Shell Wilmington Canyon 586-1 Well

OCS Report
MMS 86-0099

Geological & Operational Summary

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CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

The Shell Wilmington Canyon 586-1 well, in southeast Baltimore Canyon Trough, is about 90 miles offshore from southern New Jersey. The well, spudded on December 30, 1983, and completed on May 24, 1984, was drilled by the Discoverer Seven Seas drillship in 5,838 feet of water. Total depth of the well is 16,000 feet (below KB), and 10,114 feet of sediments and rock were penetrated beneath the sea floor.

Standard geophysical logs were run, together with Downhole While Drilling and Electromagnetic Propagation logs. Cuttings samples were collected from 8,030 feet to the bottom of the drillhole. Two hundred and fifty-nine sidewall cores were obtained, and four conventional drill cores were cut in limestone intervals of the well.

The section penetrated by the Shell 586-1 well is divided into four facies units on the basis of lithologic information, well logs, and seismic profiles. From youngest to oldest, these are a calcareous shale, a blanket-like limestone, a prograding terrigenous clastic wedge, and a platform limestone facies.

Despite excellent porosity in some of the limestone beds, no significant hydrocarbon accumulations were detected in the well. Total organic carbon content is low among the carbonate and continental clastic rocks, and kerogens are mostly terrigenous, gas-prone types. Except for the lowermost 3,590 feet, which are marginally mature, analyses indicate that the Shell 586-1 well penetrates rocks that are thermally immature for hydrocarbon generation.

ABBREVIATIONS

API	American Petroleum Institute
C_1, C_2	number of carbon atoms in a hydrocarbon chain structure (methane, ethane, etc.)
FNL	from north line
FWL	from west line
HEW	hydrocarbon evolution window
MYBP	million years before the present
OCS	Outer Continental Shelf
ppg	pounds per gallon
ppm	parts per million
PZOF	principal zone of oil formation
SFL	spherically focused log
SP	spontaneous potential
TAI	thermal alteration index
TD	total depth
TIOG	threshold of intense oil generation
TOC	total organic carbon
TTI	time-temperature index
WD	water depth
WST	well seismic tool

OPERATIONAL SUMMARY

by

Khaleeq U. Siddiqui

The Shell Wilmington Canyon 586-1 well (fig. 1) was drilled by the Discoverer Seven Seas drillship. The vessel, owned by Sonat Offshore Drilling, Inc., was completed in 1976 by Mitsui Engineering and Shipbuilding Ltd., Japan, and was classified American Bureau of Shipping (ABS) Ice Class 1A ✠ A1 ✠ AMS Ⓔ Ⓜ mobile drilling unit for unrestricted worldwide ocean use. The ship meets U.S. Coast Guard standards. Overall length is 533 feet and fully-loaded displacement is 21,216 long tons. The ship is equipped with thrusters for dynamic positioning. For the Shell drilling program, the hull was reinforced and additional risers were added to enable drilling in water depths up to 7,500 feet. The Discoverer Seven Seas was inspected before drilling began, and operations were observed by Minerals Management Service (MMS) personnel throughout the drilling period to ensure compliance with Department of the Interior regulations and orders.

Davisville, Rhode Island, and Atlantic City, New Jersey, were used as operational bases. Two 190-foot support vessels were used to transport materials and supplies. Sonat stationed a standby vessel within a 1-mile radius of the drillship at all times.

Shell Offshore, Inc., was the operator, and AMOCO Production Company and Sun Exploration and Production Company were participants. The lease was acquired at OCS (Outer Continental Shelf) Lease Sale 59, December 8, 1981, and was relinquished December 27, 1984. Well and drilling information are summarized in table 1. The well's location, within the lease block, is shown in figure 2. Drilling stipulations required the operator to provide the Minerals Management Service with well logs, lithologic samples, core slabs, geologic information, and operational reports.

Drilling Program

Shell drilled the 586-1 well to a driller's indicated depth of 16,000 feet. (All depths in this report are from well logs and are in feet below kelly bushing (KB) elevation, unless otherwise stated.) Drilling rates ranged from 2 to 26 feet per hour. Maximum borehole deviation from vertical was 4.95 degrees and was generally less than two degrees.

Five strings of casing were set in the well and are diagramed in figure 3. The 48-inch casing was driven to 5,954 feet. The 30-inch casing was set at 6,136 feet with 720 sacks of cement; the 20-inch casing was set at 7,888 feet with 2,020 sacks of cement; the 13 3/8-inch casing was set at 8,770 feet with 785 sacks of cement; the 9 5/8 inch casing was set at 11,318 feet with 875 sacks of cement. Class H cement was used for all casings.

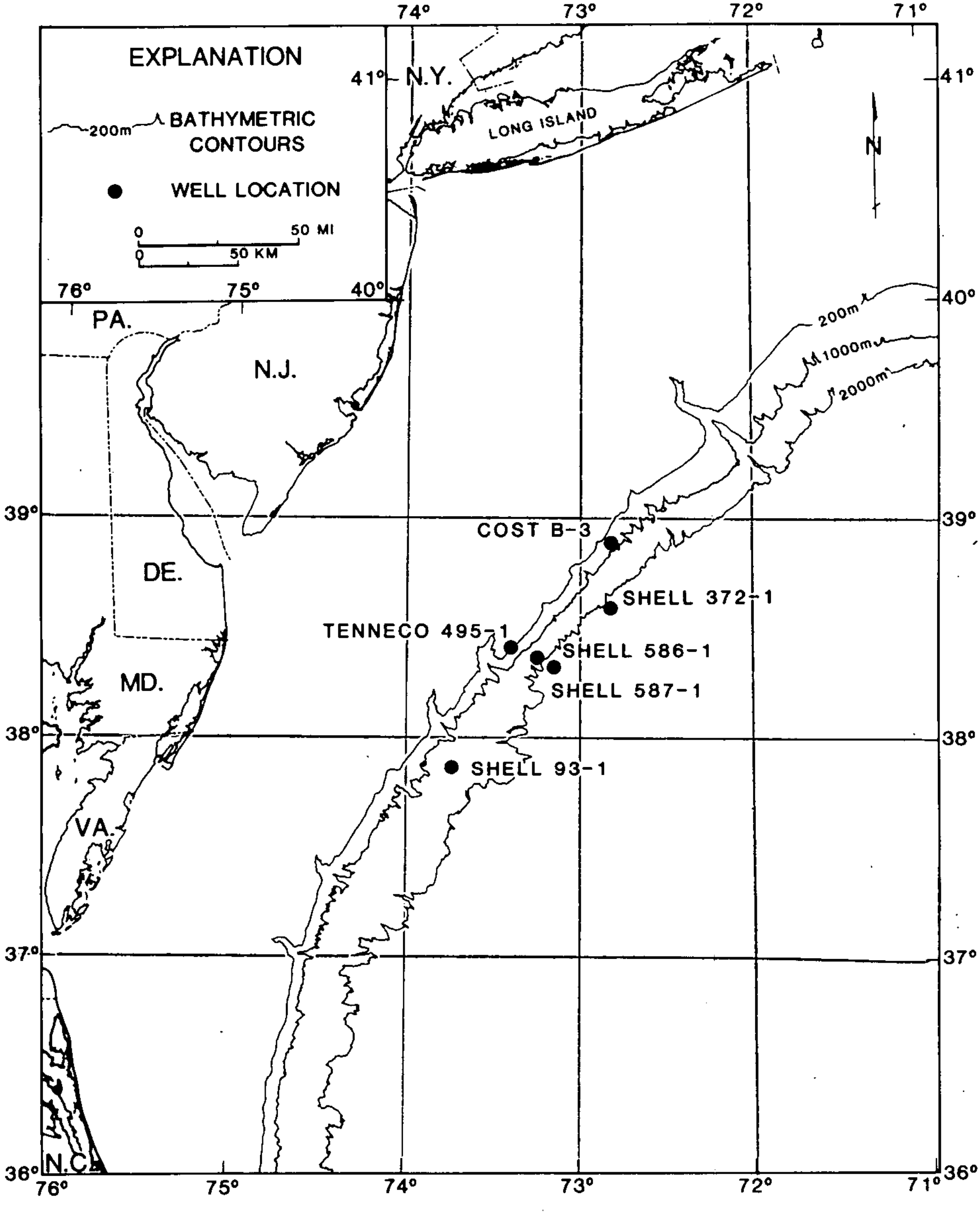

FIGURE 1.--Location map of a portion of the Mid-Atlantic offshore area showing the location of the Shell Wilmington Canyon 586-1 well and selected other wells.

TABLE 1.--Shell Wilmington Canyon 586-1 well statistics

API no.	61-104-00010
Lease no.	OCS-A-0336
Surface location	Wilmington Canyon NJ 18-6 block 586, 2,276.37 ft FNL, 6,689.82 ft FWL
	Lat. : 38° 24' 19.830" N Long.: 73° 13' 03.153" W
	X = 655,639.06 m Y = 4,252,106.16 m
Bottom hole location	At 15,890 ft depth, N 140 ft and E 228 ft from surface location
Proposed total depth	16,000 ft
Actual total depth	15,890 ft, measured
Kelly bushing elevation	48 ft
Water depth	5,838 ft
Spud date	December 30, 1983
Completion date	May 24, 1984
Final well status	Plugged and abandoned

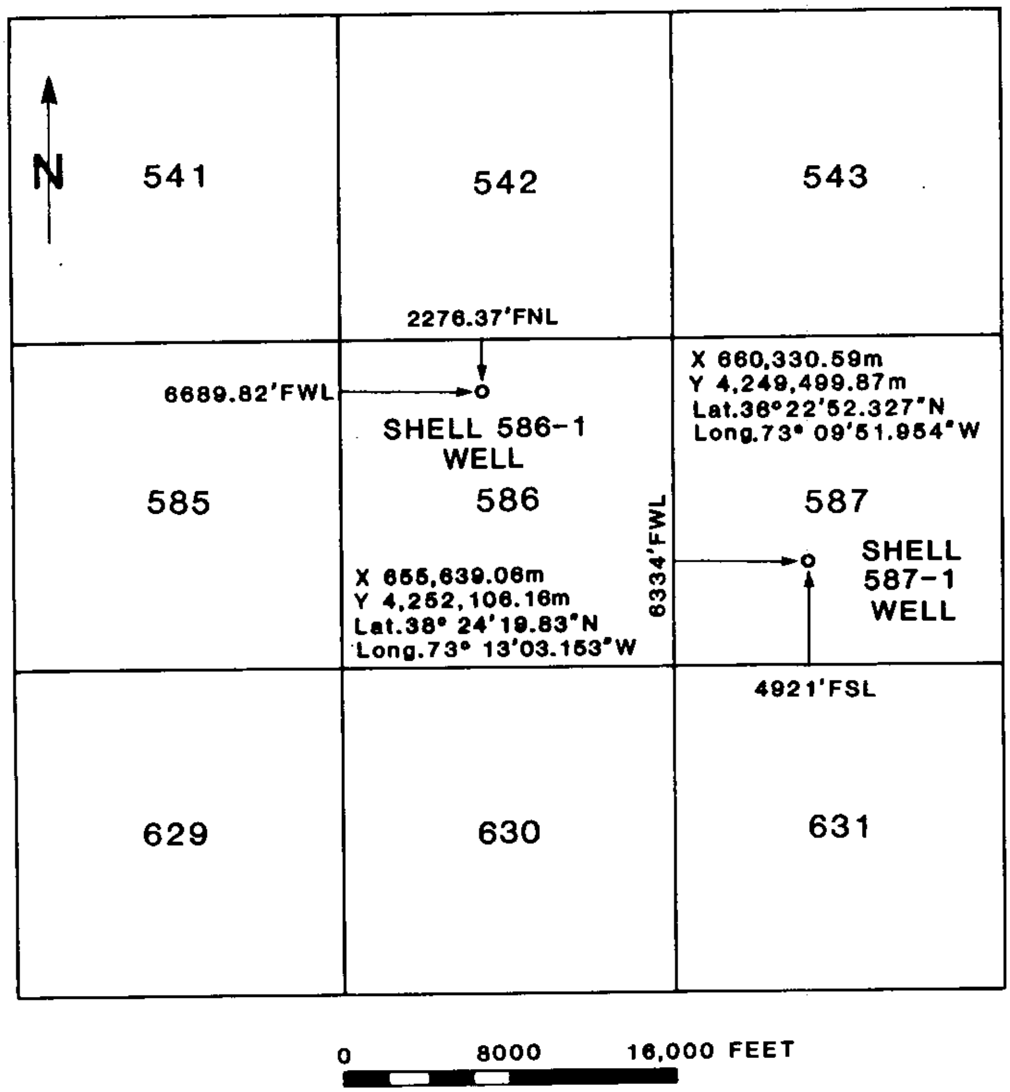

FIGURE 2.--Locations of the Shell 586-1 and 587-1 wells on OCS Wilmington Canyon NJ 18-6 protraction diagram.

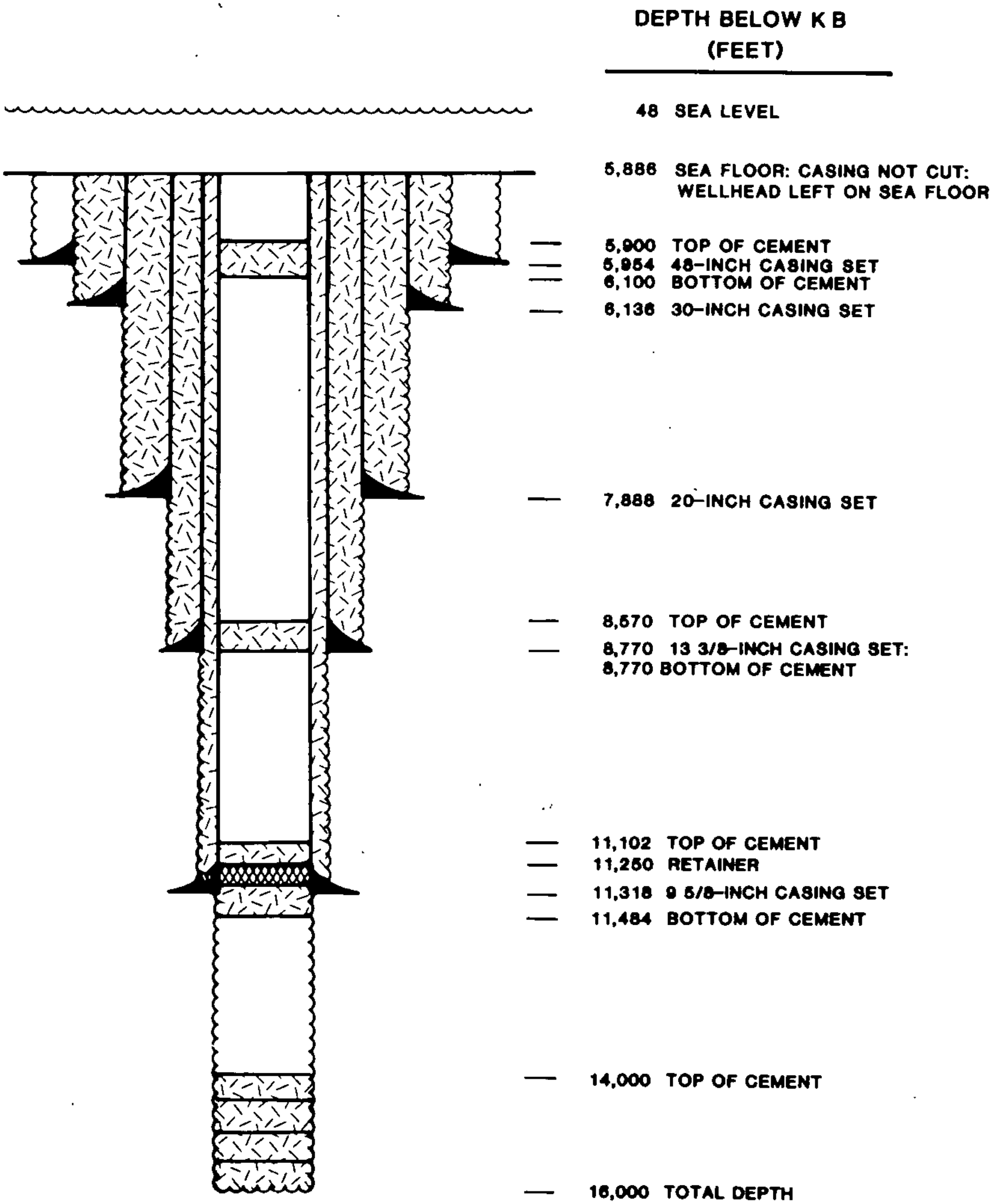

FIGURE 3.--Casing and abandonment program for the Shell 586-1 well.

At a depth of 7,936 feet, drilling was temporarily halted because of malfunctioning equipment. From January 14 through February 7, 1984, repairs were made to the coffer dam seal and capture beams in the moonpool. Drilling was also discontinued from March 29 through April 1 because of bad weather and from April 12 to 17 to allow hydraulic system repairs. Daily drilling progress is shown in figure 4. The abandonment procedure is also shown in figure 3. Shell plugged back the open hole from 16,000 feet total depth (TD) to 14,000 feet with 704 sacks of cement, pumped in four 176-sack stages. A 9 5/8-inch retainer was set at 11,250 feet, with 100 sacks of cement squeezed below the retainer and 50 sacks left on top. This plug was tested at a pressure of 1,000 PSI. A 70-sack cement plug was spotted at 8,770 feet, and a surface plug was set at 6,100 to 5,900 feet with 70 sacks of cement.

Mud Program

Seawater and gelled seawater-freshwater with a weight of 9.1 ppg (pounds per gallon) and a viscosity of 89 seconds were used as drilling fluid to a depth of 7,928 feet. Mud weight was increased to 9.3 ppg at 9,066 feet, reached 9.8 ppg at 15,304 feet, and remained at that weight to the bottom of the well. The viscosity of the mud fluctuated between 89 and 115 seconds in the first 7,941 feet and averaged about 60 seconds for the remainder of the well. Mud pH averaged 11.5 with minor fluctuation. Chloride concentrations began at 8,600 ppm (parts per million), increased to 20,000 ppm at 10,770 feet, and dropped to 14,000 ppm at TD.

Samples and Tests

Drill cuttings samples were collected from 7,940 to 15,970 feet. Four conventional cores were obtained and analyzed for lithology, paleontology, porosity, permeability, grain density, and hydrocarbon saturation (table 2)

TABLE 2.--Conventional Cores

Core No.	Depth (ft)	Recovery (ft)
1	9,036 - 9,066	22.5
2	11,605 - 11,635	24.3
3	14,882 - 14,912	28.5
4	15,970 - 16,000	28.3

Five series of sidewall cores were taken between 8,950 and 15,924 feet; 259 cores were recovered.

There were no drill stem tests made in this well. Electric logs were run in the well and are listed and discussed in the Formation Evaluation section of this report.

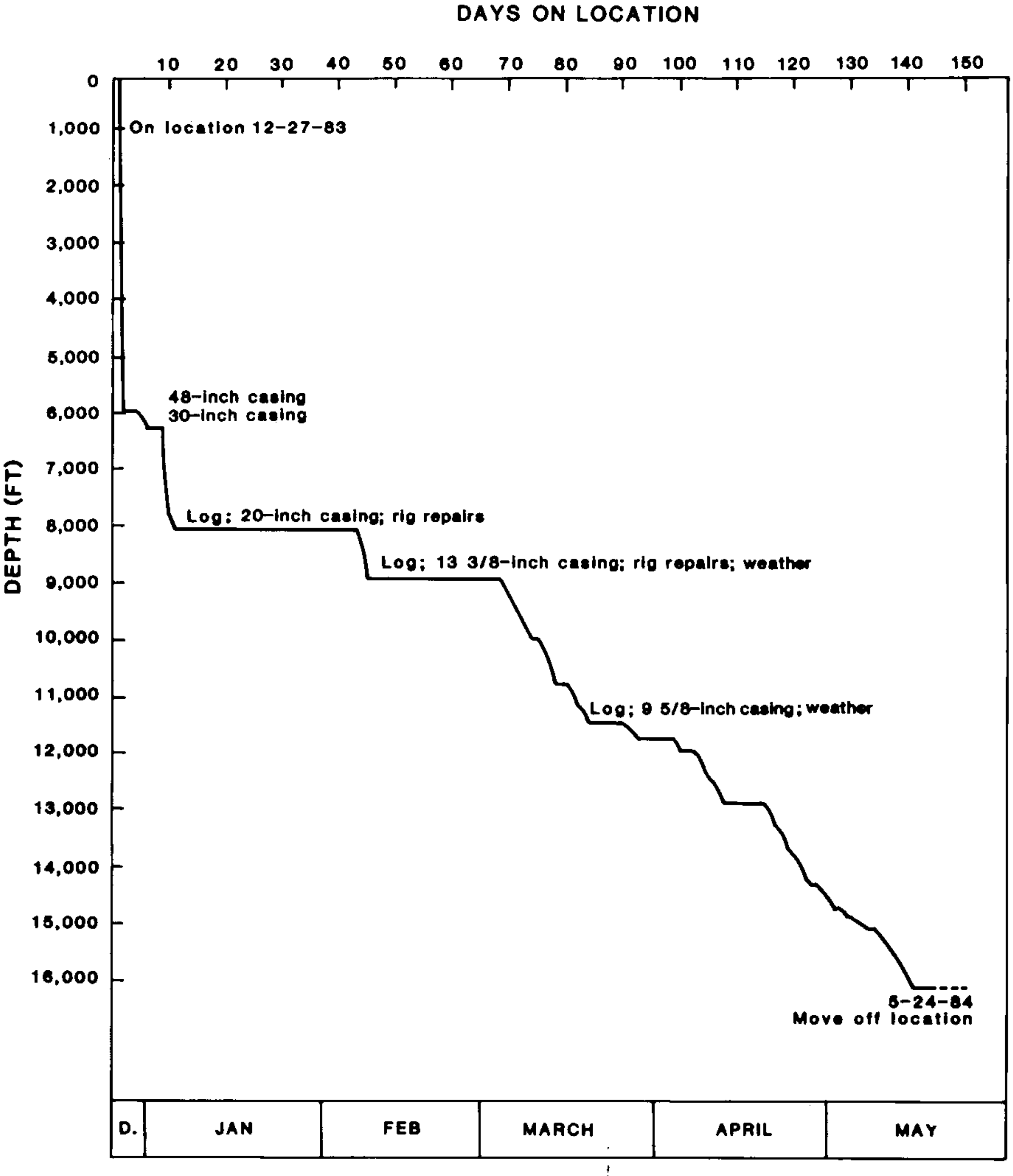

FIGURE 4.--Daily drilling progress for the Shell 586-1 well.

INTERVAL VELOCITY ANALYSIS

by

Michael N. Christos

A Schlumberger Well Seismic Tool (WST) survey was run in addition to the sonic log in the Shell Wilmington Canyon 586-1 well. The WST allows verification of sonic integrated time and establishes a reference time between the top of the well and the depth at which sonic logging began. An interval velocity profile is shown in figure 5, which was plotted from the WST data. Between 5,886 feet (sea floor) and 15,900 feet (the deepest data) four depth intervals are identified on the basis of relative interval velocities. The lower velocities of intervals 1 and 3 are consistent with terrigenous clastic lithologies, and the higher velocities of intervals 2 and 4 suggest carbonates. These four depth intervals and their inferred lithologies generally agree with the facies units identified in the lithology and petrography section of this report (see figs. 6 and 7, pages 14 and 19).

° Interval 1 -- This section is identified on the basis of relatively low velocities.

DEPTH RANGE (FEET)		5,838 - 9,000
INTERVAL VELOCITY RANGE	(FEET/SECOND)	5,350 - 12,226
AVERAGE INTERVAL VELOCITY	(FEET/SECOND)	6,519

These velocities suggest continental clastic lithologies, with shale predominating. An anomalous velocity of 12,226 feet per second occurs at 8,750 feet and may represent a thin carbonate bed.

° Interval 2 -- This section is identified by relatively high velocities.

DEPTH RANGE (FEET)		9,000 - 9,600
INTERVAL VELOCITY RANGE	(FEET/SECOND)	11,350 - 14,216
AVERAGE INTERVAL VELOCITY	(FEET/SECOND)	12,766

The increased velocities are consistent with carbonate lithologies. The uniformity of velocities for this interval suggests that noncarbonate interbeds are rare or absent.

° Interval 3 -- This section is identified on the basis of relatively low velocities.

DEPTH RANGE (FEET)		9,600 - 11,400
INTERVAL VELOCITY RANGE	(FEET/SECOND)	8,500 - 11,859
AVERAGE INTERVAL VELOCITY	(FEET/SECOND)	9,783

The decrease in interval velocities indicates an increase of terrigenous clastic lithologies, probably sandstones with interbedded shales.

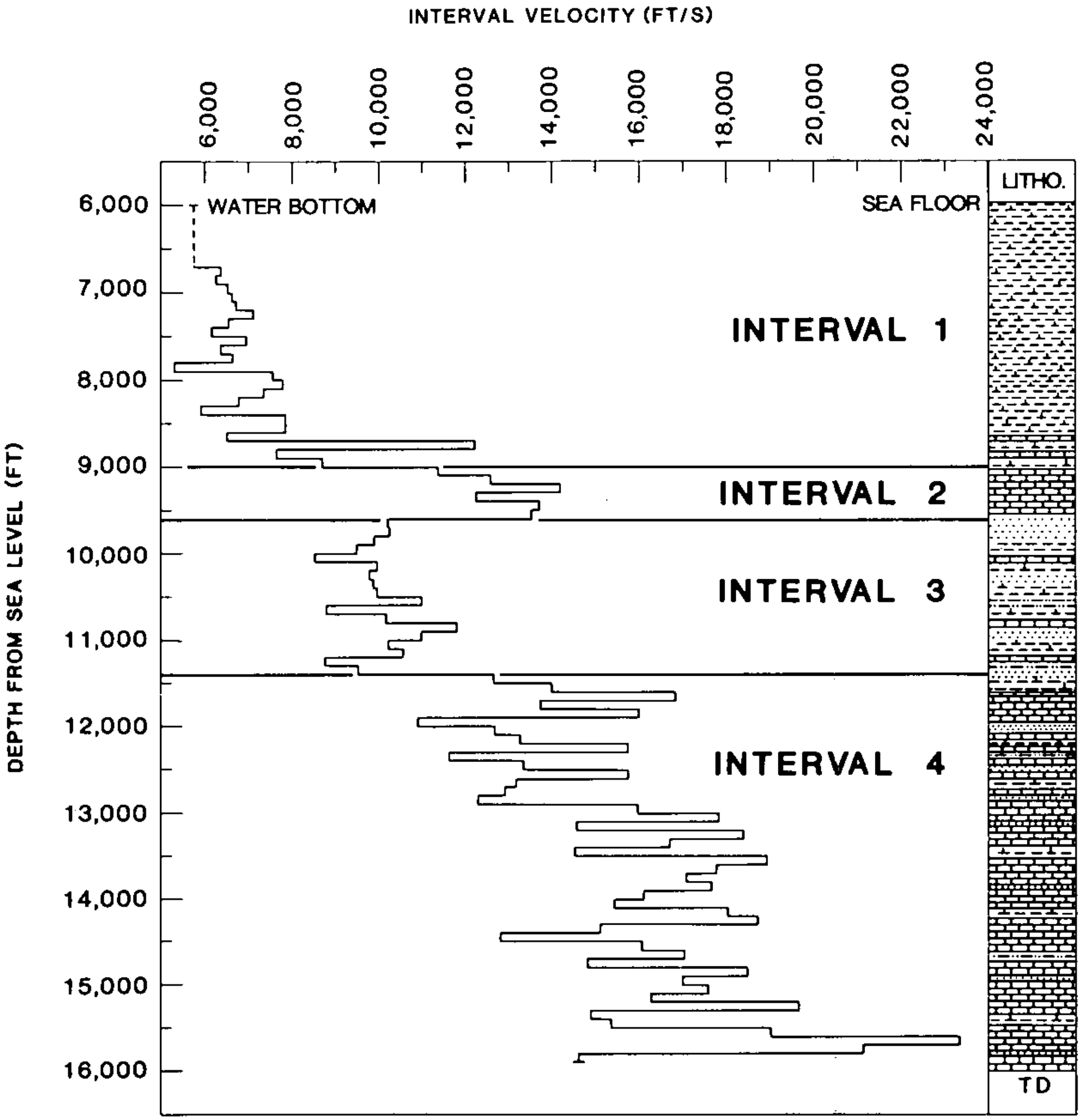

FIGURE 5.--Interval velocity profile of the Shell 586-1 drill hole, with generalized lithologic column.

° <u>Interval 4</u> -- This section is identified by relatively high velocities.

DEPTH RANGE	11,400 - 15,900
RANGE OF INTERVAL VELOCITY (FEET/SECOND)	10,899 - 23,365
AVERAGE INTERVAL VELOCITY (FEET/SECOND)	15,570

The final interval of the well contains a higher proportion of carbonates, judging from the higher velocities. However, large variations among the velocities suggest interbedded carbonate and continental clastic rocks.

LITHOLOGIC AND PETROGRAPHIC DESCRIPTIONS

by

Gary M. Edson and George B. Carpenter

The Shell Wilmington Canyon 586-1 well is located about 3 miles shoreward of the Upper Jurassic-Lower Cretaceous paleoshelf-edge carbonate buildup. The well penetrates a continental clastic and carbonate section. Correlation with the paleoshelf-edge Shell 587-1 drillhole and integration of seismic analysis have produced the facies framework shown in figure 6. The lithologies of the 586-1 well are grouped in this report according to this facies nomenclature. A lithologic column is shown in figure 7 (page 19).

Rock samples examined include drill cuttings, which were collected from 7,940 to 15,970 feet; four conventional 30-foot drill cores; and thin sections made from the cuttings, core chips, and sidewall cores. Overall, drill cuttings quality is poor because of considerable apparent mixing of samples from various depths and inclusion of drilling additives. Well logs were also studied, and for these intervals represented only by drill cuttings, the logs greatly influenced the determination of lithologies. Major lithologic breaks and their depths were picked from the logs.

° <u>Argillaceous Facies (7,940-9,030 feet; Turonian-Albian)</u>

Well logs suggest shale for this interval; the mud log indicates clay and shale; and the sidewall core report describes shale at 8 depths from 8,950 through 9,020 feet. Cuttings, however, appear more calcareous, grading from marl with shell fragments and disseminated sand grains in the upper fifth of the interval to gray argillaceous micrite with quartz silt and small quantities of sand, mica, pyrite, glauconite, collophane, and inertinite in the lower four-fifths. A few fragments of calcite spar and white micrite suggest the presence of more pure limestone interbeds. In thin section the micrite and argillaceous micrite cuttings contain abundant foraminifers, most of whose chambers are filled with calcite spar and diagenetic anhydrite. The interval appears to be variably sandy and silty and to grade downward from calcareous shale and marl to calcareous shale and marl interbedded with argillaceous micrite and minor pure micrite.

Effective porosity is inferred to be poor for the interval. Well log analysis (table 4, page 28) did not identify any zones of significant porosity. Cuttings thin sections show some intraskeletal porosity within foraminifer chambers in the micritic beds. However, well logs suggest that limestone is not abundant. Shale and marl predominate; therefore, porosities are probably fair to poor and permeabilities poor. This facies could be a reservoir seal, unless it contains too much detrital sand and silt.

° <u>Blanketlike Carbonate Facies (9,030-9,540 feet; Aptian)</u>

This relatively thin unit is widely distributed along strike immediately shoreward of the southeast Baltimore Canyon Mesozoic paleoshelf edge. Seismic analysis indicates that the unit extends for about 25 miles to the southwest and at least 75 miles to the northeast of the Shell 586-1 well.

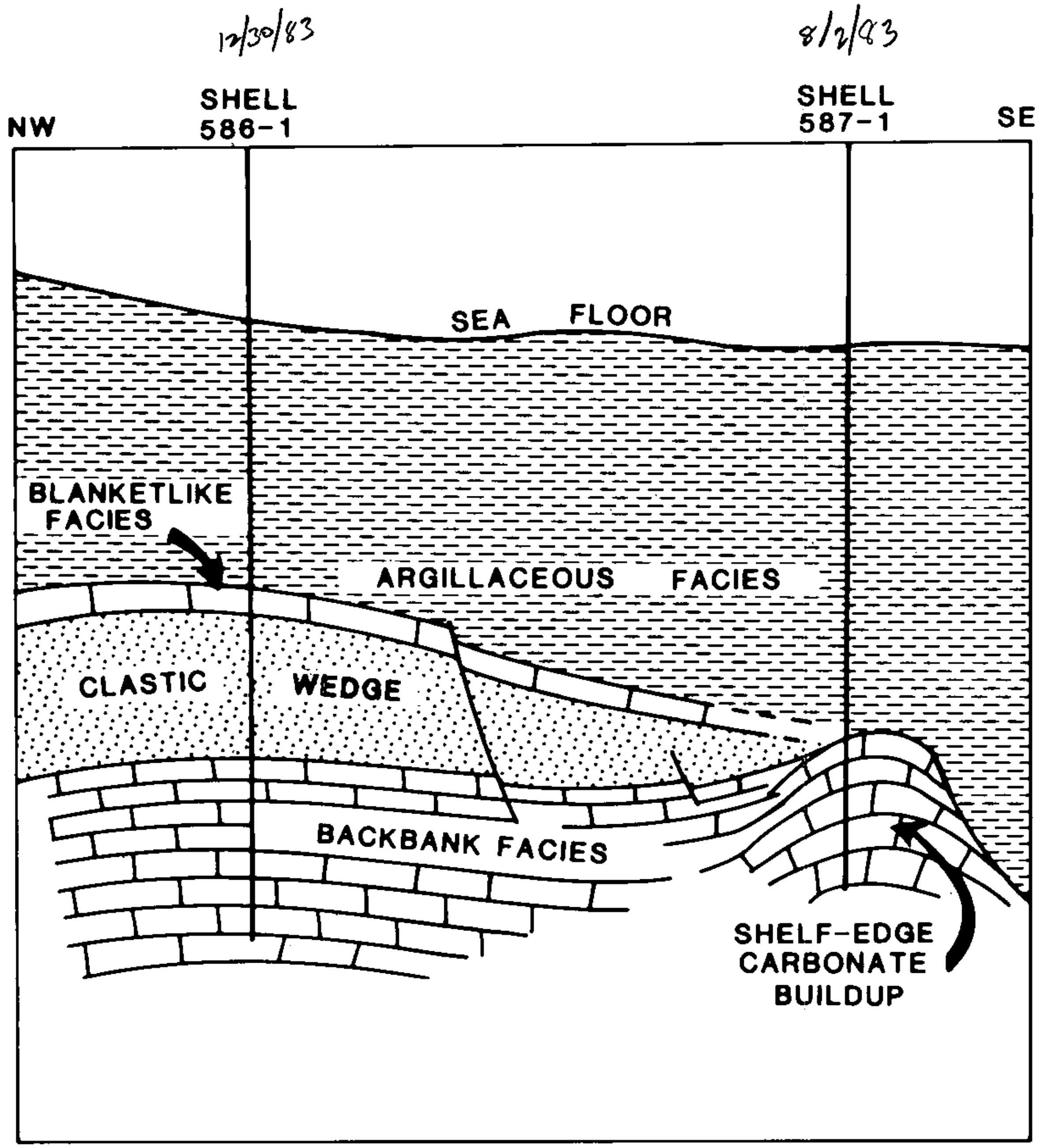

FIGURE 6.--Diagrammatic cross section through the Shell 586-1 and 587-1 wells.

Seismic lines and well logs show thicknesses ranging from about 200 to 500 feet. Logs suggest sharp upper and lower contacts with overlying and underlying lithologies.

Drill core and cuttings indicate limestone for the blanketlike facies interval, and well logs suggest the presence of only a few shale interbeds. The sidewall core report states that samples from the uppermost 300 feet are wackestone, packstone, and grainstone and that samples from the lower 200 feet are limestone, silty sandstone, and minor shale. Examination of conventional drill core and of cuttings also shows grainstone, as well as wackestone and packstone. However, thin sections show abundant areas of micrite within intergranular calcite spar mosaics; also there are a few floating clasts within the spar. In summary, it appears that some of the calcite spar of the apparent grainstone is recrystallized micrite. However, thin sections do show primary grainstone, as well as spar fossil replacements and spar-filled shelter porosity, within the more abundant wackestone and packstone.

Intergranular spar crystals are mostly calcite but also include minor amounts of gypsum/anhydrite and minute dolomite rhombs. This recrystallization and these secondary minerals are much more abundant among the carbonates of the Shell 586-1 well than those of the Shell 587-1 and 372-1 wells, which penetrated the paleoshelf edge.

The first conventional core was taken from 9,036 to 9,058.6 feet and is chalky, cream-to-white, oolitic, and bioclastic packstone, wackestone, and minor grainstone. The upper half of the core has several 0.3-0.8-foot intervals of marl and calcareous shale which contain abundant sand- and granule-sized limestone clasts. Much of the lower half of the limestone core is laminated, having wavy argillaceous laminae and organic stylolites.

Throughout the core, grains and granules are quite round, have soft calcite coatings, and are loosely cemented at their points of mutual contact. Interparticle porosity is high, perhaps 20 percent or more, but permeability appears to be low, owing to the soft calcite which also plugs up the intergranular channelways. The chalky character of the core is due to soft calcite grains, as well as grain coatings and oolitic rinds. In fact, the core can be carved with a knife. The soft character of the core is probably due to chalky weathering caused by postdiagenetic subaerial emergence and freshwater leaching.

Cuttings and core thin sections contain oolith-pellet-grapestone-oncolite skeletal packstone, wackestone, and minor grainstone. Among and within the limestone clasts are flecks of pyrite and inertinite and occasional silt- to fine sand-sized quartz grains.

Granular bioclasts include abundant calcareous sponges, echinoderms, molluscs, gastropods, bluegreen algae, tubiphytes, and foraminifers, including Epistomina, Lenticulina, and Trocholina. In lesser abundance are corals, bryozoans, stromatoporoid fragments, and dasycladacean algae. In very low abundance are hexactinellid silicious sponge, red algae, brachiopod, and rudist fragments. Finally, from 9,038.7 to 9,048.0 feet, in the conventional core, there are several metazoan fossils that are 2 cm or larger in diameter. These include calcareous sponges, corals, and stromatoporoids. A few of the stromatoporoids appear to be crustose and conformable with the enclosing sediments, suggesting that this facies unit includes minor bindstone intervals. However, the unit appears to be a dominantly bioclastic detrital accumulation.

In addition to the intergranular porosity already described, thin sections show a lesser amount of intragranular porosity caused by selective leaching of bioclasts. Also, minor vugular porosity results from a few completely dissolved fossils. Petrophysical analysis indicates porosities from 10 to 24 percent and air permeabilities from 0.042 to 12.2 millidarcies (md) among core plugs.

° Clastic Wedge (9,540-11,600 feet; Barremian-Berriasian)

On seismic dip sections, this facies unit is wedge shaped in cross section. It is approximately 2,500 feet thick about 5 miles shoreward of the Mesozoic paleoshelf edge, and it thins seaward to a feather edge that meets the top of the paleoshelf-edge carbonate buildup.

No conventional cores were cut in this interval, but drill cuttings and sidewall cores indicate that the uppermost 300 feet contain friable fine- and medium-grained sandstone beds with siltstone, shale, and minor limestone. The remaining 1,700 feet are calcareous shale with limestone, siltstone, and sandstone interbeds. Well logs suggest thinly interbedded lithologies in the upper 300 feet of this unit and thicker beds of various lithologies in the lower 1,700 foot subinterval.

Well log analysis (table 4, page 28) indicates that this facies unit has low porosity except in its uppermost part, from 9,562 to 9,706 feet, within which a total of 46 feet of potential reservoirquality rocks were identified as having an average porosity of 26 percent. These thin, porous intervals probably correspond to the friable sandstone beds sampled by sidewall cores.

Well cuttings and cuttings thin sections from the upper subinterval contain disaggregated, very fine to medium-grained quartz sand that is angular to subrounded and occasionally ironstained. The few fragments of sandstone remaining intact have calcite spar and micritic cement and contain calcareous peloids and fossil fragments. Throughout the upper and lower subintervals, many shale fragments are silty and have abundant organic material and pyrite flecks. Siltstone is frequently argillaceous and organic-rich and sometimes contains abundant mica. Limestone fragments are micritic and often argillaceous, sometimes containg quartz silt and sand. Fossils occurring in the limestone and occasionally in the sandstone include echinoderm plates, echinoid spines, microgastropods, and foraminifers. Glauconite is moderately abundant among the cuttings, and anhydrite and minute dolomite rhombs are seen in the lower 500 feet of this unit.

° Backbank Facies (11,600-16,000 feet; Berriasian-Bajocian?)

This tabular carbonate facies unit underlies the clastic wedge and is immediately shoreward of the Mesozoic paleoshelf-edge carbonate buildup. The Shell 586-1 well bottoms in this unit.

This final interval is mostly carbonate but includes significant terrigenous clastic material, both as interbeds and as disseminated sand, silt, and clay within the limestone. Well logs suggest that from 11,600 to 11,940 feet the lithology is clean, dense limestone with minor shaley breaks; sidewall core samples agree. According to the logs, from 11,940 to 12,970 feet there are thinly interbedded lithologies. The sidewall cores indicate limestone, sandstone, and shale in subequal proportions with subordinate siltstone. From 12,970 to 16,000 feet the logs and sidewall core samples are consistent with one another, and this subinterval contains limestone with sandstone, siltstone, and shale interbeds.

Conventional cores were cut at 11,605 feet (core 2), 14,882 feet (core 3), and 15,970 feet (core 4). Core 2 is light gray bioclastic wackestone with occasional thin shaley breaks and abundant wavy shale laminae in the limestone. The bioclasts are sand size to 3 mm in diameter. In addition, larger clasts, 1 to 3 cm, are coral, calcareous sponge, and stromatoporoid. A few much larger fossils, having diameters larger that the drill core, may be bioclasts or reefal framework elements. Many fossils are recrystallized to spar mosaics.

Cores 3 and 4 are medium to dark gray wackestone and packstone. Some portions of core 3 approach lime mudstone in composition. This core also has 1- to 5-inch-thick shale intervals, some of which are carbonaceous, and thin siltstone intervals that are micaceous. In core 4 there are stylolites, stylolitized contacts between large fossils and matrix, and abundant very small solution-enlarged voids, which apparently developed from fractures or stylolites. Cores 3 and 4 have abundant large metazoan fossils as large as 18 cm in diameter. Some appear to be in place and may be reefal framework elements. Therefore, some short intervals may be boundstone.

Core thin sections show skeletal bioclastic wackestone and packstone for all three cores. They also show argillaceous carbonate mudstone from the "shaley breaks" and laminated micaceous siltstone and organic-rich shale with disseminated pyrite from the terrigenous interbeds. In addition, there are a few quartz sand grains disseminated within the limestone.

Within the wackestone and packstone, skeletal grains are echinoderm plates, echinoid spines, gastropods, ostracods, foraminifers (Epistomina and Lenticulina), and bryozoan, brachiopod, coral, sponge, and bivalve fragments. Most grains have micritic rinds and are well rounded. Core 2 contains abundant tubiphytes and oncolites and a few pieces of hexactinellid silicious sponge of a different species than that of the blanketlike facies.

The large bioclasts and framework elements in the three cores are difficult to identify, owing to recrystallization, but they include calcareous sponge, coral, and stromatoporoids. Many of the large metazoan fossils have crusts of bluegreen algae and encrusting foraminifers. Bluegreen algae are abundant in the three cores; dasycladacean algae are fairly rare; and red algae are very rare.

Among the three cores, recrystallization to spar mosaics becomes more prevalent with depth. Bioclasts, large metazoan fossils, and micritic matrix are altered to spar in core 4 to the extent that fossil and texture identification is difficult. Most of the spar is calcite but some is anhydrite. Minute dolomite rhombs are disseminated in the spar.

Porosities are poorer in the backbank facies unit than in the blanketlike facies. Observed porosity is low, consisting of inter- and intragranular solution effects, voids associated with fractures, stylolites, and edges of large fossils, and very minor vugular space owing to dissolved clasts. Petrophysical analysis indicates porosities of 3.7 to 13 percent for core 2, 0.5 to 6.3 percent for core 3, and 0.7 to 6.4 percent for core 4. Air permeabilities range from 0.008 to 5.2 md among the plugs from the three cores.

BIOSTRATIGRAPHY

by

William E. Steinkraus, Harold L. Cousminer, and Raymond E. Hall

Three factors limit the reliability of paleontologic data from offshore Atlantic wells. (1) Most analyses are made from drill cuttings, which are often heavily contaminated by cavings from higher in the drill hole. For this reason, only "tops," or the uppermost appearances of species, are recorded. (2) Reworked, older fossil assemblages and individual specimens are commonly reincorporated in detrital sedimentary rocks. These fossils must be recognized to avoid misdating an interval as older than it is. (3) Biostratigraphic control is poor in pre-Late Jurassic strata. Calcareous nannofossils and foraminifers are rare to nonexistent. Palynomorphs are more common, but their biostratigraphic distribution is not fully documented with reference to the European type stage localities.

This report replies on the Jurassic palynostratigraphy of offshore eastern Canada (Bujak and Williams, 1977) because many of the Canadian palynomorph marker species are also present in the United States offshore Atlantic subsurface. Although the European stage equivalence of many species is not fully resolved, several species have recently been documented in European type sections (Woollam and Riding, 1983; Riding 1984; Davies, 1985).

This investigation is based on examination of fossil foraminifers, dinoflagellates, spores, pollen, and calcareous nannofossils by the paleontology staff of the Atlantic Regional Office of MMS. Foraminiferal studies were based on 145 samples at 30-foot intervals. Palynological analyses were made from 90 slides prepared from 90-foot composite samples. Nannofossil studies were made from 227 slides representing 10-foot to 40-foot intervals. Cuttings samples were collected from a depth of 7,940 feet (below KB) to the total depth of the well, 16,000 feet. Micropaleontological analyses employed well cuttings samples and samples from conventional cores.

Ages of the section examined range from Late Cretaceous (Turonian) to Middle Jurassic (Bajocian?). Unconformities occur between the Aptian and Barremian at 9,790 feet and possibly between Oxfordian and Bathonian at 13,090 feet. The biostratigraphic chart (see fig. 7, page 19) shows the highest occurrences of the marker fossils and the locations of the unconformities.

Late Cretaceous

° Turonian (7,940-8,480 feet)

Microfossil markers of Turonian age are observed in the highest sample available: the nannofossil marker is Radiolithus planus. The dinoflagellate species Surculosphaeridium longifurcatum and Deflandrea pirnaensis also are present and have Turonian range. The planktonic foraminifer Praeglobotruncana stephanii occurs at 7,970 feet, and the nannofossil species Corollithion achylosum was identified at 8,300 feet.

° Cenomanian (8,480-8,750 feet)

The upper limit of the Cenomanian stage at 8,480 feet is determined by the nannofossil species Podorhabdus albianus. The highest occurrence of Corollithion kennedyi was observed at 8,510 feet. The dinocysts Cleistosphaeridium huguonioti and Apteodinium grande and the spore Coronatispora valdensis were identified at 8,660 feet.

Early Cretaceous

° Albian (8,750-9,070 feet)

The top of the Early Cretaceous section is located by the highest occurrence of the nannofossil species Braarudosphaera stenorhetha, B. africana, and Nannoconus bucheri. The dinocyst Spinidinium vestitum was identified within the interval at 8,800 feet; also Astrocysta cretacea and Dingodinium alberti were observed at 8,890 feet, both of which do not occur above the Albian.

° Aptian (9,070-9,790 feet)

The dinocyst Canningia attadalica, identified at 9,070 feet, is reported to have its highest exinction in the Early Aptian on the Scotian Shelf. The trilete spore sp. "119" (Bebout, 1981) was identified at 9,390 feet. The foraminifer Lenticulina nodosa and the nannofossil marker Nannoconus "asqeloni" were identified at 9,490 feet.

° Barremian (9,790-9,880 feet)

The top of this stage is placed at 9,790 feet on the basis of the highest occurrence of the nannofossil species Nannoconus steinmanni. The dinocyst Aptea anaphrissa, having its highest occurrence at 9,850 feet, has peak occurrence in the Barremian Tenua anaphrissa subzone on the Scotian Shelf and Grand Banks. Muderongia staurata was recovered at 9,850 feet.

° Hauterivian (9,880-10,150 feet)

The upper limit of the Hauterivian stage at 9,880 feet is determined by the nannofossil species Nannoconus colomi. The foraminifer markers identified at 10,020 feet include Lenticulina saxonica saxonica, L. guttata, and Planularia crepidularis. The dinocyst Kleithriasphaeridium corrugatum was recovered at 10,030 feet.

° Valanginian (10,150-11,480 feet)

At 10,150 feet, the Valanginian determination is based on the foraminifer "Lenticulina" schreiteri and the nannofossil marker Bipodorhabdus colligatus. Lenticulina saxonica bifurcella had its highest occurrence at 10,180 feet. The dinoflagellate species Oligosphaeridium perforatum was identified at 10,660 feet.

° Berriasian (11,480-12,050 feet)

The top of the Berriasian is based on the highest occurrence of the dinocyst Occisucysta evittii. Polycostella sonaria, the nannofossil marker species for this stage, was identified at 11,560 feet.

Late Jurassic

° Tithonian (12,050-12,110 feet)

The upper limit of the Jurassic is interpreted according to the highest occurrence of the foraminifer marker Epistomina uhligi.

° Kimmeridgian (12,110-12,260 feet)

The top of the Kimmeridgian is based on the joint occurrence of the dinocyst species Gonyaulacysta globata, G. longicornis, and Senoniasphaera jurassica at 12,110 feet. The nannofossil Hexalithus noelae at 12,300 feet ranges into the late Kimmeridgiän.

° Oxfordian (12,260-13,090 feet)

The top of this stage is placed at 12,260 feet on the basis of the highest occurrence of the forminifer, Lenticulina varians. The dinocyst marker Adnatosphaeridium aemulum was identified at 12,290 feet. This species is unknown above the Oxfordian on the Scotian Shelf.

Middle Jurassic

° Bathonian? (13,090-13,860 feet)

The Bathonian age is indicated by the highest occurrence of the foraminifer Spiroloculina? lanceolata. The dinocyst marker Gonyaulacysta filapicata is present in this interval. The occurrence of this species higher in the section is attributed to considerable reworking of the sediments upwards to the Berriasian. The palynomorph species Sentusidinium sp was identified at 13,570 feet.

° Bajocian? (13,860-16,000 feet)

The possible Bajocian top is based on the highest occurrence of several poorly preserved dinoflagellate species belonging to Mancodinium-Dapcodinium plexus. There is no real evidence to indicate the presence of Early Jurassic deposits in this well. The interval between 15,090 and 15,900 feet is essentially barren. Rare specimens of Middle Jurassic palynomorphs were identified in the deepest sample 15,900-15,990 feet.

DEPOSITIONAL ENVIRONMENTS

by

Gary M. Edson, Harold L. Cousminer, and Raymond E. Hall

The Shell Wilmington Canyon 586-1 well penetrated limestones associated with the Late Jurassic-Early Cretaceous paleoshelf-edge carbonate trend, immediately to the east, and with terrigenous clastic rocks, representing sediments shed into the Baltimore Canyon Trough from the west. The Shell 586-1 well is located in a transition zone and shows characteristics of both lithologic environments.

Four facies units were identified in the well from rock samples, well logs, and seismic profiles. These units are described in the lithology and petrography section of this report (page 13), and a diagrammatic dip cross section is shown in figure 6. Ages of these units are reported in the biostratigraphy section (page 21), and inferred paleobathymetry is shown in figure 7. From bottom to top, the facies units are the backbank facies, the clastic wedge, the blanketlike facies, and the argillaceous facies. The environments they represent are discussed in that order.

° Backbank Facies (11,600-16,000 feet; Berriasian-Bajocian?)

This is mostly a carbonate interval, but it contains abundant shale, sandstone, and subordinate siltstone, especially between 11,940 and 12,970 feet, which contains the Jurassic-Cretaceous transition subinterval. Throughout this facies interval, limestone beds contain continental detrital clasts. About 7 miles to the northwest, the Tenneco 495-1 well penetrated a section of approximately the same age that contains more sandstone, siltstone, and shale than limestone. About 3 miles to the southeast, in the Shell 587-1 well, rocks of about the same age are limestone. Therefore, within the backbank facies, the Shell 586-1 well is located within a transition zone between the more shoreward, clastic basin-fill sediments and the paleoshelfedge carbonate trend.

Paleobathymetric analysis (see fig. 7) suggests a very shallow-water depositional setting within the inner neritic zone. Carbonate lithologies are those of a low-energy depositional environment: packstones, wackestones, and minor carbonate mudstones. Drill cores contain organic argillaceous limestone interbeds that grade into carbonaceous shale, indicating shallow, near-shore conditions such as lagoons. However, slightly higher energy and probably deeper water are indicated by the locally abundant oncolites and by some of the macrobiota, such as the hexactinellids.

In summary, the backbank facies including the terrigenous detrital beds is interpreted to represent alternating shallow marginal marine environments such carbonate mud flats, oncolite shoals, lagoons, and small coalescing deltas. Some of the apparently *in situ* large metazoan fossils, such as stromatoporoids, sponges, and corals, may be patch reef framework elements.

° Clastic Wedge (9,540-11,600 feet; Barremian-Berriasian)

This facies unit also consists of sandstone, siltstone, shale, and limestone, but the continental detritus predominates. Paleobathymetric interpretation indicates very shallow, inner neritic conditions except for the upper 1,000 feet, which deepen, possibly to mid-neritic depths. Detailed lithologic and petrographic information is not available because conventional cores were not cut in this interval. However, there appears to be more sandstone in the thinly interbedded upper 300 feet of this unit than in the remaining 1,700 feet, which are thicker bedded and contain more shale.

According to Vail's global cycles of relative sea level change (1977), a major marine regression occurred at the beginning of Valanginian time. In the Shell 586-1 well, lithologies indicate that the entire Valanginian was a time of increased terrigenous sedimentation into the Baltimore Canyon Trough. The resulting clastic wedge prograded over the backbank facies, covered the paleoshelf-edge carbonate buildup by the end of the Valanginian, and continued to accumulate into the Barremian. The depositional environments that predominated in the time period represented by the wedge were probably coalescing deltas, sedimentary responses to periods of low sea level during the generally transgressive Early Cretaceous.

° Blanketlike Facies (9,030-9,540 feet; Aptian)

According to seismic analysis, this unit is regionally persistent along strike and is consistent in thickness in southeastern Baltimore Canyon Trough. Paleobathymetric interpretation suggests mid-neritic water depths, but fossils include shallow- (e.g., Trocholina) and deeper-water indicators (e.g., hexactinellids). Petrographic textures indicate mostly quiet-water deposits (wackestones and packstones) but also higher energy environments (grainstone), as well. The ooliths are further indications of higher energy, as well as water depths above wave base. Moderate-energy and shallow-water signs include oncolites and coated grains. However, most ooliths, oncolites, and coated grains are enclosed in wackestones or packstones.

The blanketlike unit appears to be underlain by an unconformity. In figure 7 the unconformity is placed about 250 feet below the base of the blanketlike facies, because of the uppermost occurrence of Nannoconus steinmanni (uppermost Barremian range). There are no diagnostic fossils within the 250-foot interval. Seismic sections show a prominent unconformity at the base of the blanketlike unit and so it is concluded that this location is correct.

Vail and others (1977) indicate a major regression in the Aptian stage. The unconformity at the base of the blanketlike unit probably marks this event. The blanketlike unit itself is limestone deposited during sea level fluctuations associated with the succeeding transgression. The variations of water depth and energy indicated by the biota and petrographic textures may be caused by fluctuations of depth and to reworking caused by storm activity.

° Argillaceous Facies (above 9,030 feet; Albian and younger)

The calcareous shales overlying the blanketlike facies unit were deposited in 300-500 feet of water, according to paleobathymetric analysis (see fig. 7). It appears that shales overlie the Aptian limestone because marine transgression resumed in the late Aptian and Albian (Vail and others, 1977).

FORMATION EVALUATION

by

Renny R. Nichols

Well ("electric") logs were run in the Shell Wilmington Canyon 586-1 well by Schlumberger Ltd. to provide information for stratigraphic correlation and for evaluation of formation fluids, porosity, and lithology. Table 3 shows some of the logs.

TABLE 3.--Well logs

Log Type	Depth Interval (ft)
Dual Induction Spherically-Focused Laterolog (DISFL)	7,885-8,792
Borehole-Compensated (BHC) Sonic	7,885-8,792
Dual-Induction Tool (DIT)	8,871-15,994
Long-Spaced Sonic (LSS)	8,871-15,994
Caliper	8,871-15,994
Gamma Ray	8,871-15,994
Compensated Neutron (CNL)	8,771-15,999
Lithodensity Tool (LDT)	8,771-15,999
High-Resolution Dipmeter (HDT)	8,802-16,000

Exploration Logging, Inc., provided a Formation Evaluation ("mud log") which included a rate of penetration curve, sample description, and a graphic presentation of hydrocarbon shows (7,940-15,970 feet). In addition, a Drilling Data Pressure Log, a Pressure Evaluation Log, and a Temperature Data Log were run (7,940-16,000 feet).

The electric logs, 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 present. Rocks with indicated 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, would be necessary to substantiate the estimates shown in table 4.

The electric logs were of acceptable quality. However, the spontaneous potential is offscale from 15,946-15,976 feet. From 12,980-15,994, the Induction Log-Medium (ILM) shows what appears to be a false salt water annulus

TABLE 4.--Well log interpretation summary

Depth Interval (ft)	Feet of Potential Reservoir (a)	Average Porosity (%)	Water Saturation (%)	Feet of Hydrocarbon (b)
6,320-6,750	430 (?)	35+	-	-
7,005-7,295	290 (?)	35+	-	-
9,034-9,048	14	23	96	-
9,096-9,108	12	24	-	-
9,502-9,541	26	33	-	-
9,562-9,608	29	26	-	-
9,686-9,706	17	26	-	-
11,636-11,668	29	8	77	-
11,714-11,757	43	9	-	-
11,829-11,884	50	8	-	-
12,059-12,073	14	5	-	-
12,102-12,118	16	6	-	-
12,295-12,307	12	7	-	-
12,469-12,487	18	14	-	-
12,699-12,720	18	12	-	-
12,850-12,868	14	17	-	-
12,883-12,923	36	19	76	-
12,978-13,120	61	7	-	-
13,520-13,554	16	6	-	-
13,652-13,690	30	10	-	-
13,832-13,846	14	10	-	-
13,890-13,924	9	5	-	-
14,290-14,302	11	6	-	-
14,423-14,443	20	17	34	- (c)
14,510-14,520	6	4	44 (d)	-
14,945-14,952	7	8	34 (e)	-
15,031-15,038	7	9	37 (f)	-
15,082-15,087	5	7	1 (g)	-

a) Generally in beds > 10 ft thick and porosity (Ø) > 5%.
b) Generally in beds > 10 ft thick, Ø > 5%, and water saturation < 50%.
c) Hot wire (HW, in units) = 34, $C_{1-2-3-4i-n}$, sand with poor spontaneous potential response, no fluorescence, no cut, one sidewall core (SWC) at 14,429 ft with slow milky cut.
d) Limestone (LS) with high true resistivity (Rt), poor Ø, no sample show.
e) LS with high Rt, no sample show, HW = 17, C_{1-3}.
f) LS with high Rt, no sample show, HW = 12, C_{1-3}.
g) LS with high Rt, no sample show, HW = 14, C_{1-2-3}, SWCs at 15,083-15,085 ft with residual cut/odor.

effect, probably caused by hole enlargement. Severe hole enlargement can be seen on the caliper at 11,300-11,510, 11,940-12,270, 14,350-14,550, 14,810-15,030, and 15,430-15,450 feet. The resistivity log values match the repeat run (11,600-11,700 feet) very closely although the depth of response on the log is 6 feet lower than on the repeat section. Downhole While Drilling and Electromagnetic Propagation Tool logs were run in this well although they are still in the early stages of development.

Sidewall Core Analysis

A total of 259 sidewall cores were taken from 8,950 to 11,340 feet and from 11,380 to 15,924 feet. Descriptions were received, but analyses were not available.

Conventional Core Analysis

Four conventional cores were taken in this well (table 5).

TABLE 5.—Conventional core properties

Core No.	Depth Interval (ft)	Recovery (ft)	Lith	Porosity (%)	Perm. (md)	Oil Pore	Gas Pore	Gas Vol.
1	9,036-9,066	22.5	LS[1]	10-24	0.042-12.2	-	-	-
2	11,605-11,635	24.3	LS	3.7-13	0.0008-2.0	-	-	-
3	14,882-14,912	28.5	LS	.5-6.3	0.020-5.2	-	-	-
4	15,970-16,000	28.3	LS	.7-6.4	0.011-1.4	-	-	-

[1]LS means limestone.

Log analysis results for the Core 1 interval revealed that density porosity ranged from 15 to 24 percent, while the sonic porosity averaged 22 percent. For Core 2, the density porosity ranged from 5 to 18 percent, while the sonic porosity averaged 13 percent. For Core 3, the density porosity ranged from 1 to 6 percent, while the sonic porosity averaged 8 percent. For Core 4, the density porosity ranged from 0 to 4 percent.

Dipmeter

Results of the high-resolution dipmeter survey were recorded on a dipmeter arrow plot from 11,326 to 15,993 feet. Possible structural anomalies may be present at 12,040, 13,210, 13,810, 14,680, 15,100, 15,560, and 15,960 feet. The dip direction and magnitude in the well are shown in table 6.

TABLE 6.—Dipmeter results

Depth Interval (ft)	Predominant Direction	Magnitude
11,326-12,100	West	1°-21°
12,100-13,100	Northwest	1°-15°
13,100-14,500	West	1°-24°
14,500-15,400	Southwest	1°-24°
15,400-15,900	Northwest	1°-28°
15,900-15,993	Northwest	1°-33°

Significant Shows

Table 7 lists all shows of hydrocarbon encountered in this well. None of the shows were judged to be significant.

Formation Pressures

Mud weight stayed at or below 9.5 ppg until a depth of 14,700 feet, where it was increased to 9.6 ppg. It was further increased to 9.8 ppg at 15,304 feet.

TABLE 7.--Summary of hydrocarbon shows

[Ø, porosity in percent; K, permeability in milidarcies; SW, water saturation in percent]

Depth Interval	Drilling Break ft/hr	Sample Description (Mud Log)	Total Gas back-ground	Total Gas inter-val	Chroma-tograph	Cutt. Gas	Conventional Cores[1] interval	Conventional Cores[1] Ø	Conventional Cores[1] K	Sidewall Cores[2] interval	Sidewall Cores[2] Ø	Well Log Interp. interval	Well Log Interp. Ø	Well Log Interp. SW	Repeat Formation Tester
12,890-12,910	10-25	siltstone, slightly calcareous	3	7	C_1-2-3 4i-n	2				12,887 12,895 12,900	22 10 20	12,883-12,923	19	76	
14,432-14,462	9-70	sandstone, slightly calcareous	5	34	C_1-2-3-4i-n	5				14,429-14,465	10	14,423-14,443	17	34	test 3 at 14,433 low perm. no seal, mud test
14,516-14,525	7-30	limestone, dense	2	9	C_1-2	2				14,511-14,517	None	14,510-14,520	4	44	
14,915-14,940	4-13	limestone and sandstone	2	17	C_1-2-3	-	14,882-14,912	.5-6.3	.02-5.2	14,917-14,949	None	14,945-14,952	8	34	
15,030-15,050	9-24	limestone and sandstone	3	12	C_1-2-3	3				15,031-15,037	None	15,031-15,038	9	37	
15,085-15,100	9-10	limestone and siltstone	2	14	C_1-2-3	2				15,081-15,085	-	15,082-15,087	7	31	
15,265-15,280	10-25	limestone and siltstone	3	13	C_1-2-3	2				-	-	15,284-15,294	2	53	
15,330-15,340	6-40	sandstone, calcareous	3	22	C_1-2-3	2				15,332-15,340	-	15,320-15,323	6	33	tests 1&2 at 15,337 ft Rec. 4 cu. ft. gas, 9,500 cc water
15,460-15,480	10-14	siltstone and limestone	3	18	C_1-2-3-4i-n	3				15,466	<10	15,454-15,466	2	95	
15,925-15,935	9-16	limestone, slightly oolitic	2	24	C_1-2-3-4i-n	1				15,920-15,924	-	15,927-15,933	5	13	
15,960-15,970	10-15	limestone	2	10	C_1-2-3	1	15,970-16,000	.7-6.4	0.01-1.4	-	-	15,959-15,966	4	17	

1. No oil pore, oil bulk, or gas bulk values were recognized from the data provided.
2. Permeabilities not reported.

OPTICAL KEROGEN ANALYSIS

by

Charles E. Fry

Microscopic analysis was used to determine the type and thermal rank of kerogen contained in cuttings samples of the Shell Wilmington Canyon 586-1 well. The insoluble organic material is classified in this report as four major types: Algal, organic material mostly of marine origin, either recognizable algae or its unstructured remains; Herbaceous, leafy portions of terrestrial plants, also including spores and pollen; Woody, plant detritus with a fibrous, lignified texture; Coaly, black opaque material, considered to be chemically inert (Adapted from Bayliss, 1980, and Hunt, 1979). Abundance estimates for each of these types are made from the palynology slides. Algal and marine-derived kerogen have the best potential for oil and gas generation, depending on temperature and burial conditions; more structured terrestrial kerogen has less oil generation potential but can generate gas hydrocarbons at higher temperatures (Tissot and Welte, 1978).

Thermal maturity is estimated by comparing palynomorph color with the thermal alteration index (TAI) scale (fig. 8a; Jones and Edison, 1978). Colors displayed by the organic matter indicate the degree to which the kerogen has been thermally altered (Staplin, 1969).

Kerogen Types

The first samples examined, from 7,940 to 8,750 feet, are of Turonian and Cenomanian (Late Cretaceous) age. They are very sparse in kerogen content, which is at least 80 percent woody and coaly kerogen with only trace amounts of algal material (see fig. 8b).

Early Cretaceous samples (8,750-12,050 feet) begin with an increase in the relative abundance of algal (10 to 15 percent) and herbaceous (20 to 35 percent) kerogen in an interval (8,750 to 9,160 feet) roughly equivalent to the Albian stage. Much of the herbaceous material in these samples is decayed and unstructured. From 9,160 to 9,940 feet, algal material is seen in trace amounts, and herbaceous kerogen continues to be approximately 25 percent of the observed kerogen. Near the Barremian-Hauterivian boundary, 9,790 feet, the abundance of algal kerogen increases to 15 percent and continues at that level past the Valanginian boundary down to 10,660 feet. From this depth to the top of the Jurassic, 12,050 feet, the distribution of kerogen types is as follows: algal, 5 percent; herbaceous, 30 to 40 percent; woody, 30 to 40 percent; and coaly, 20 to 25 percent.

Slides examined from 11,930 to 12,290 feet (Berriasian-Oxfordian) indicate a kerogen content similar to those of the later Cretaceous, but display a small increase in algal abundance to 10 percent. Oxfordian-Bathonian samples (12,290 to 13,860 feet) indicate minor algal content down to 13,050 feet. From 13,050 to 13,390 feet, algal kerogen is 15 percent and herbaceous kerogen is 40 percent. This is also the only interval in the well in which combined woody and coaly kerogens comprise less than 50 percent of the observed kerogen.

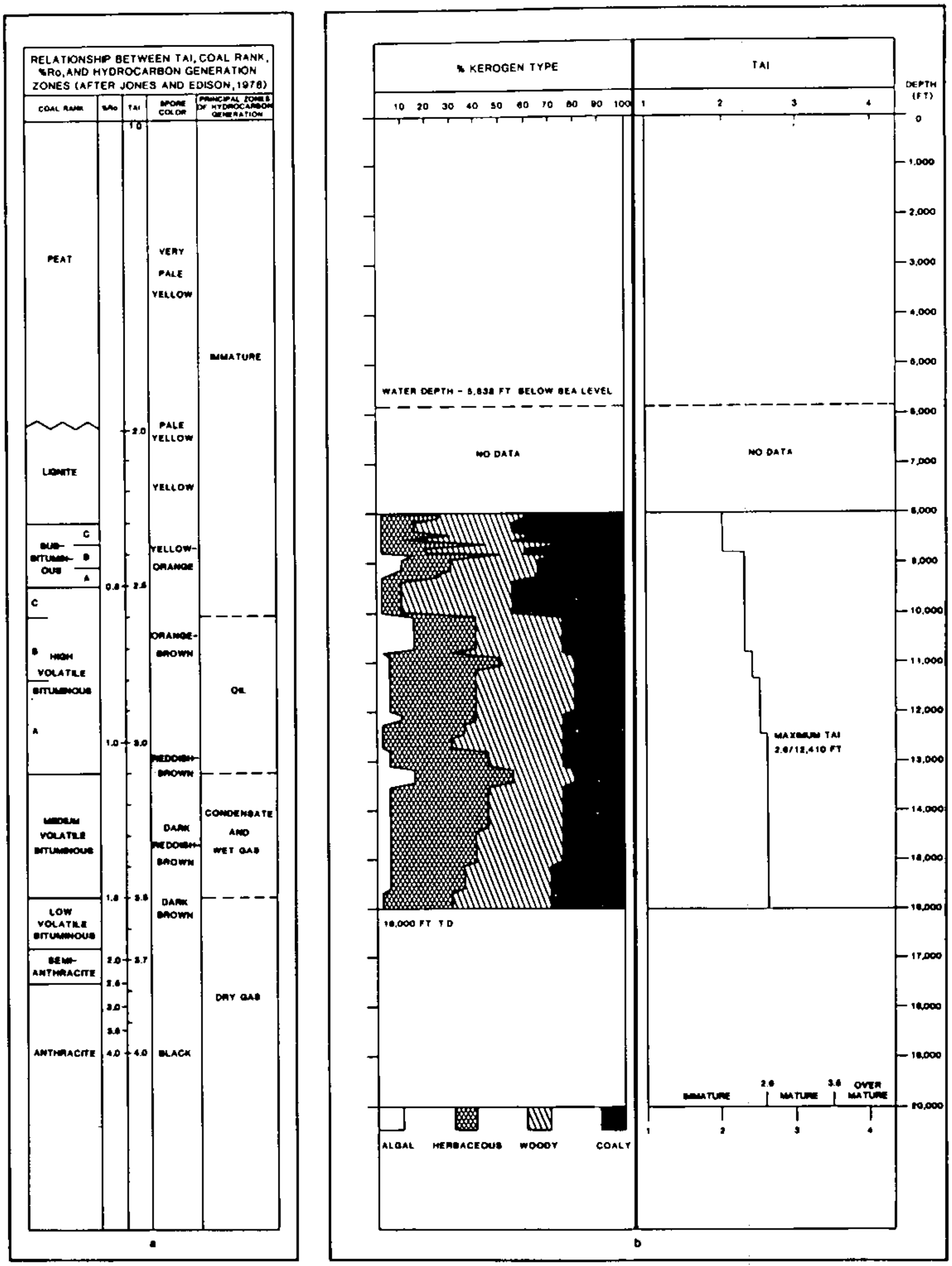

FIGURE 8.--Thermal maturity and hydrocarbon generation (a) and kerogen analysis for the Shell 586-1 well (b).

From 13,390 feet to the bottom of the well at 16,000 feet, the abundance of terrestrial kerogen steadily increases. Algal kerogen is almost constant at 5 percent, herbaceous kerogen ranges from 30 to 40 percent, woody kerogen ranges from 30 to 40 percent, and coaly kerogen ranges from 25 to 30 percent.

Thermal Maturity

Kerogen thermal maturities from the Shell 586-1 well were estimated by visual observation of palynomorph color (see fig. 8b). Palynomorphs with mature colors were not seen above the Jurassic. At 12,410 feet, just below the top of the Oxfordian stage, there are indigenous orange-brown dinoflagellates. This color corresponds to a TAI value of 2.6, indicating borderline maturity. Material of this same color is observed in all samples below this depth, down to 16,000 feet (TD). Below 15,000 feet, there are dark reddish-brown palynomorphs that accompany the orange-brown material. The former are judged to be reworked and not true indicators of thermal maturity.

Conclusions

Optical kerogen analysis provides a general indication of the types of organic source material present in sediments and suggests the extent of thermal alteration. This information can be used to supplement geochemical laboratory data.

Every slide examined from the Shell 586-1 well contained a combination of black inertinite, structured woody material, plant cuticle, spores, pollen, and unstructured, decomposed material probably of terrestrial origin. Algal material is present but never as a large proportion of the kerogen population. The above types of kerogen characterize a terrestrial, gas-prone source.

Orange-brown palynomorphs, indicating borderline maturity, are found beginning at 12,410 feet (Oxfordian). The extent of alteration does not appear to increase among deeper samples; indigenous material having the same color was observed to 16,000 feet (TD).

This combination of terrestrial kerogen and marginal maturity suggests poor source quality and limits probable hydrocarbon generation to the lowest 3,600 feet of the well.

PETROLEUM GEOCHEMISTRY

by

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

The objectives of this study are: (1) to examine and define the source-rock characteristics of the stratigraphic intervals in the Shell Wilmington Canyon 586-1 well that may have potential for generation of oil and natural gas, (2) to assess time-temperature-burial depth relationships for the onset of thermal maturation, and (3) to assess the influence of any mud additives on source rock measurements.

The definitions, concepts, and terminology used in this report are those established by Vassoyevich and others (1970), Dow (1977), Tissot and Welte (1978), Hunt (1974, 1978, 1979), Miller and others (1979, 1980, 1982), Momper (1978), Walper and Miller (1983, 1985) and Waples (1980).

Analytical Methods and Procedures

The MMS Petroleum Geochemistry Group analyzed 28 wellcuttings samples for their C_{15}+ characteristics and 169 gas samples from 7,940 feet to 16,000 feet depth. The unwashed cuttings samples were first analyzed by the "head-space" procedure to determine the concentration of the C_1 to C_5 light hydrocarbons present in one-quart cans, filled and sealed on the drillship.

Following the "head-space" analysis, each selected cuttings sample can was opened and drilling mud was removed from rock fragments by carefully washing them under running water through a Tyler 100-mesh screen. Each sample was then air dried. Solid contaminants composed of metal fragments, rubber, plastic, fibers, walnut husks, and various solid to semi-solid hydrocarbons thought to be gilsonitelike and tar-like substances were also removed from the cuttings by hand. The samples were then described, using a binocular microscope, and divided into aliquots for gasoline-range hydrocarbon analysis, total organic carbon analyses, thermal pyrolysis-gas chromatography procedures, Soxhlet solvent extraction and liquid column chromatography, and high-resolution glass capillary gas chromatographic analyses of the saturated paraffin-napthene hydrocarbon fractions.

Results and Discussion

Source Rock Quality and Type

The source rock potential of the Shell 586-1 well is shown in figure 9, which describes the distribution of total organic carbon and depicts the richness, or quality, of source beds penetrated by the well. The Late Cretaceous shales, 7,940 to 8,750 feet, have total organic carbon values that range from 0.74 to 0.83 weight percent. Such values are in the fair range for argillaceous source beds. The Early Cretaceous mixed lithologies, 8,750 to 12,050 feet, have total organic carbon values that range from 0.04 to 0.82 weight percent and are considered to be in the poor to fair

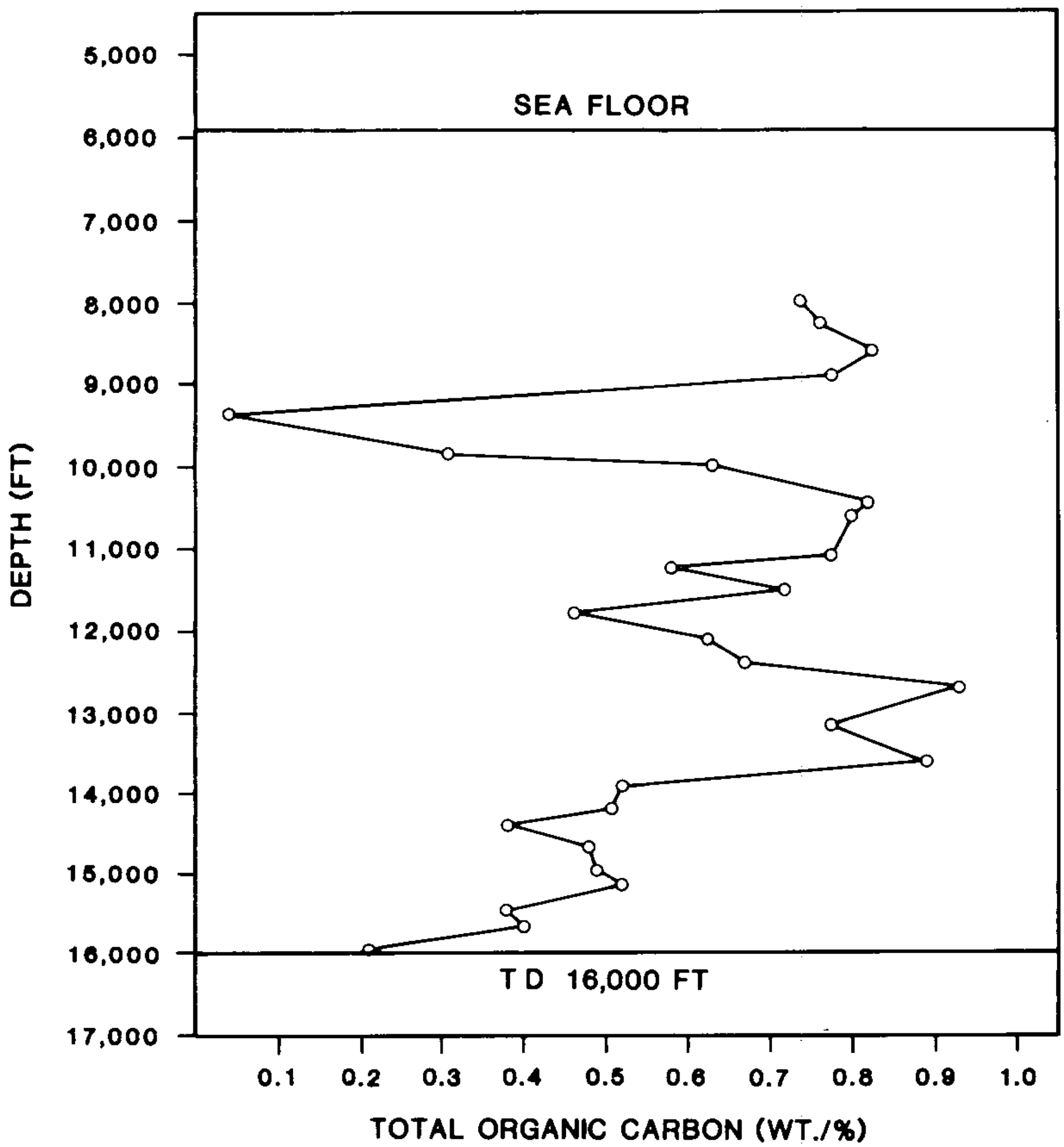

FIGURE 9.--Total organic carbon content of rocks in the Shell 586-1 well.

category for source beds. The Late and Middle Jurassic carbonates with interbedded terrigenous clastics, 12,050 to 16,000 feet, have total organic carbon values that range from 0.21 to 0.94 weight percent. Such values are within the good to very good range, in so far as they apply to the carbonates. The total extractable hydrocarbons (50 to 600 ppm parts per million) and pyrolytic-volatile hydrocarbon content (10 to 72 ppm) for the Cretaceous section are in the poor to fair source rock quality range. The Jurassic section contains both extractable and pyrolytic-free hydrocarbons that range from 100 to 500 ppm and 10 to 40 ppm, respectively.

The abnormally high extractable C_{15}+ hydrocarbon concentrations in many of the cuttings samples are believed to be the result of mud additive contamination or associated lubricants introduced into the mud fluid system. The elimination of mud-additive contamination from well cuttings is at best a difficult and time-consuming process. However, on the basis of the extractable hydrocarbon and total organic carbon values of the rock chips that were cleaned by washing and picking, the source rock potential of the Lower Cretaceous and Upper Jurassic to Middle Jurassic shales in the Shell 586-1 appears to be in the poor to fair range.

Types of Organic Matter

Organic geochemical elemental analyses of the Cretaceous and Jurassic ground whole rock samples show that the organic matter is predominantly of the hydrogen-lean, gas-prone variety. The H/C (hydrogen/carbon) ratios of the Upper Cretaceous shales and Lower Cretaceous mixed lithologies, 7,940 to 12,050 feet, range from 0.25 to 0.79. The Jurassic section from 12,050 feet to the total well depth of 16,000 feet contains organic matter with H/C ratios that vary from 0.28 to 0.61, also indicating the presence of hydrogen-deficient, gas-prone kerogens. The molecular and elemental geochemical signatures of source type are consistent with both the whole-rock thermal pyrolysis and pyrolysis of the chloroform-extracted rock. These data suggest that the predominant organic matter type present in both the Cretaceous and Upper to Middle Jurassic are of a terrestrial (Type III) variety. The molecular geochemical signatures for the type of kerogens identified in the 586-1 well are consistent with the optical-light descriptions of organic matter types reported by Fry (page 33).

Thermal Maturity

The geothermal gradient for the Shell 586-1 well was determined from well bore temperatures taken at five depths with an assumed ambient temperature of 60°F. The gradient was determined to be 1.0°F/100 ft. This value was lower than expected, given a geothermal gradient of 1.25°F/100 ft for the COST (Continental Offshore Stratigraphic Test) B-3 well and 1.26°F/100 ft for the Tenneco 495-1 well. Possible explanations for the lower gradient may be: (1) The more seaward location of the wedge of sediments penetrated by the Shell 586-1 well relative to the location of the transition crust indicated by the East Coast Magnetic Anomaly; (2) well logging errors in determining the borehole temperatures; (3) possible lower temperatures because of heat loss from circulation of formation fluids. The first explanation provides the most likely reason for the lower gradient. This notion is reinforced when a comparison is made with the Shell 587-1 well (0.97°F/100 ft). There appears to be a progression from the 587-1 to the

586-1 to the 495-1 of increasing geothermal gradients that in a semiquantitative sense correlates with the relative location of the transition zone crust.

The molecular geochemical methods used to establish the Hydrocarbon Evolution Window (HEW) for liquids and condensates are based on the temperature sensitivity of the ratio of the paraffin-napthene C_{15}+ hydrocarbon-to-total organic carbon (fig. 10). This ratio is susceptible to mud additive or other hydrocarbon contamination of the cuttings samples. In the Shell 586-1 well the saturated paraffin-napthene-to-total organic carbon ratio shows the influence of high levels of contamination that are believed to have masked the HEW in the thermally immature zones.

Light-optical methods for establishing thermal maturity consist of vitrinite reflectance (R_o%) and thermal alteration index (TAI) techniques. In this well, vitrinite reflectance measurements were not available for comparison with TAI or molecular geochemical methods. On the basis of a geothermal gradient of 1.0°F/100 ft, the theoretical threshold of intense oil generation (TIOG) should occur at a depth of about 16,000 feet, relative to sea level, or at about 9,500 feet, relative to the sediment-water interface. Peak liquid generation is predicted to occur at a depth of about 17,500 feet, relative to sea level, or at a burial depth of 12,500 feet. The theoretical depth limits for the HEW were compared with the depth limits for the thermal liquid maturity window determined by TAI values. The borderline maturity TAI color value of 2.6 was observed at depths as shallow as 12,410 feet below sea level or at a sediment thickness depth of 6,572 feet. The apparent onset of thermal generation processes for liquid hydrocarbons (TIOG) indicated by the light-optical TAI method is shallower than the depth of burial indicated by the theoretical burial depth model, which is based on a gradient of 1.0°F/100 ft. Consistent agreement is observed, however, for the Principal Zone of Oil Formation (PZOF) and peak generation. It is important to note that the TAI values observed in the Shell 586-1 well did not exceed a value of 2.6 even at the bottom of the well. Although the burial depths for the thermal chemical-kinetics model and the TAI light optical method are inconsistent, it is clear that the principal zone of oil formation (PZOF) is interpreted to occur at a burial depth below the section penetrated.

The molecular gases examined in the Shell 586-1 cuttings samples were the C_1 to C_4 (methane through butane) headspace components and the C_4 to C_7 (butane through heptane) detailed gasoline-range species. The average concentration of the total methane through butane molecular species was generally about 3,000 ppm for the entire stratigraphic section, or about 6 times that of the Shell 587-1 well. Exceptions to this value are: samples from 10,900 to 11,200 feet, where total concentrations ranged from about 4,000 ppm to 6,500 ppm, and samples from 14,800 to 15,000 feet, where values ranged up to 21,000 ppm (table 8). The shallowest gas is believed primarily to be biogenic methane. The highest percentage of gas wetness (60 percent) -- which is defined by the ratio of the ethane, propane, and butane components to methane in a unit volume of gas -- was found to occur from about 11,500 to 12,00 feet. A second maximum (50 percent) was found to be present at about 13,500 to 14,000 feet. The higher homologs may indicate that petrogenic thermal generation processes are active at greater burial depths. The low gas concentrations in the Shell 586-1 well are discouraging with regard to possible source bed quality seaward of the Jurassic-Cretaceous

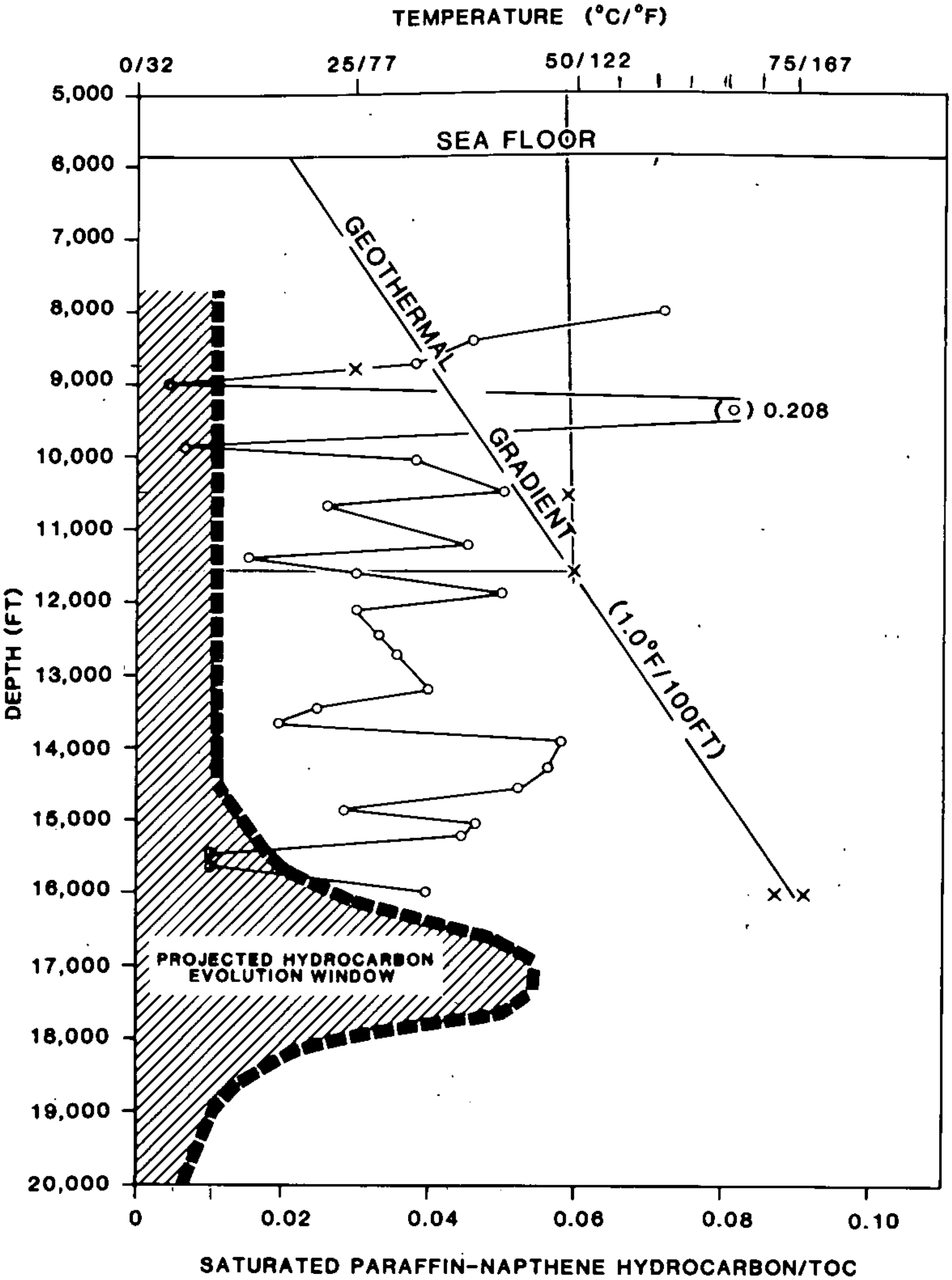

FIGURE 10.--Hydrocarbon evolution window and geothermal gradient for the Shell 586-1 well.

TABLE 8.--Light hydrocarbon geochemical analyses

[Ranges of concentrations, values, and ratios are based on averages of triplicate analyses]

Depth Interval (ft)	C_1-C_4 (ppm)	Gas Wetness (%)	$iC_4/n\text{-}C_4$	$iC_5/n\text{-}C_5$
7,900-8,000	3,500-3,900	---	---	---
8,000-8,500	1,500-2,000	2-9	0.75-1.5	1.5-5.0
8,500-9,000	2,150-4,200	3-5	1.5-2.1	---
9,000-9,500	400-600	5-9	0.80-1.6	---
9,500-10,000	1,500-1,800	10-13	0.80-1.6	---
10,000-10,500	2,000-2,400	10-30	0.70-0.82	1.2-1.8
10,500-11,000	2,200-4,100	22-38	0.82-1.6	1.2-3.0
11,000-11,500	4,000-6,500	30-60	1.0-2.0	1.0-3.5
11,500-12,000	600-1,800	36-60	0.90-1.0	1.2-1.8
12,000-12,500	2,000-4,200	34-42	0.45-0.70	0.80-1.5
12,500-13,000	2,800-4,800	46-48	0.50-0.70	0.80-1.3
13,000-13,500	1,800-3,800	43-50	0.48-0.50	0.80-1.4
13,500-14,000	900-1,500	28-54	0.40-0.50	0.80-1.8
14,000-14,500	1,100-8,500	28-48	0.42-0.45	1.1-1.3
14,500-15,000	3,800-21,000	28-38	0.40-0.45	1.0-1.1
15,000-15,500	2,800-3,800	26-35	0.42-0.45	1.0-1.3
15,500-16,000	3,000-4,200	22-30	0.38-0.42	0.80-1.2

shelf break. However, the higher C_1 to C_4 concentrations and the 50 to 60 percent gas wetness of the source beds behind the shelf edge are encouraging.

The trends of the isopentane-to-n-pentance and n-butane-to-isobutane ratios suggest that low-grade thermal maturation processes are active at burial depths of about 8,500 feet, as indicated by the increase of permanant gas concentrations (see table 8). The near absence of C_4 to C_7 gasoline-range hydrocarbons in the Shell 587-1 well indicates a relatively low-level thermal history, coupled with predominantly Type III, gas-prone organic matter in the Cretaceous and Upper Jurassic units. However, the Shell 586-1 source shales contain low but signifcant concentrations of C_4 through C_7 gasoline-range hydrocarbons, indicating that the shales (which contain predominantly terrrestrial, Type III kerogens) have experienced a slightly higher-level thermal history. This conclusion is consistent with the results of the time-temperature burial model described below.

Time-Temperature Burial Model

Time-temperature burial model relationships for the Shell 586-1 well are based on stratigraphic tops and thicknesses described on pages 21 through 23. The geothermal gradient (1.0°F/100 ft) is assumed to have been relatively constant for the past 150 million years. On the basis of the chemical kinetics concept that the thermal generation of hydrocarbons occurs between the temperature range of 50°C and 110°C, it is clear that the Upper Jurassic (Tithonian) section present in the Shell 586-1 entered the principal zone of oil formation approximately 15 million years before the present (MYBP), whereas the Oxfordian (Upper Jurassic) to Bathonian (Mid-Jurassic) section entered this time-temperature relationship 25 MYBP and 60 MYBP, respectively (fig. 11). The Late Cretaceous units of the Shell 586-1 well have not entered the Principal Zone of Oil Formation and, therefore, are not considered to be potential source rocks. This observation is consistent with the molecular geochemical and light-optical (TAI) determinations made for thermal maturity.

The burial history model of the stratigraphic section represented in the Shell 586-1 well suggests the presence of two periods of relatively rapid subsidence and burial: 130 to 125 MYBP and 112 to 90 MYBP. The intervals from 125 to 112 MYBP and 90 to 0 MYBP were periods of reduced sedimentation and slower subsidence. This sedimentation-burial history, coupled with a low geothermal gradient of 1.0°F/100 ft, suggests a low to moderate time-temperature burial history for the Upper to Mid-Jurassic stratigraphic units encountered in the Shell 586-1 well. This burial model is consistent with the notion that the "transition crust" is believed to be the zone of highest heat flow between the continental sialic and the oceanic basaltic crust. Those depositional sites that contain Early Cretaceous and Late to Middle Jurassic sediments that are located nearest to the transition crust zone will most likely have had the higher heat flows. This hypothesis is subject to further modification and change based upon the geochemical results from the Shell 372-1 and 93-1 wells.

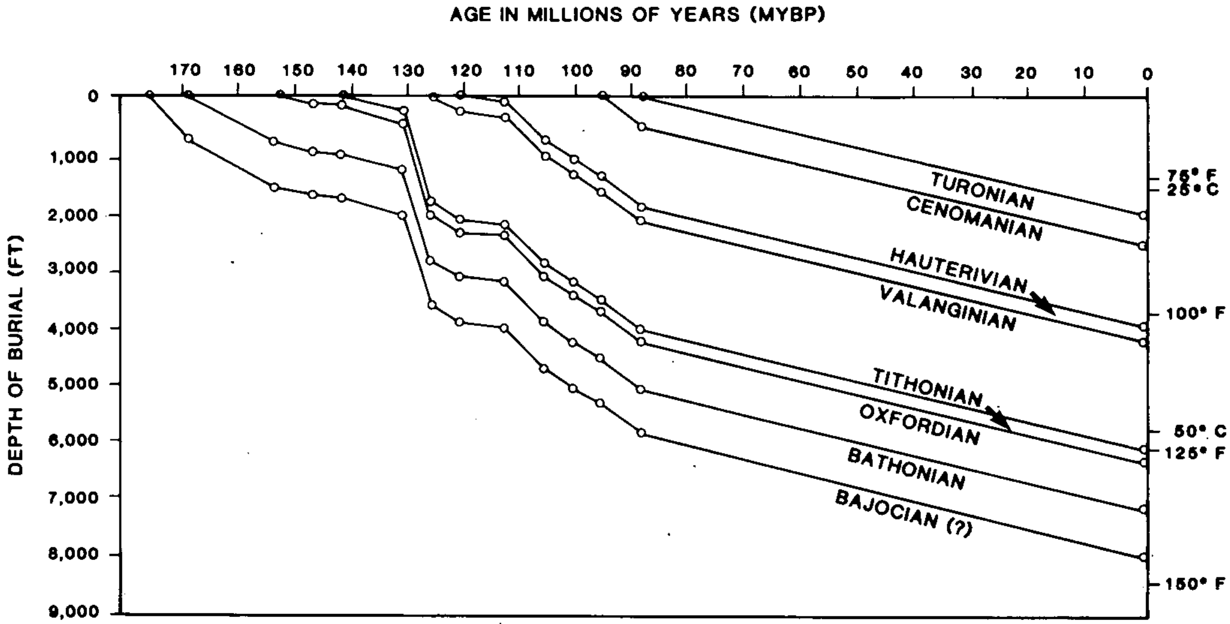

FIGURE 11.--Time-temperature burial profile for the Shell 586-1 well.

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