}$ | 50 | | | | | | | | | | | | | 12,814-12,832 | 9 | 47 | 12,790-12,822 feet<br>= 18.9 MMCFGDP +<br>15 gal. cond./MM |
| 13,055-13,075 | 10-2 | ss, calc. | 5 | 75 | $C_{1-2}$ | 2 | | | | | | | | | | | | | 13,026-13,056 | 8 | 50 | 13,003-13,036 feet<br>= 750 MCFGPD |
| 13,265-13,275 | 8-2 | ss, vy.hd.,calc.,<br>brt.orge.flu. | 10 | 112 | $C_{1-2-3}$ | 20 | | | | | | | | | | | | | 13,222-13,248 | 15 | 543 | |
| 13,495-13,535 | 6-2 | ss, hd., calc.,<br>brt.yel.flu.occ.<br>milky yel.wht.cut | 8 | 85 | $C_{1-2-3}$ | 8 | | | | | | | 13,486-<br>13,510 | 20-<br>22 | 6-<br>11 | - | - | 3.6-<br>4.8 | 13,478-13,510 | 12 | 29 | 13,450-13,487 feet = 14.2<br>MMCFGPD + 0.4bbl cond./MM |
| 13,650-13,665 | 8-2 | ss, occ.brn.stn.,<br>calc.,dull orge.<br>flu. | 20 | 60 | $C_{1-2-3}$ | 3 | | | | | | | | | | | | | 13,622-13,652 | 8 | 67 | |
| 14,000-14,050 | 10-2 | ss, hd.,calc. | 10 | 211 | $C_{1-2-3-4}$ | 10 | 14,044-<br>14,078 | 2.6-<br>9.9 | <.1<br>1.5 | | | | 13,990 | 18 | 1.7 | - | - | 5.7 | 14,000-14,034 | 7 | 76 | |
| 14,145-14,185 | 9-2 | ss, hd.,calc.,occ.<br>yel.flu. | 20 | 137 | $C_{1-2-3-4}$ | 8 | | | | | | | 14,122 | 19 | 2.1 | - | - | 2.0 | 14,114-14,129<br>14,129-14,154 | 8<br>8 | 51<br>65 | 14,078-14,115 feet<br>some gas cut mud |
| 14,650-14,670 | 8-2 | ss, hd.,silic.,<br>sli. orge.flu. | 15 | 152 | $C_1$-to-$_{4i-n}$ | 15 | | | | | | | 14,620-<br>14,640 | 14-<br>17 | .1-<br>5.2 | | | 3.8-<br>6.7 | 14,616-14,648 | 12 | 51 | |
| 14,765-14,775 | 8-2 | ss, hd.,silic. | 20 | 235 | $C_{1-2-3}$ | 8 | | | | | | | 14,734-<br>14,740 | 16-<br>19 | .8-<br>2.1 | -<br>- | -<br>- | 4.2-<br>4.8 | 14,731-14,748 | 9 | 52 | |

Ø - porosity
K - permeability in md
$O_p$ - oil saturation
b.g. - background gas
$O_b$ - oil (bulk), weight % of oil relative to bulk sample weight
occ. - occasionally
$G_b$ - gas (bulk), Weight % of gas relative to bulk sample weight
$S_w$ - water saturation
*derived empirically

Table 10.--Summary of hydrocarbon shows--continued

| Depth Interval (feet) | Drilling Break min/ft | Sample Description (mud log) | Gas (Mud log units) b.g. | Gas (Mud log units) total | Chromatograph | Cuttings Gas | Conventional Cores Interval | Ø | K | $O_p$ | $O_b$ | $G_b$ | Sidewall Cores Depth | Ø | K* | Op | $O_b$ | $G_b$ | Well Log Interpretation Interval (feet) | Ø | $S_w$ | Tests |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14,950-14,965 | 10-1 | ss, hd. | 20 | 208 | $C_1-_2-_3-_{4i}$ | 10 | | | | | | | | | | | | | 14,920-14,940 | 9 | 55 | |
| 15,065-15,080 | 8-1 | ss, hd.,calc., sli.yel.flu. | 15 | 438 | $C_1$-to-$_{4i-n}$ | 8 | | | | | | | 15098 | 15 | .8 | | | 5.0 | 15,042-15,054 | 11 | 49 | |
| 15,105-15,140 | 8-1 | ss, hd.,calc. | 20 | 473 | $C_1$-to-$_{4i-n}$ | 8 | | | | | | | | | | | | | 15,082-15,114 | 11 | 42 | |
| 15,160-15,170 | 9-1 | ss, hd.,calc. | 30 | 271 | $C_1-_2-_3$ | 8 | | | | | | | | | | | | | 15,172-15,182 | 18 | 17 | |
| 15,200-15,210 | 8-3 | ss, hd.,calc. | 30 | 652 | $C_1-_2-_3$ | 8 | | | | | | | | | | | | | 15,230-15,240 | 11 | 39 | |
| 15,255-15,255 | 8-4 | ss, hd. | 30 | 441 | $C_1-_2-_3$ | 10 | | | | | | | | | | | | | 15,290-15,314 | 11 | 44 | |
| 15,315-15,335 | 8-2 | ss, hd. | 10 | 441 | $C_1-_2-_3$ | 10 | | | | | | | | | | | | | 15,314-15,338 | 11 | 50 | |
| 15,350-15,365 | 5-2 | ss, calc. | 65 | 192 | $C_1-_2-_3$ | 8 | 15,344-15,375 (STH) | 5.5-13.2 | <.1-.5 | | | | | | | | | | 15,365-15,384 | 18 | 65 | 15,350-15,385 feet =120 MCFGPD |
| 15,390-15,425 | 8-2 | ss, calc. | 23 | 433 | $C_1-_2-_3$ | 8 | | | | | | | | | | | | | 15,384-15,402 | 12 | 57 | |
| 15,540-15,550 | 10-1 | ss, calc.,coal | 10 | 130 | $C_1-_2$ | 2 | | | | | | | | | | | | | 15,522-15,593 | 15 | 80 | 15,548-15,610 feet =5.5 MMCFGPD + 3.3 bbl cond./MM |
| 15,655-15,690 | 10-1 | ss, hd.,calc. | 30 | 428 | $C_1-_2-_3$ | 7 | 15,608-15,654 (STH) | 2.2-21.7 | <.1-46 | | | | | | | | | | 15,629-15,702 | 11 | 72 | |
| 15,760-15,795 | 8-2 | ss/sltstn.,hd. calc. | 26 | 450 | $C_{1-2-3}$ | 3 | | | | | | | | | | | | | 15,740-15,753<br>15,753-15,765 | 8<br>11 | 57<br>55 | |
| 15,810-15,830 | 8-2 | sltstn. hd.,vy. calc. | 42 | 418 | $C_{1-2-}{}^3$ | 3 | | | | | | | | | | | | | 15,792-15,813 | 9 | 66 | |
| 15,875-15,885 | 8-2 | ss, hd.,calc. | 30 | 418 | $C_1-_2-_3$ | 3 | | | | | | | | | | | | | 15,834-15,844 | 9 | 57 | |
| 15,895-15,925 | 6-2 | ss, hd.,calc. | 150 | 268 | $C_1-_2-_3$ | 2 | | | | | | | | | | | | | 15,850-15,892 | 8 | 65 | |
| 15,940-15,960 | 8-2 | ss, calc. | 40 | 456 | $C_{1-2}$ | 6 | | | | | | | | | | | | | 15,913-15,936 | 7 | 82 | |
| 16,065-16,085 | 8-2 | ss, hd., coal | 20 | 402 | $C_{1-2-3}$ | 4 | | | | | | | | | | | | | 16,048-16,080 | 8 | 62 | |
| 16,220-16,250 | 9-2 | ss, hd.,calc. | 20 | 316 | $C_{1-2-3}$ | 3 | | | | | | | | | | | | | 16,199-16,225 | 8 | 59 | |
| 16,425-16,450 | 8-2 | ss, fri.,calc. | 20 | 124 | $C_{1-2-3}$ | 2 | | | | | | | | | | | | | 16,399-16,412 | 9 | 100 | |
| 16,625-16,640 | 8-4 | ss, sft.,calc. tr.dull yel.flu. | 12 | 25 | $C_1$-2 | 1 | | | | | | | | | | | | | 16,636-16,624 | 8 | 97 | |
| 16,895-16,945 | 10-2 | ss, sli. calc. | 12 | 1280 | $C_{1-2-3}$ | 15 | 16,911-16,966 | 1.0-10.3 | <.1-.1 | | | | | | | | | | 16,858-16,887 | 8 | 92 | |
| 17,040-17,090 | 12-4 | ss, hd.sli.calc. occ.brn.stn.,yel. flu. | 25 | 255 | $C_{1-2-3}$ | 4 | | | | | | | | | | | | | # | | | |
| 17,325-17,360 | 7-2 | ss, hd.,calc. scatt. yel.flu. | 30 | 178 | $C_{1}$-to-$_{4i}$ | 10 | | | | | | | | | | | | | # | | | |
| 17,600-17,660 | 12-3 | ss, firm, calc. sli.scatt. flu. | 20 | 222 | $C_{1}$-to-$_{4i}$ | 8 | | | | | | | | | | | | | # | | | |
| 17,795-17,807 | 12-1 | ss, vy.hd., silic., calc. | 12 | 828 | $C_{1}$-to-$_{4i}$ | 36 | | | | | | | | | | | | | # | | | |

tr. - trace (STH) sidetrack hole * derived empirically

# Note: No electric logs available below 16,938 feet.

KEROGEN ANALYSIS

by

Charles E. Fry

## Method

The palynology slides were analyzed to determine the type and thermal rank of the kerogen contained in the cuttings, sidewall core, and conventional core samples of the Texaco 6421 well. For this analysis, the insoluble organic material dispersed in sedimentary rock is classified as four major types: Algal (organic material of marine origin, either recognizable algae or its unstructured remains); Herbaceous (leafy portion of terrestrial plants, also including spores and pollen); Woody (terrestrial plant detritus with lignified fibrous textures); and Coaly (black opaque material considered to be chemically inert) (adapted from Hunt, 1979; and Bayliss, 1980). Algal and marine-derived kerogen have the best potential for oil and gas generation, depending on temperature and burial conditions. The more structured terrestrial kerogens have less oil generation potential, but can generate gas hydrocarbons at higher temperatures (Tissot and Welte, 1978). For this analysis, the percentage of each type contained on the kerogen and palynology slides was estimated.

The maturity of the organic material was estimated by comparing the color of various palynomorphs to a thermal alteration index (TAI) scale (fig. 8, modified from Jones and Edison, 1978). The colors displayed by the organic matter indicate the degree to which the kerogen has been thermally altered (Staplin, 1969). The kerogen type and thermal alteration data complement laboratory geochemical analyses in determining whether or not sediments encountered in a well are prospective as petroleum source rocks.

## Kerogen Type

Figure 9 summarizes the results of the kerogen analyses for the Texaco 642-1 well. The kerogen observed in samples above 2,080 feet was evenly distributed among the algal, herbaceous and woody kerogen types with a small amount of coaly material. Samples examined between 2,080 feet and 2,710 feet were 70-80 percent herbaceous and woody kerogen. The lower part of the Tertiary section (2,710 to 5,120 feet) displayed a marine distribution with the algal and herbaceous types comprising 80-85 percent of the kerogen population.

Upper Cretaceous samples (5,120 to 7,970 feet) have a marine kerogen distribution of 35-45 percent algal kerogen, 25 percent herbaceous, 15-20 percent woody, and 15-20 percent coaly material. An erratic terrestrial trend was observed through the lower part of the Upper Cretaceous, but the lowest sample examined in this section displays a kerogen distribution of 5 percent algal, 40 percent herbaceous, 30 percent woody, and 25 percent

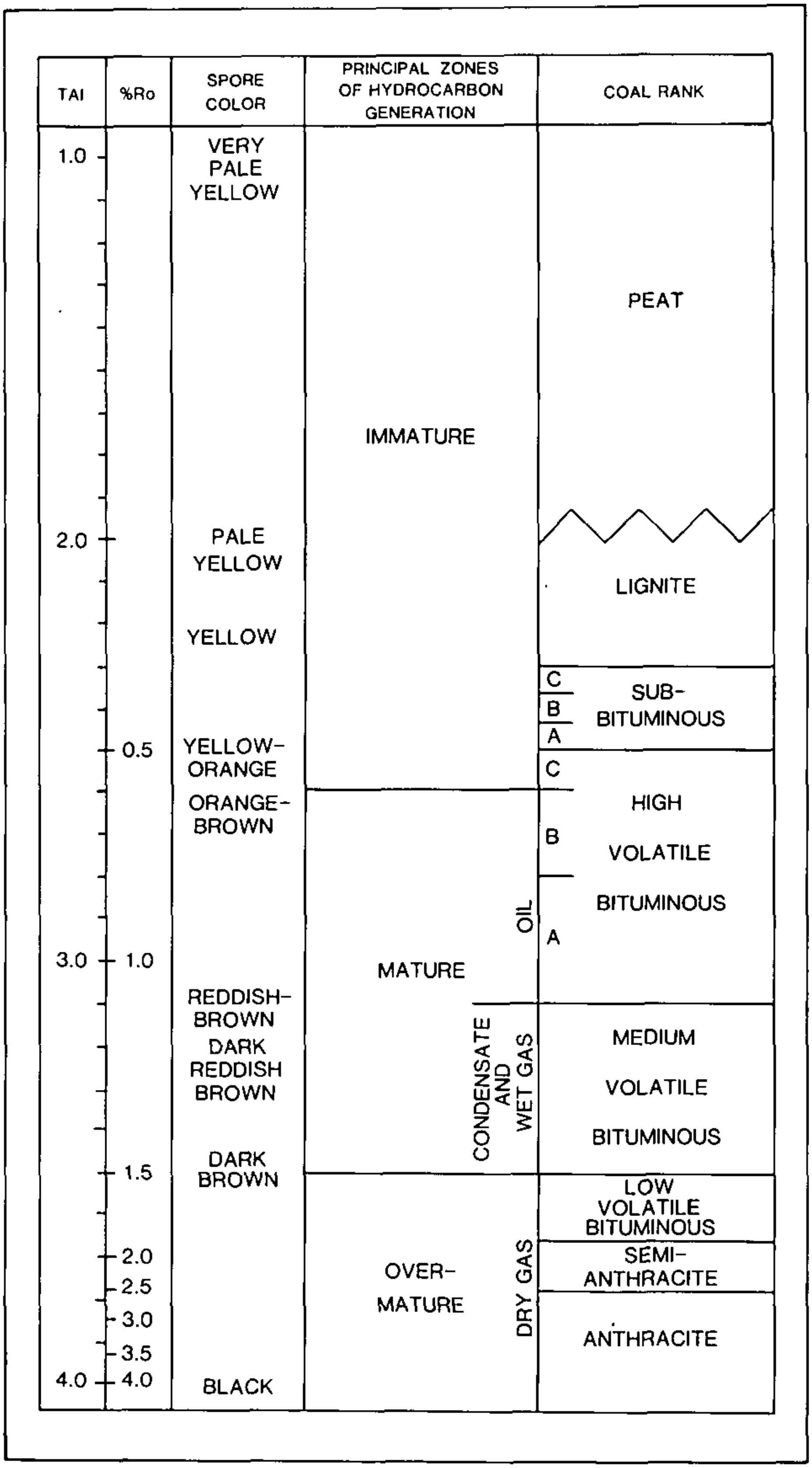


Figure 8.--Relationships among TAI, $\%R_O$, spore color, hydrocarbon generation, and coal rank (after Jones and Edison, 1978)

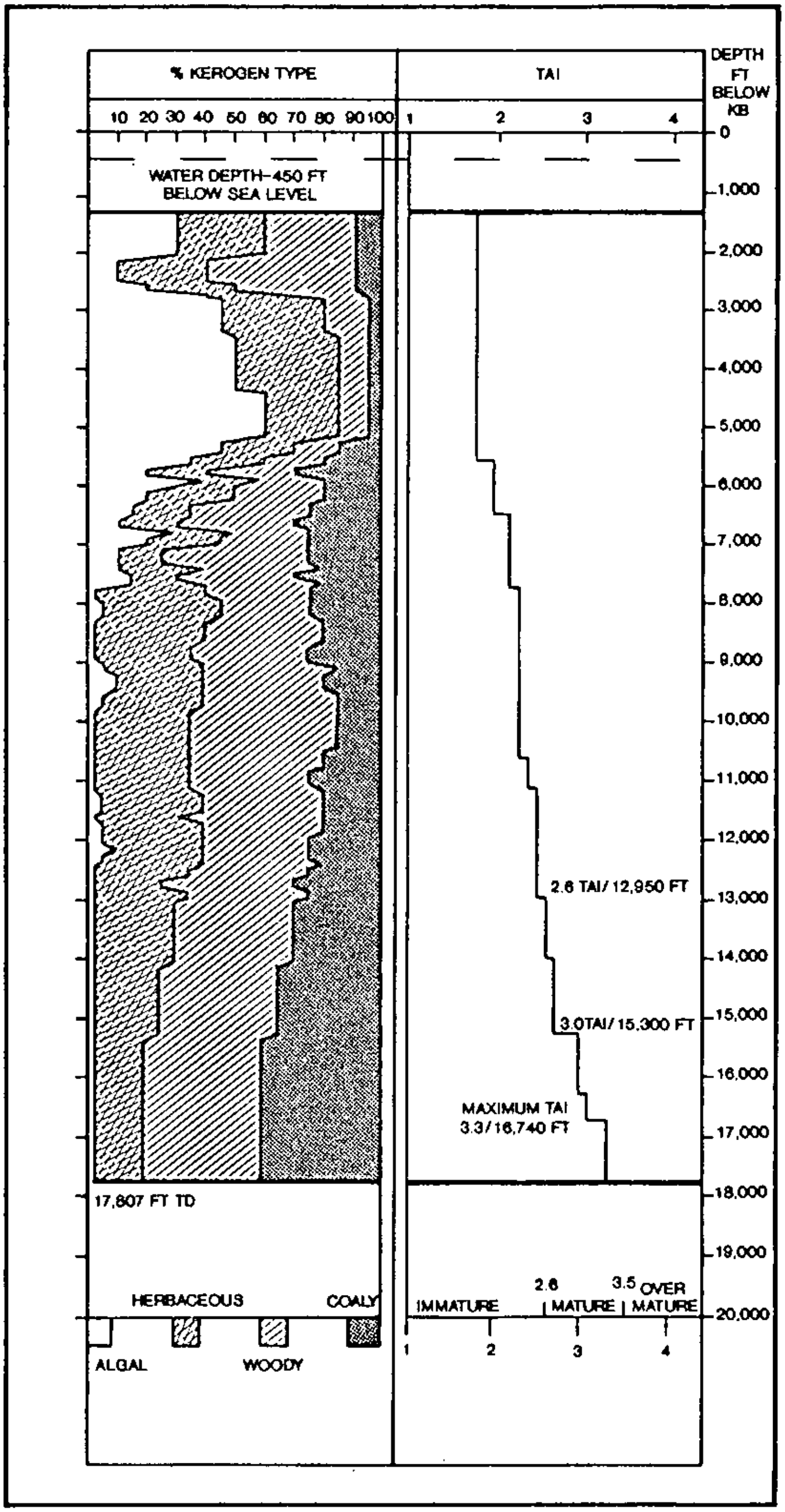


Figure 9.--Kerogen types and thermal maturity of sediments in the Texaco 642-1 well

coaly. Lower Cretaceous samples (7,970 to 11,870 feet) were all determined to be terrestrial with the following kerogen distribution: <5 percent algal kerogen (except within the Albian, where a slight marine trend was observed), 30-40 percent herbaceous, 30-50 percent woody, and 15-25 percent coaly.

The woody and coaly kerogen types dominated all Jurassic samples examined (11,870 to 17,790 feet), especially those below 14,000 feet. Algal kerogen is only present in trace amounts in samples deeper than 12,230 feet.

In summary, marine oil-prone kerogen is present in significant amounts in Tertiary sediments below 2,710 feet and in several intervals within the Upper Cretaceous. Lower Cretaceous and Jurassic samples contained mostly terrestrially derived material with only small amounts of algal material observed.

Maturity

Judging thermal maturity from well cuttings and core samples must be done skillfully to ensure that the material being analyzed is indigenous to the level sampled. Caved or reworked material will give false indications of thermal maturity. Oxidation caused by high-energy depositional environments can also alter the appearance of the kerogen. For this analysis, TAI values were recorded using palynomorphs considered to be in-situ.

The thermal maturity of the kerogen analyzed from the Texaco 642-1 well was estimated by observing palynomorph color. All kerogen observed in samples above the Jurassic (11,870 feet) was determined to be thermally immature. The first occurrence of mature TAI colors is observed in the sample from 12,950 feet. The orange-brown color of palynomorphs from this sample indicates a TAI value of 2.6, which represents borderline maturity. Orange-brown palynomorphs with a reddish hue are first observed in the sample from 14,030 feet. This color indicates an increase in thermal alteration and is assigned a TAI value of 2.7. Red-brown colors representing peak maturity (3.0 TAI) were displayed in samples beginning at 15,300 feet. Dark red-brown colors observed in the samples from 16,290 feet and 16,740 feet indicate levels of thermal alteration beyond peak maturity, but are not considered overmature (>3.5 TAI).

Conclusion

The Upper Cretaceous and Tertiary sections of the well contain primarily marine, oil-prone kerogen, whereas Lower Cretaceous and older sediments from the well contain predominantly terrestrial (gas-prone) kerogen. Based on thermal alteration color indicators, the younger section down to 12,950 feet appears to be thermally immature (TAI <2.4) and is unlikely to have generated significant amounts of hydrocarbons. The lower 5,000 feet of sediment in the well appears to have reached a stage of thermal maturity where hydrocarbon generation is possible.

PETROLEUM GEOCHEMISTRY

by

Robert E. Miller, David M. Schultz, Harry E. Lerch,
Dennis T. Ligon and Paul C. Bowker

The quality of the organic richness of a source rock and its ability to provide petroleum hydrocarbons may be indicated by (1) a minimum amount of total organic carbon (0.7 to 1.0 weight percent for argillaceous rocks), (2) pyrolytic oil yields greater than 0.2 to 0.3 percent, and (3) solvent extractable hydrocarbon concentrations exceeding 100 to 500 parts per million (ppm). However, the weight percent of total organic carbon required to provide or constitute an excellent, good, or poor source rock is not as well defined for fine-grained, medium to dark gray limestone and dolomites. The amorphous nature of the organic matter derived from hydrogen-rich marine algal substances in dark gray carbonates may provide the potential to generate more hydrocarbons than shales with the equivalent amounts of total organic matter. As a consequence, medium- to fine-grained, dark gray to dull brown limestones and dolomites with a total organic carbon as low as 0.3 percent may have sufficient richness to be classifed as source rocks (Hunt, 1967).

The objectives of this study are (1) to examine and define the source rock characteristics of the stratigraphic intervals in the Texaco 642-1 well, (2) to determine the time-temperature-burial depth relationships for the onset of the thermal maturation processes, and (3) to determine if drilling and mud additives have affected the interpretation of the source rock characteristics.

The definitions, concepts, and terminology used in this report are those established by Vassoyevich and others (1970), Hunt (1967, 1974, 1978, 1979), Claypool and others, (1977), Dow (1977), Momper (1978), Tissot and Welte (1978), Miller and others (1979, 1980, 1982), and Waples (1980).

## Analytical Methods and Procedures

The analytical methods and procedures used in the analysis of the well cuttings samples from the Texaco 6421 follow the methods and techniques described in Miller and others (1979, 1980, and 1982). The Minerals Management Service Petroleum Geochemistry Group analyzed 17 well cuttings samples for their $C_{15}$+ characteristics from well depths from 1,500 to 17,750 feet.

Solid contaminants composed of metal fragments, rubber, plastic, fibers, walnut husks, and various morphological forms of solid to semisolid hydrocarbons thought to be tarlike substances soluble in benzene were removed from the cuttings by hand. The samples were then described by light-optical binocular methods and divided into aliquots for total organic carbon analyses, Soxhlet solvent extraction and liquid column chromatography, and high-resolution glass capillary gas chromatographic analyses of the saturated paraffin-napthene $C_{15}+$ hydrocarbon fractions.

Source Rock Characterization--Quality and Type

The source rock potential of the Texaco 642-1 well is shown in figure 10. The total organic carbon (TOC) weight percent plot depicts the richness or quantity of the organic carbon present in the stratigraphic units penetrated. The Tertiary shales present in this well (3,640-5,030 feet) have total organic carbon values that range from 0.25 to 2.0 weight percent. Such values are in the fair to good range for source rocks. The Upper Cretaceous shales from 5,120 to 7,850 feet are characterized by total organic carbon values that range from 0.38 to 1.10 weight percent and are considered to be in the poor to fair category for source rocks. The Lower Cretaceous shales (7,970 to 11,870 feet) have total organic carbon values that range from 0.60 to 2.60 weight percent. The total extractable hydrocarbons, extractable paraffin-naphthene, aromatic hydrocarbons, nitrogen-sulphur-oxygen (NSO), and total extractable fractions are summarized in table 11. These data show that source rock quality for the Upper Cretaceous section from the Campanian (5,120 feet) to the top of the Lower Cretaceous at 7,970 feet is in the poor to fair source rock quality range. The Lower Cretaceous section (7,970-11,870 feet) contains extractable hydrocarbons in the fair to good source rock range (100-400 ppm). The Jurassic section (11,870-17,750 feet) contains extractable hydrocarbons in a range from 100 to 400 ppm, which is in the fair to good range of source rock potential.

The possibility of contamination from mud additive is believed to be minimal in the Texaco 6421 well with slight amounts possible from the mud line to a depth of about 5,000 feet.

Types of Organic Matter

Organic geochemical elemental analyses of the ground whole rock samples of the Upper Cretaceous show that the predominant form of organic matter is of the hydrogen-rich, oil-prone variety. The hydrogen-carbon (H/C) ratios of the Upper Cretaceous shales range from 0.40 to 1.10. The Lower Cretaceous shales have H/C ratios that range from 0.30 to 0.40 and are gas prone. The Jurassic section from 11,870 feet to the deepest sample at 17,750 feet contains organic matter with H/C ratios that vary from 0.20 to 0.45 and suggests the presence of predominantly hydrogen-deficient, gas-prone kerogens (fig. 11).

The (H/C) ratios indicate that the predominant type of organic matter present in the Upper Cretaceous rocks is of the marine oil-prone variety, whereas the Lower Cretaceous to Upper-Middle Jurassic shales are of the terrestrial, gas-prone variety. These molecular geochemical signatures for predominant kerogens are consistent with the light-optical descriptions of the organic matter types. Very high total organic carbon values present in the Lower Cretaceous and Upper Jurassic are believed to be the result of coal.

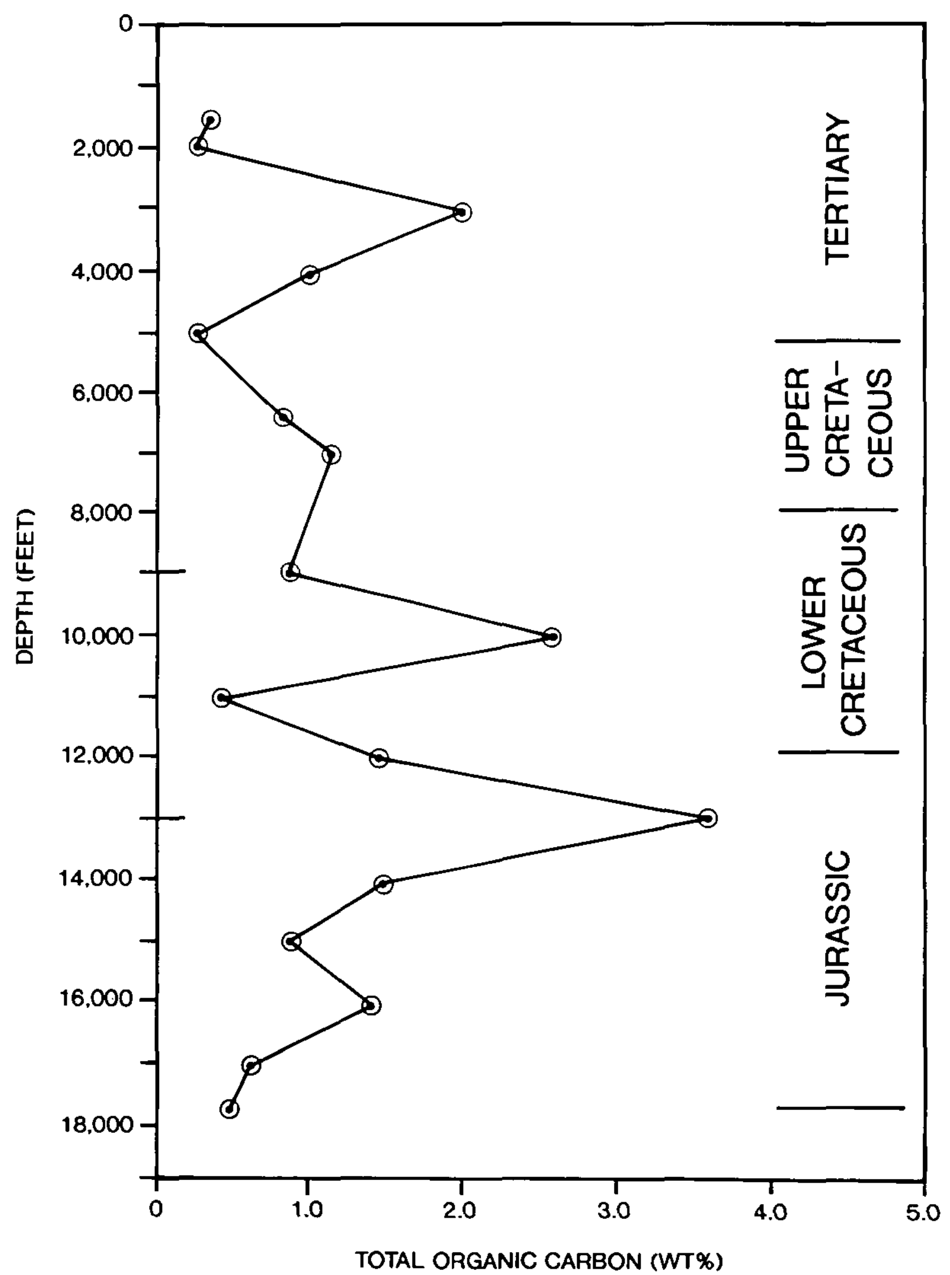


Figure 10.--Total organic carbon content of rocks in the Texaco 642-1 well.

Table 11.--Solvent-extractable organic matter from Texaco 642-1 well samples

[Results in parts per million (ppm) from Soxhlet solvent extraction and liquid column chromatography. NSO is nitrogen, sulphur and oxygen compounds. H/C is hydrocarbon-carbon ratio.]

| Sample Depth (feet) | Total Hydrocarbon Concentrations | Paraffin-Naphthene H/C Concentrations | Aromatic Hydrocarbons | NSO Compound Concentrations | Total Extractables |
|---|---|---|---|---|---|
| 1,550 | 85 | 60 | 22 | 86 | 170 |
| 2,000 | 45 | 35 | 8 | 36 | 70 |
| 3,100 | 145 | 110 | 35 | 256 | 530 |
| 4,050 | 70 | 57 | 15 | 116 | 220 |
| 5,100 | 70 | 57 | 17 | 53 | 130 |
| 6,400 | 45 | 30 | 17 | 98 | 180 |
| 7,100 | 85 | 60 | 23 | 127 | 255 |
| 9,000 | 110 | 85 | 22 | 81 | 185 |
| 10,050 | 410 | 115 | 292 | 328 | 770 |
| 11,000 | 80 | 40 | 41 | 90 | 170 |
| 12,100 | 180 | 70 | 108 | 138 | 380 |
| 13,050 | 445 | 140 | 304 | 319 | 760 |
| 14,100 | 150 | 65 | 91 | 163 | 320 |
| 15,050 | 135 | 50 | 82 | 92 | 260 |
| 16,150 | 95 | 65 | 53 | 106 | 210 |
| 17,100 | 165 | 110 | 54 | 138 | 340 |
| 17,800 | 110 | 65 | 46 | 73 | 235 |

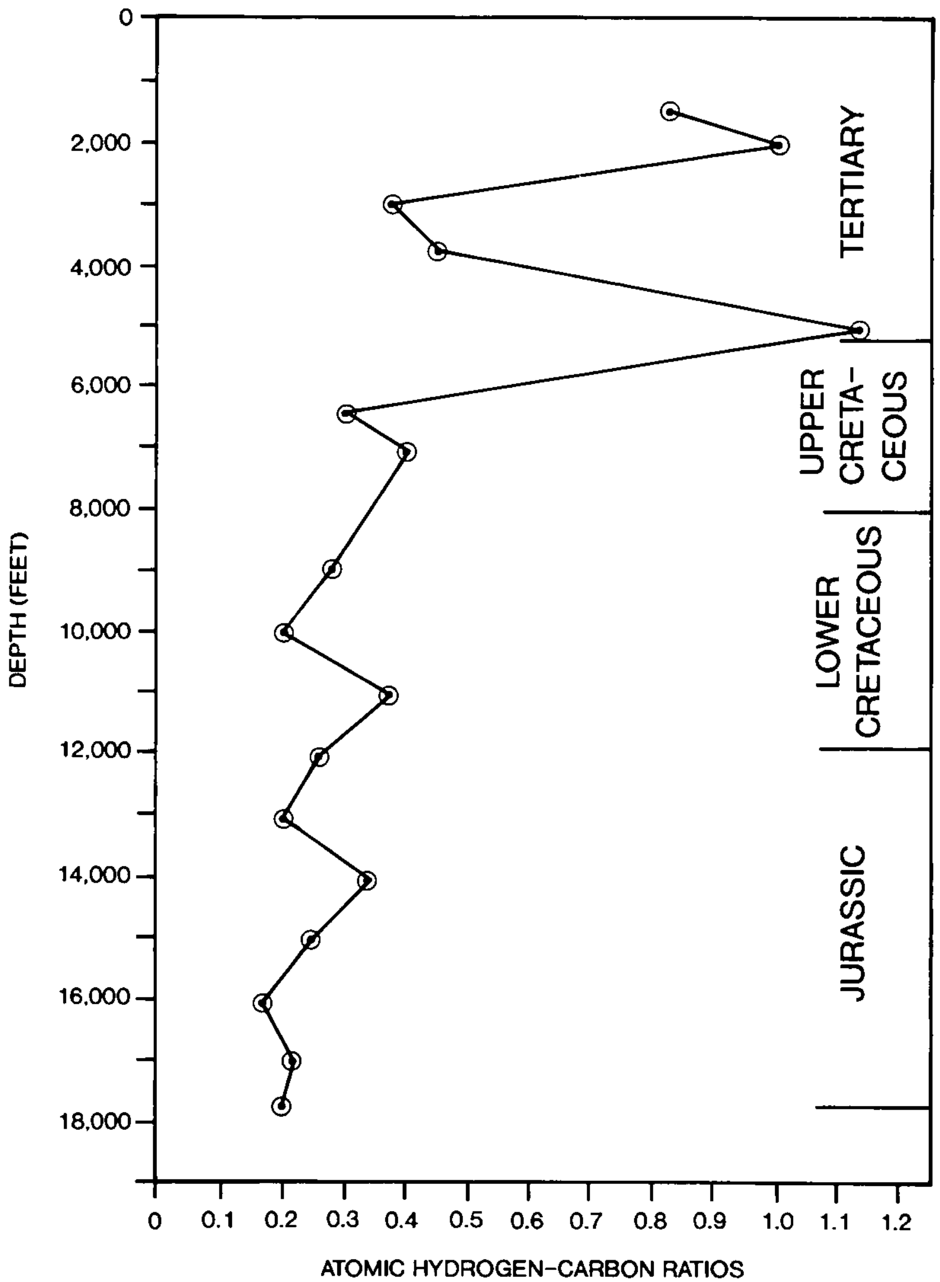


Figure 11.--Hydrogen-carbon atomic ratios plotted against depth for the Texaco 642-1 well.

be the result of coal. This interpretation is consistent with the lithologic descriptions of the sample intervals and the very high total extractables, aromatic hydrocarbons, and NSO concentrations (ppm) (table 11).

Thermal Maturity

The geothermal gradient for the Texaco 642-1 well was determined from the well bore temperatures taken at four depth points. The gradient was calculated to be 1.25 °F/100 feet (fig. 12). This value is similar to the gradient of the COST B-3 well (1.3 °F/100 feet) but higher than the Shell 586-1, 587-1, 372-1 and 93-1 well gradients, which had values of about 1.0 °F/100 feet.

The light-optical methods for establishing thermal maturity consist of the vitrinite reflectance ($\%R_o$) and the thermal alteration index (TAI) techniques. In the Texaco 642-1 well only TAI values were available. Based on a geothermal gradient of 1.25 °F/100 feet, the theoretical threshold of intense oil generation (TIOG) should occur at a depth of about 11,400 feet relative to the sediment-water interface. Peak liquid generation is theoretically predicted to occur at a depth of about 13,800 feet.
The theoretical projected depth limits for the hydrocarbon evolution window (HEW) based on the present day gradient (1.25 °F/100 feet) are inconsistent with the experimentally determined depth limits for the thermal liquid maturity window defined by molecular geochemical ratios and light-optical TAI methods (fig. 12).

In the Texaco 642-1 well, the TAI values determined from kerogen palynomorph colors suggest that borderline maturity values of 2.6 were reached at burial depths of 12,950 feet. Peak generation color changes (3.0) were determined by the TAI method to occur at a burial depth of about 15,300 to 16,290 feet with a maximum TAI of 3.3 at 16,740 feet. These TAI values are consistent with the molecular geochemical thermal maturation interpretation of the HEW data determined on the basis of the ratio of saturated paraffin-naphthene-total organic carbon (fig. 12).

As shown in the following time-temperature burial history discussion, the molecular geochemistry and light-optical methods are consistent in determining the TIOG and peak oil generation. The burial history interpretation time-temperature index (TTI) values are also consistent with the light-optical and molecular geochemical data.

Time-Temperature Burial Model

The time-temperature burial model relationships for the Texaco 642-1 well are based upon stratigraphic tops and thicknesses, discussed in the Paleontology and Biostratigraphy chapter of this report, and are shown in figure 13. The geothermal gradient is assumed to be relatively constant for the past 150 million years based on thermal subsidence model studies (Royden and others, 1980). According to the chemical kinetics concept that the thermal generation of hydrocarbons (principal zone of oil formation) occurs between the temperature range of 60 °C and 150 °C, that the Upper Jurassic at

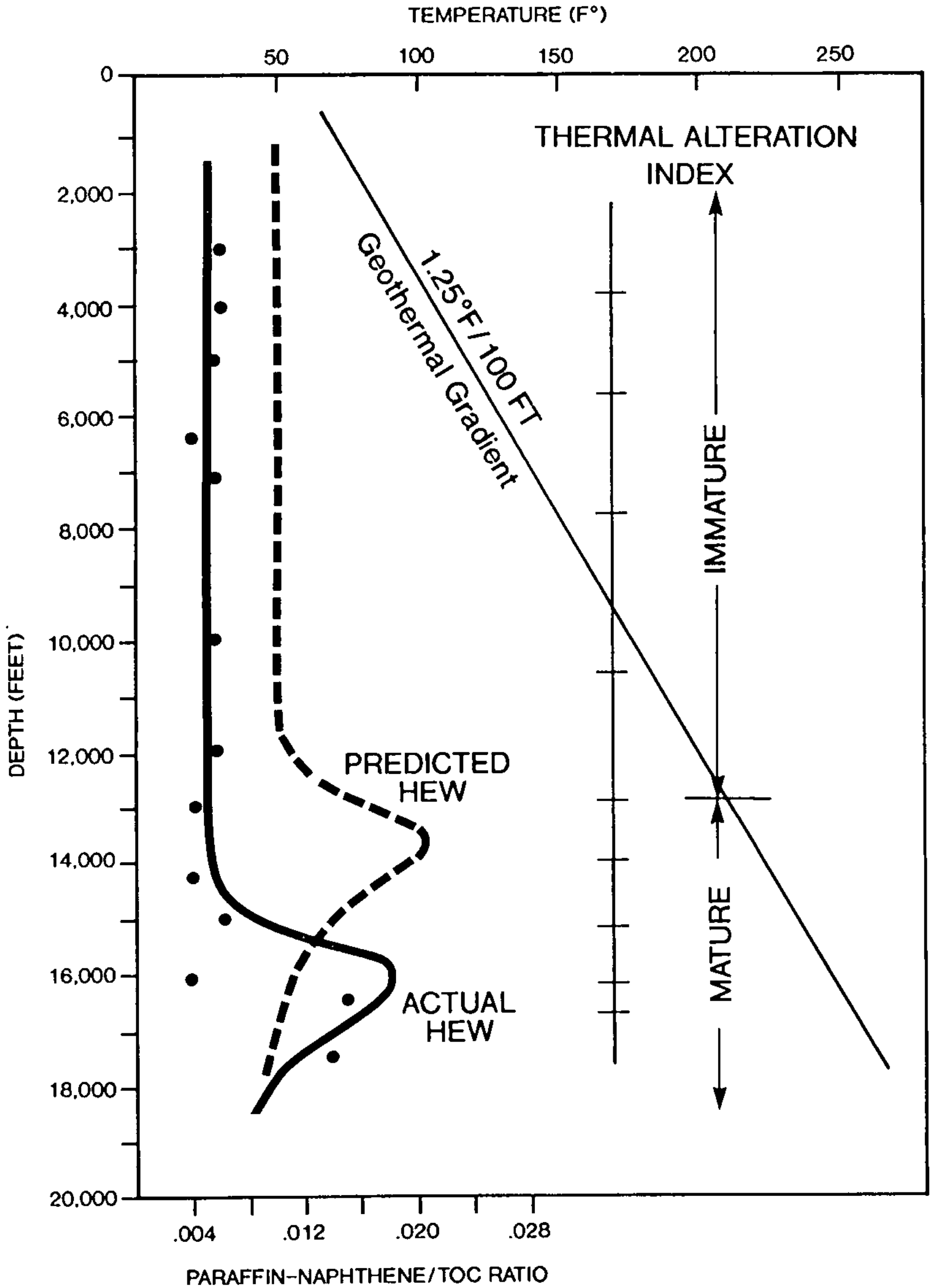


Figure 12.--Predicted and actual hydrocarbon evolution windows (HEW), TAI, and geothermal gradient for the Texaco 642-1 well.

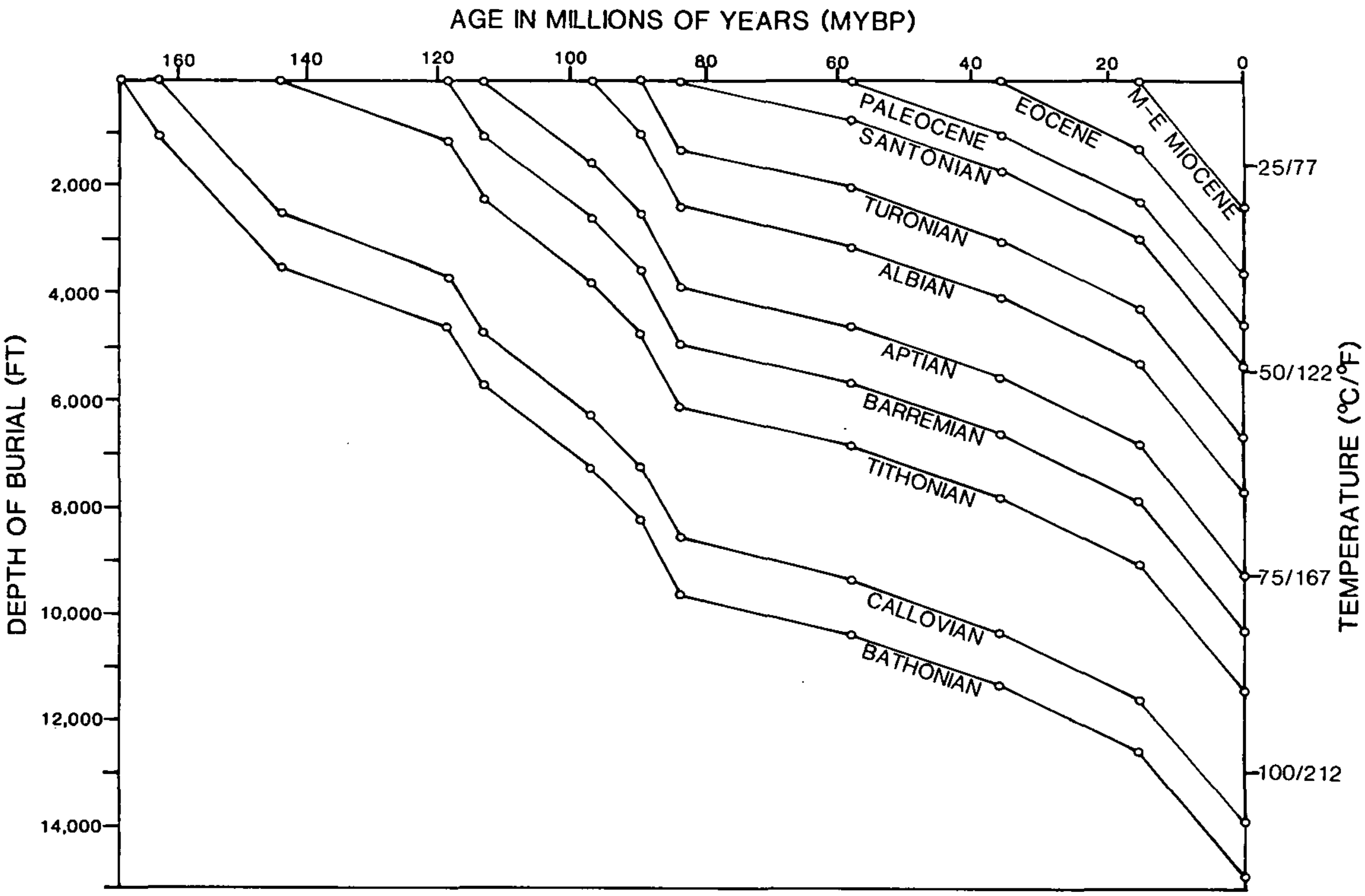


Figure 13.--Time-temperature burial profile for the Texaco 642-1 well. Geologic time scale from Kent and Gradstein (1986).

11,870 feet with a TTI value of 11.09 has not yet entered the threshold of intense oil generation (TIOG), whereas the Callovian to Bathonian sediments are in the mature stage with TTI values of 61 to 89. For the younger, overlying Cretaceous stratigraphic section, the time-temperature burial history is inadequate to have generated significant liquids or gases in the vicinity of the 642-1 well.

The burial history model of the stratigraphic section represented in the Texaco 642-1 well (fig. 13) suggests the presence of a rather continuous rapid subsidence and burial. The inconsistency between the predicted and actual hydrocarbon evolution windows is believed to be a function of the structural history of the shelf in the vicinity of the 642-1 well. The Upper to Middle Jurassic section has been downfaulted into a warmer thermal regime, and the petroleum generation processes are now acting to reestablish a normal hydrocarbon evolution window profile.

The basin sedimentation and structural history and the geothermal gradients of the shelf and slope, when combined with the geochemical history for the Lower Cretaceous and Upper Jurassic stratigraphic units, support the notion that the "transition crust" represents the region where the highest heat flow transfer occurs between the continental sialic and the oceanic basaltic crust. Those depositional basin sites that contain the Lower Cretaceous to Upper-Middle Jurassic sediments and that are located nearest to the zone of transition crust are believed to have had the greatest opportunity for higher heat flows.

Thus, source rocks nearest to this transition are most likely to have generated hydrocarbons. The gas in the Texaco 642-1 well and the gas and oil in the Tenneco 642-2 well indicate that good source rocks occur near the blocks 598-643 structure.

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