OCS Report
MMS 87-0118

# Shell Wilmington Canyon 372-1 Well

## Geological & Operational Summary

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

1988

WELL REPORT SERIES

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ABSTRACT

The Shell Wilmington Canyon 372-1 well, in southeast Baltimore Canyon Trough, is about 90 miles offshore from southern New Jersey. The well, spudded on May 26 and completed on July 11, 1984, was drilled by the Discoverer Seven Seas drillship in 6,952 feet of water. Total depth of the well is 11,631 feet (below kelly bushing), and 4,631 feet of sediment and rock were penetrated beneath the sea floor.

Standard well logs were run, together with electromagnetic propagation logs and downhole logging while drilling. Cuttings samples were collected from 9,140 feet to the bottom of the drill hole. Fourteen sidewall cores were obtained, and four conventional drill cores were cut in shale and limestone intervals of the well.

The section penetrated by the Shell 372-1 well is divided into three facies units on the basis of lithologic information, well logs, and seismic profiles. From youngest to oldest, these are an argillaceous facies, a paleoshelf-edge carbonate cap, and a paleoshelf-edge carbonate buildup.

Drill-core petrophysical data indicate poor porosity, but Shell's drilling reports and Minerals Management Service well log analyses indicate zones of good to excellent porosity. However, no significant hydrocarbon accumulations were detected in the well. Total organic carbon content is low among the shales and carbonate rocks, and kerogens are mostly terrigenous, gas-prone types.

Light-optical thermal alteration index values and petroleum geochemical analyses indicate that all rocks penetrated by the Shell 372-1 well 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.) |
| COST | Continental Offshore Stratigraphic Test |
| DLWD | downhole logging while drilling |
| DST | drill stem test |
| FEL | from east line |
| FSL | from south line |
| FT | formation tester |
| H/C | hydrogen/carbon ratio |
| HEW | hydrocarbon evolution window |
| KB | kelly bushing |
| LS | limestone |
| MD | millidarcies |
| MMS | Minerals Management Service |
| MYBP | million years before the present |
| OCS | Outer Continental Shelf |
| ppg | pounds per gallon |
| ppm | parts per million |
| psi | pounds per square inch |
| PZOF | principal zone of oil formation |
| SFL | spherically focused log |
| SP | spontaneous potential |
| Sw | water saturation |
| 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 |
| $\%R_o$ | vitrinite reflectance |

# INTRODUCTION

A Mesozoic paleoshelf-edge reef trend, extending from Nova Scotia to Florida in the offshore subsurface of eastern North America, has been inferred by several seismic interpreters (Mayhew, 1974; Schlee and others, 1976; Emery and Uchupi, 1984, p. 389 f). According to seismic profiles, the reef, or carbonate buildup, appears to form a raised rim along the seaward edge of a carbonate platform. These units have a northeast-southwest orientation along the oceanward margin of Baltimore Canyon Trough, and the buildup appears to be a discontinuous ridge of variable morphology along trend.

Shell Offshore, Inc., tested the Baltimore Canyon Mesozoic carbonate buildup and associated other facies with three exploratory wells in 1983 and 1984 (see fig. 1). The first drill hole is the Shell 587-1 well, which penetrated the platform-edge carbonate buildup. The second, the Shell 586-1, is about 3 miles shoreward; and the third, the Shell 372-1, is on trend with the 587-1 well and about 22 miles to the northeast, also penetrating the platform-edge buildup. A fourth exploratory well, the Shell 93-1, is almost 50 miles to the southwest of the 587-1 well, but it penetrated an approximately coeval continental clastic section on trend with the carbonate platform and buildup.

Shell established world deepwater drilling records in this four-well exploration program about 90 miles offshore from New Jersey, Delaware, and Maryland. The first record was set while drilling the 587-1 well in 6,448 feet of water, but this depth was exceeded by the 372-1 well (6,952 feet).

Although no commercially significant hydrocarbon shows were encountered in any of the wells, Shell's exploration drilling provided the first samples of the buried carbonate buildup and associated facies units. Among the 3 carbonate drill holes, 11 conventional drill cores were recovered which, together with a large quantity of other data, considerably advance understanding of the Mesozoic western Atlantic carbonate trend and paleoshelf edge.

This report relies on geologic data provided to the Minerals Management Service (MMS) by Shell Offshore, Inc., according to offshore petroleum exploration regulations and lease stipulations. The data were released to the public after Shell relinquished the Wilmington Canyon NJ 18-6 block 372 lease on December 27, 1984. Interpretations of the data contained in this report are those of MMS and may differ from those of Shell Offshore, Inc., and other company participants in the well.

## OPERATIONAL SUMMARY

by

Khaleeq U. Siddiqui

The Wilmington Canyon Shell 372-1 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 Company, Ltd., Japan. It was classified by the American Bureau of Shipping (ABS) as Ice Class 1A A1 AMS E M 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 to 7,500 feet.

The Discoverer Seven Seas was inspected before drilling began, and operations were observed by MMS personnel throughout the drilling period to ensure compliance with Department of 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 material and supplies. Sonat maintained 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 Lease Sale 59, December 8, 1981, and was relinquished December 27, 1984. Well and well drilling information are summarized in table 1. The well's location within the lease block is shown in figure 2.

The Shell 372-1 was part of a four-well program. The other three, the Shell 586-1, 587-1, and 93-1 wells, were drilled in 1983 and 1984 and are shown in figure 1. Drilling stipulations required the operator to provide Minerals Management Service with well logs, drill cuttings, core slabs, geologic information, and operational reports.

### Drilling Program

Shell drilled the 372-1 well to a total depth (TD) of 11,631 feet. All depths in this report are driller's depths and are in feet below kelly bushing (KB) elevation, unless otherwise stated. Drilling rates ranged from 0.75 to 55.8 feet per hour. Maximum borehole deviation from vertical is 3.15 degrees, and deviation is generally less than 2 degrees.

Four strings of casing were set in the well and are diagrammed in figure 3. The 48-inch casing was driven to 7,068 feet. The 30-inch casing was set at 7,245 feet with 720 sacks of cement; the 20-inch casing was set at 9,103 feet with 1,425 sacks of cement; the 13 3/8-inch casing was set at 10,276 feet with 890 sacks of cement. Class H cement was used for all casings.

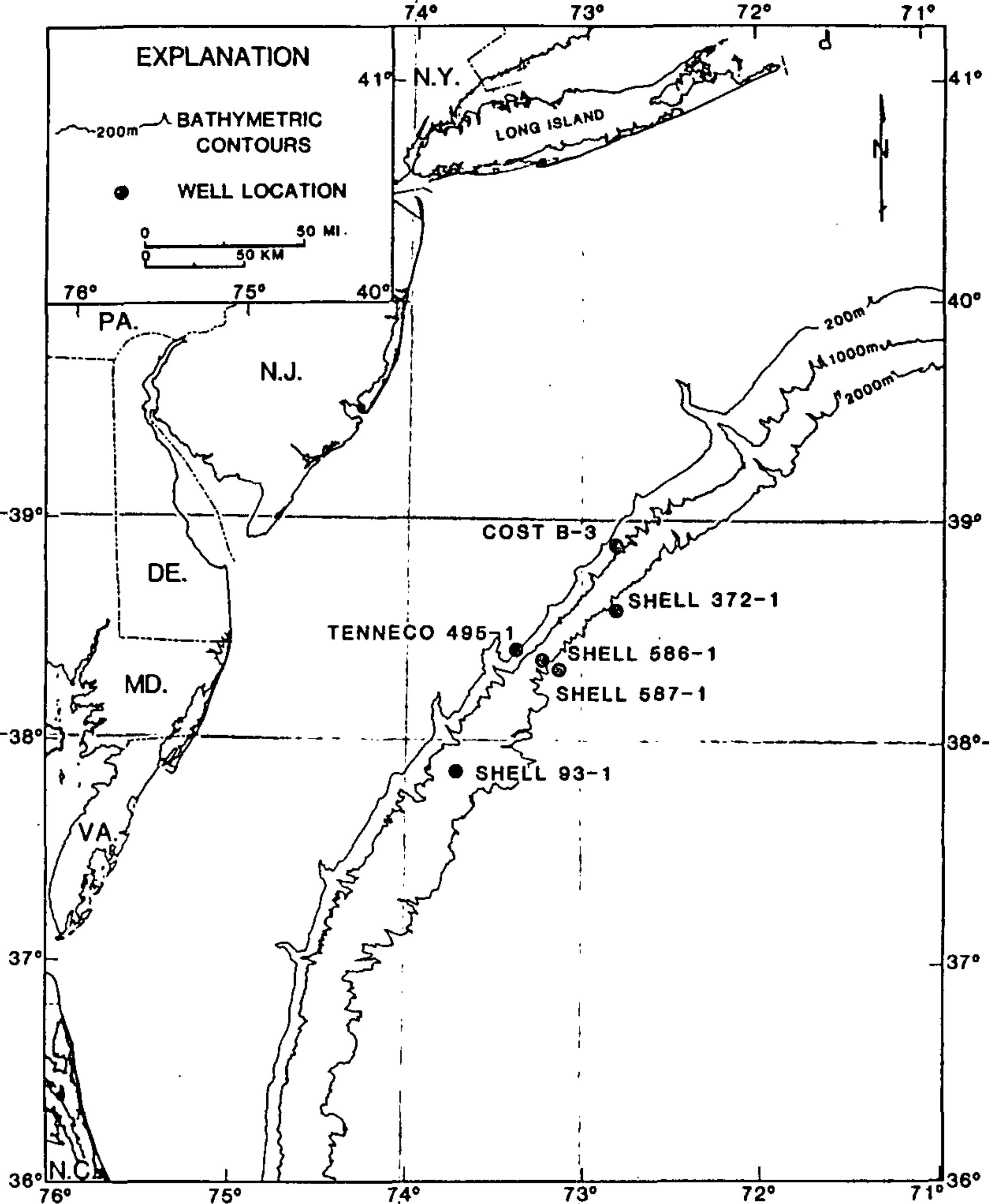


Figure 1.--Location map of a portion of the Mid-Atlantic offshore area showing the location of the Shell Wilmington Canyon 372-1 well and selected other wells.

Table 1.--Shell 372-1 well statistics

| | |
|---|---|
| Well identification | API No. 61-104-00011<br>Lease No. OCS A0317 |
| Surface location | Wilmington Canyon NJ 18-6<br>block 372, 7,774 ft FSL,<br>5,762 ft FEL |
| | Lat.: 38°36'01.182" N.<br>Long.: 72°52'13.825" W. |
| | X = 685,443.67 m<br>Y = 4,274,369.59 m |
| Bottom hole location | Survey not available |
| Proposed total depth | 11,600 ft |
| Driller's total depth | 11,631 ft |
| Actual total depth | 11,650 ft, measured |
| KB elevation | 48 ft above sea level |
| Water depth | 6,952 ft |
| Sea floor | 7,000 ft below KB |
| Spud date | May 26, 1984 |
| Completion date | July 11, 1984 |
| Final well status | Plugged and abandoned |

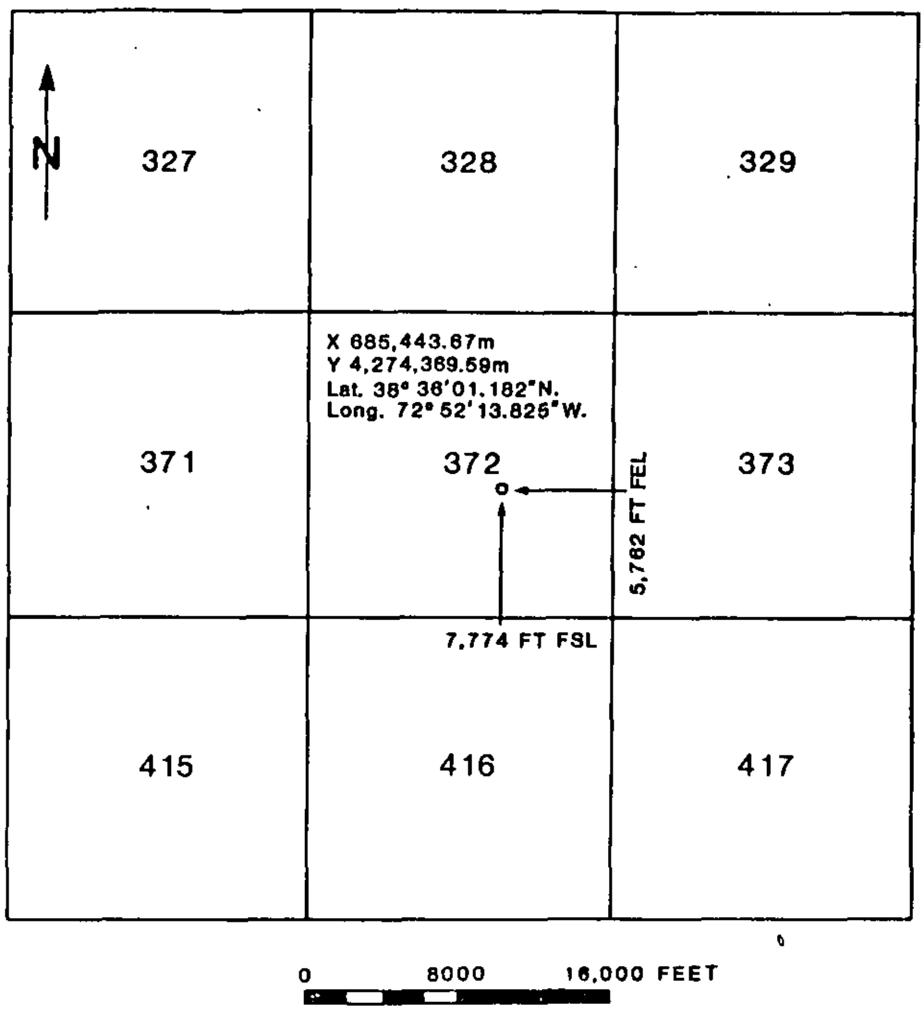


Figure 2.--Location of the Shell 372-1 well in block 372 of the OCS Wilmington Canyon NJ 18-6 protraction diagram.

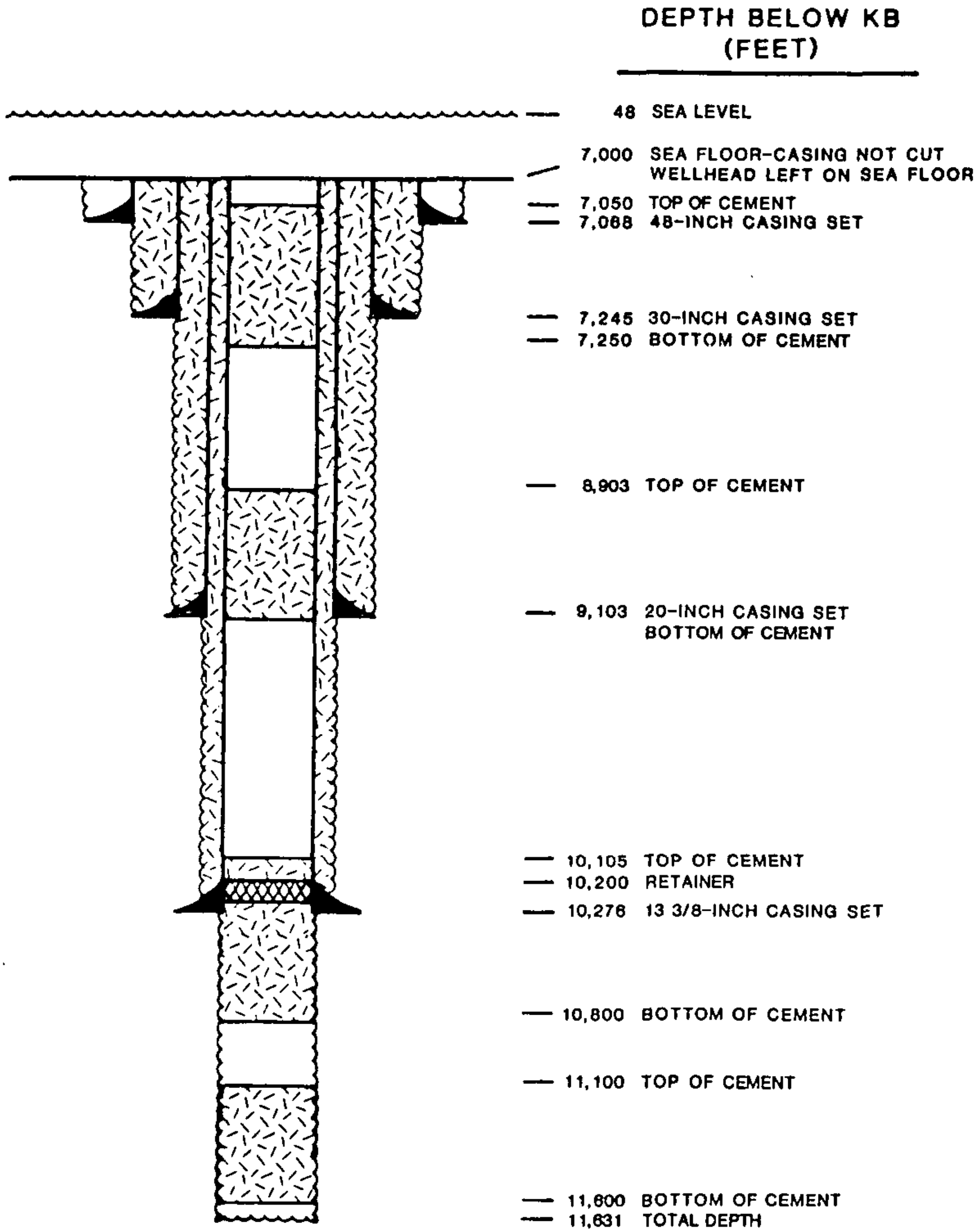


Figure 3.--Casing and abandonment diagram for the Shell 372-1 well.

From May 28 to 30, 1984, drilling was halted at a depth of 7,294 feet to repair leaks in the hydraulic system. From June 18 through 21 at a depth of 10,314 feet, repairs were made to the blowout prevention equipment. Daily drilling progress is shown in figure 4.

The abandonment procedure is also shown in figure 3. Shell plugged back the open hole from 11,600 feet to 11,100 feet with 420 sacks of cement. A cement retainer was set at 10,200 feet, and 460 sacks of cement were squeezed below it to 10,800 feet. Fifty sacks were spotted on top of the retainer with the top of the cement at 10,105 feet. The 13 3/8-inch casing and retainer were tested at a pressure of 1,000 pounds per square inch (psi). A cement plug was set at 9,103 to 8,903 feet with 139 sacks of cement, and the final plug was set at 7,250 to 7,050 feet with 139 sacks. Class H cement was used for all cement plugs. The wellhead, mudmat, guidebase, and four transponders were left on the seabed.

## Mud Program

Seawater and gelled seawater with a weight of 8.9 pounds per gallon (ppg) and a viscosity of 70 seconds were used as drilling fluid to a depth of 7,795 feet. Seawater, gelled freshwater, and Drispac with a weight of 9.7 ppg were used as drilling fluid to a depth of 9,135 feet. Mud weight was reduced to 8.9 ppg at 9,840 feet, reached 9.4 ppg at 11,006 feet, dropped to 9.0 ppg at 11,233 feet, and remained at 9.0 ppg to the bottom of the well. Mud viscosities fluctuated between 70 and 100 seconds in the first 10,314 feet and averaged about 54 seconds for the remainder of the well. Mud pH was about 11 with minor fluctuations. Chloride concentration began at 10,000 parts per million (ppm) increased to 17,500 ppm at 10,619 feet, and dropped to 16,000 ppm at TD.

## Samples and Tests

No drill cuttings samples were obtained until the marine riser was installed at a depth of 9,140 feet. Samples were then collected in 10-foot intervals to TD.

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. | Interval (feet) | Recovery (feet) |
|---|---|---|
| 1 | 10,864 - 10,894 | 30 |
| 2 | 10,975 - 11,006 | 31 |
| 3 | 11,252 - 11,264 | 12 |
| 4 | 11,563 - 11,593 | 21 |

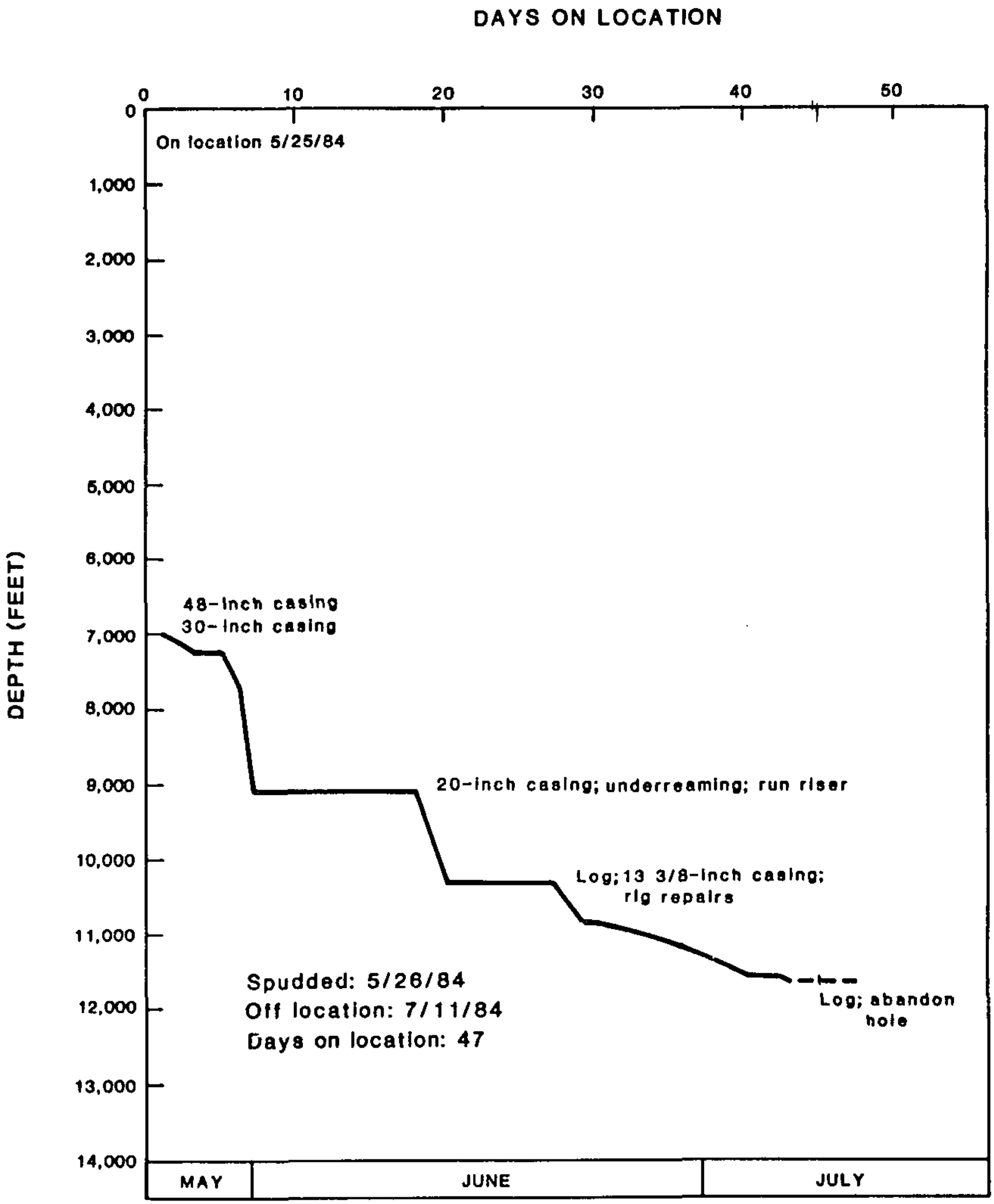


Figure 4.--Daily drilling progress for the Shell 372-1 well.

Seventy-two sidewall core samples were attempted in the interval of 10,930 to 11,552 feet, but only 14 samples were recovered. There were no drill stem tests made in this well. Electric logs were run and are listed and discussed in the Formation Evaluation section (page 29).

## INTERVAL VELOCITY ANALYSIS

by

Fred W. Lishman and Andrew Kopec

An interval velocity profile for the Shell 372-1 well, which was plotted using data from the Schlumberger geophysical airgun report, is shown in figure 5. Two depth zones are identified on the basis of changes in relative interval velocities between 7,302 feet, the shallowest data, and 11,502 feet, the deepest data. These depths are measured from sea level. The relatively low interval velocities of zone 1 are consistent with the predominantly calcareous and silty claystone and shale of the argillaceous facies described in the lithology and petrography section (page ). The high velocities of zone 2 are consistent with the paleo-shelf-edge carbonate facies units (see page 15).

- DEPTH ZONE 1--This section is identified on the basis of relatively low velocities.

| | |
|---|---|
| DEPTH RANGE (feet) | 7,302-10,802 |
| INTERVAL VELOCITY RANGE (feet/second) | 5,554-11,108 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 7,055 |

This zone contains an anomalously high interval velocity from 10,202 to 10,302 feet that may result from a limestone interbed or multiple thin interbeds.

- DEPTH ZONE 2--This section is identified by very high velocities.

| | |
|---|---|
| DEPTH RANGE (feet) | 10,802-11,502 |
| INTERVAL VELOCITY RANGE (feet/second) | 12,496-19,990 |
| AVERAGE INTERVAL VELOCITY (feet/second) | 17,065 |

Within this zone, interval velocities increase in a steplike fashion. From 10,802 to 10,902 feet the interval velocity is 12,496 feet per second; from 10,902 to 11,202 feet, 16,600 feet per second; from 11,202 to 11,502 feet, 19,990 feet per second. In turn, these acoustic velocity intervals may represent the interbedded shale and limestone of the lowermost argillaceous facies, the weathered limestone with shaley interbeds of the paleoshelf-edge carbonate cap, and the less porous and more massive limestone of the paleoshelf-edge carbonate buildup (see pages 13-17).

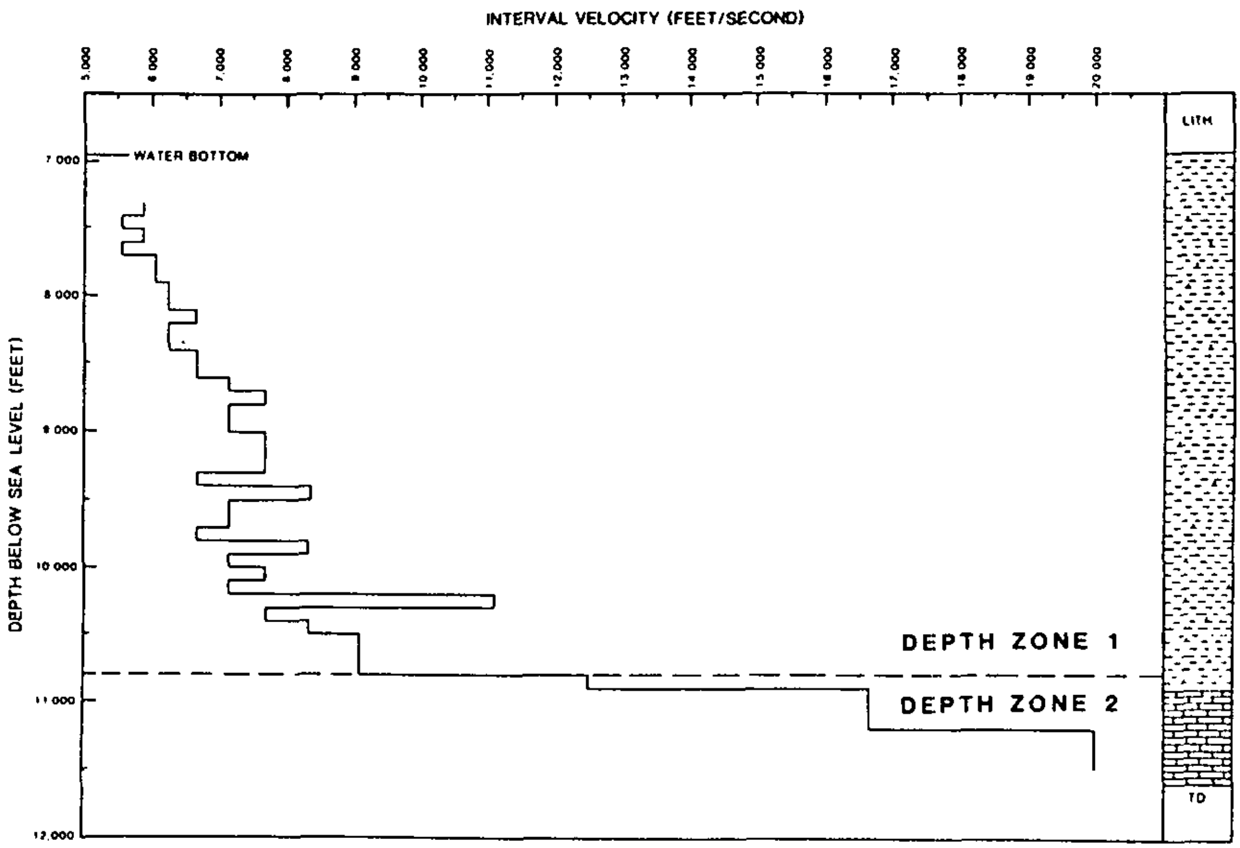


Figure 5.--Interval velocity profile of the Shell 372-1 well, with generalized lithologic column.

## LITHOLOGIC AND PETROGRAPHIC DESCRIPTIONS

by

Gary M. Edson and Donald W. Olson

The Shell Wilmington Canyon 372-1 well penetrated the Lower Cretaceous paleoshelf-edge carbonate buildup at the seaward edge of the Jurassic-lowermost Cretaceous carbonate platform. Correlation with the Shell 586-1 and 587-1 drill holes and integration of seismic analysis have produced the lithofacies framework shown in figure 6. The lithologies of the 372-1 well are grouped into three facies units according to this nonmenclature. A lithologic column is shown in figure 7 (page 20).

Although 4,631 feet of sediment and rock were penetrated by the well, only 2,491 feet of well cuttings were collected, from 9,140 feet to total depth, 11,631 feet. Samples also include four conventional drill cores and thin sections made from the cuttings, core chips, and sidewall cores. Drill cuttings quality ranges from good to very poor. There is apparent mixing of samples from various depths, and some samples consist largely of drilling mud or are heavily contaminated by drilling additives. Well logs were also studied, and for those 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.

### ° Argillaceous Facies (9,140-10,960 feet; Campanian-Albian)

Natural gamma values increase downward through the interval to 10,950 feet from about 30 to 80 API units, and there is an abrupt increase of about 10 units at about 10,350 feet. Within the bottom 30 feet of the interval, resistivity and sonic values increase considerably. In the lowest 10 feet, natural gamma increases considerably.

For most of the interval, lithologic examination is based on well cuttings because sidewall and conventional cores were taken only in the lowermost 90 feet. Cuttings samples consist largely of drilling mud and drilling additives. However, thin sections made from cuttings contain unlaminated silty claystone or marl fragments above 10,350 feet and poorly laminated silty shale or marl below this depth. Cuttings fragments contain abundant foraminifer tests, pelecypod shell fragments, pyrite blebs and fragments, quartz silt, and minute dolomite rhombs. In moderate abundance are inertinite, other organic material, and shreds of muscovite. Minor constituents include glauconite, collophane, and quartz sand grains. The cuttings thin sections also contain a few fragments of foraminiferal packstone. The drill core, 10,864 to 10,894 feet, is dark gray, silty, calcareous, well-laminated shale with thin argillaceous limestone interbeds.

The MMS staff concluded that the overall interval of 9,140 to 10,960 feet consists of variably calcareous, silty claystone (above 10,350 feet) and shale (below 10,350 feet). The more calcareous subintervals grade

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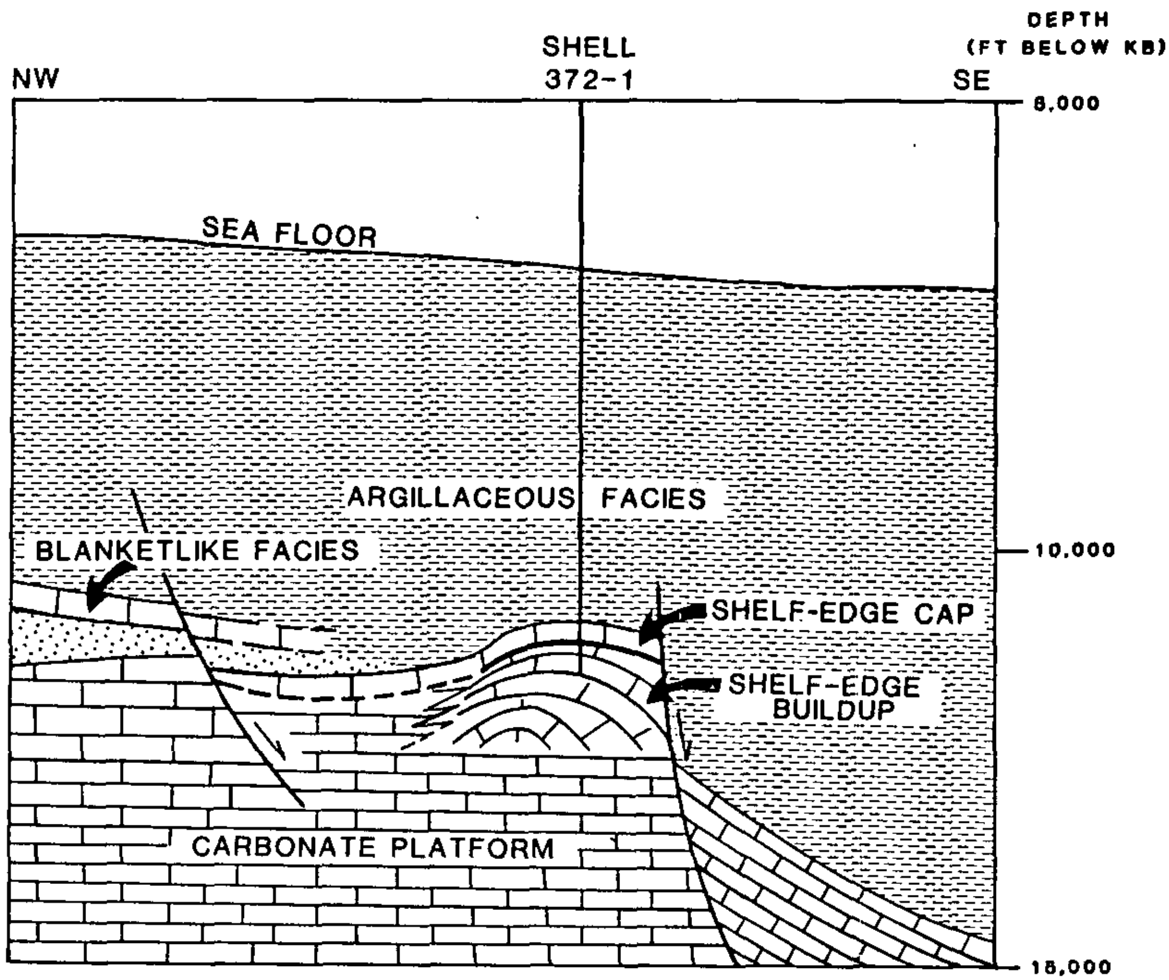



Figure 6.--Diagrammatic cross section through the Shell 372-1 well. Interpretation based on seismic and geologic data. The blanketlike facies and carbonate platform are described in Edson and Carpenter (1986 and 1987).

into argillaceous foraminiferal packstone. According to well logs, there is apparently a 10-foot limestone bed at 10,930 feet. Finally, the operator reported that sidewall cores, at 10,952 feet and 10,956 feet, contain bentonite or montmorillonite that may be altered volcanic ash. This clay bed may account for the high natural gamma log readings within the bottom 10 feet of the argillaceous facies unit.

° Paleoshelf-edge Carbonate Cap Facies (10,960–11,150 feet; Hauterivian)

The rest of the well is in limestone section, which is divided into two facies units: carbonate cap and carbonate buildup. The upper 190 feet are dominated by packstone and wackestone that contain a biotic assemblage distinct from that in the underlying grainstone, packstone, and wackestone. These facies units are seismically distinguishable from one another since the upper unit is bracketed by a pair of strong reflectors. Also, well logs indicate that a 15-foot zone having a high natural gamma response, low resistivity, and low interval transit time separates the limestone units.

The upper facies unit is named the paleoshelf-edge carbonate cap facies because it is relatively thin and appears to mantle the top and shoreward slope of the immediately underlying ridgelike shelf-edge carbonate buildup, according to seismic analysis. According to paleontological analyses (see page 22), the uppermost 16 feet of this facies unit is Albian. However, the 16-foot difference more likely reflects poor stratigraphic control than the presence of a thin Albian component at the top of the cap facies unit. A carbonate cap limestone unit was penetrated in the Shell 587-1 well but was dated as Valanginian (Cousminer and others, 1987). Therefore, the carbonate caps in the 372-1 and 587-1 wells may not be stratigraphically the same, since a unit of this type would probably not be significantly diachronous along depositional strike. However, the cap facies units of the two wells do appear to represent similar depositional environments.

A relatively high natural gamma interval (10,955 to 10,970 feet), indicating up to 150 API units, is at the same horizon as the unconformable contact of the argillaceous facies unit with the cap unit. This high-gamma zone also includes the upper part of the cap unit. Devitrified volcanic ash, reported by the operator in sidewall cores at 10,952 and 10,956 feet, may be the source of the higher natural gamma values and may be incorporated into the upper portion of the cap.

Conventional core No. 2, 10,975 to 11,006 feet, was cut near the top of the cap unit and consists of light to medium gray, dense, granular bioclastic limestone. Most of the core is massive, but about 1 1/2 meters are thinly bedded, and intervals of a few centimeters are dark gray and shaley. Some portions of the core are densely stylolitized.

Thin sections show massive and thinly bedded clastic and bioclastic packstone and wackestone. Clasts are micrite, containing microfossils and fossil fragments and frequently having mottled textures suggestive of blue-green algae. Bioclasts are rounded or angular; some have micritic rinds. Most clasts and bioclasts are sand sized, but others range up to a centimeter or more in diameter. A wide diversity of biota is represented, including abundant hexactinellid siliceous sponges, echinoderms, tubiphytes, ostracods, calpionellids, and foraminifers, including Trocholina, Epistomina, rare Lenticulina, and uniserial, biserial, and triserial arenaceous forms. In moderate abundance are bryozoans, calcareous sponges, brachiopods, and bivalves. Rudists and stromatoporoids are rare. Algae include very abundant blue-green, sparse green, and rare red forms. Flecks and small blebs of pyrite and black organic material are common throughout the core, and there are occasional patches of anhydrite, especially replacing echinoid spines.

In part of the core, there is pervasive recrystallization of micrite clasts and matrix to finely crystalline calcite spar. In areas of coarsely crystalline spar, both fossils and clasts are recrystallized. Interparticle and intraskeletal calcite spar forms anhedral mosaics that are finely crystalline at the margins and coarse in the interiors. Visible porosity is negligible, and petrophysical analysis indicates porosities averaging only 1.4 percent for plugs from core No. 2 (see table 5).

° Paleoshelf-edge Carbonate Buildup Facies (11,150-11,631 feet; Hauterivian)

The carbonate buildup formed a ridgelike limestone rim along the seaward edge of the Jurassic-Cretaceous carbonate platform (fig. 6). According to seismic analysis, the topography and morphology of the rim vary along strike. The Shell 587-1 well penetrated the shelf-edge buildup facies about 21 miles to the southwest, where its upper surface is much flatter (Edson and Carpenter, 1987).

In the Shell 372-1 well, the top of this facies unit is placed at a break in the well logs, where a high natural gamma, low resistivity interval is indicated from 11,150 to 11,165 feet. Six sidewall core samples from within this interval are limestone, some of which is chalky, perhaps indicating a weathered horizon.

Conventional core No. 3 was taken at 11,252 feet to 11,264 feet and core No. 4 at 11,563 feet to 11,593 feet. Both contain massive, bioclastic limestone with little visible porosity except for numerous small calcite-crystal-lined vugs, which are generally developed within large metazoan fossils. Core No. 3 is cream-colored and light gray bioclastic grainstone, packstone, and wackestone with large bioclasts or framework elements having diameters to 5 centimeters. Core No. 4 is light brown limestone with a grainy appearance owing to its grainstone and packstone composition with very coarse sand-sized bioclasts. This core also contains many pieces of metazoan fossils that range to several centimeters in size and that are mostly altered to coarse crystalline spar mosaics. In thin section, recrystallization is extensive, especially in core No. 4. Many bioclasts are replaced by coarsely textured spar mosaics, and some original micritic matrix is now very finely crystalline spar. In addition, interparticle spar consists of very fine crystals around void margins and coarse anhedral mosaics in the interiors. The coarse mosaics are mostly calcite, but also include anhydrite. Flecks of pyrite and organic material are distributed throughout the micritic matrix areas of both cores, and core No. 4 contains a very small amount of glauconite.

The extensive spar replacement of fossils makes biological identification difficult. However, among the smaller bioclasts, echinoderm plates, echinoid spines, and calcareous sponges are abundant. Less numerous are gastropods, brachiopods, and solitary hexacorals. Minor constituents include green algae, bryozoans, rudists, and foraminifers, including Epistomina, Trocholina, and arenaceous forms. In addition, core No. 4 contains abundant tubiphytes and calpionellids. In both cores, many bioclasts have micritic rinds, and in core No. 4 these grain coatings tend to be laminated and to have a sharply defined contact with the enclosed fossil. Thus, the rinds are thought to be accretionary. Also, in both cores, the large bioclasts or reefal framework elements are stromatoporoids and communal corals, many of which have well-developed blue-green algae and foraminiferal crusts. These large fossils are irregularly shaped, from lobate to angular to tabular; the latter are interlaminated with the bioclastic matrix. Finally, core No. 4 contains many stylolites.

Except for the vugs, visible porosity is low in the cores. Intraskeletal and interskeletal porosity were estimated at 2 to 4 percent among thin sections of core No. 3, and less than 2 percent in core No. 4. Petrophysical analysis showed porosities averaging 5.2 percent for core No. 3 and 2.6 percent for core No. 4 (see table 5). All permeability values were considerably less than 1 millidarcy. However, there also appear to be zones of good effective porosity. The well operator reported a drilling break at 11,165 feet, lost circulation at 11,224 feet, and a cavern at 11,233 feet. Minerals Management Service well log analysis also identified zones of porosity in this facies unit (see page 30).

## BIOSTRATIGRAPHY

by

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

Two factors limit the reliability of paleontologic data from exploration 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 so that intervals are not dated older than they really are.

This investigation is based on examination of fossil foraminifers, calcareous nannofossils, dinoflagellates, spores, and pollen by the paleontological staff of the Atlantic Outer Continental Shelf Region Office of the Minerals Management Service. Foraminiferal studies were made from 46 samples representing 30-foot intervals. Nannofossil studies were made from 82 slides from 10- to 40-foot intervals. Palynological analyses were made from 28 slides prepared from 90-foot composite samples. Micropaleontological analyses were based on drill cuttings collected from 9,140 to 11,631 feet (TD). In addition, samples from the four conventional cores were examined.

Age determinations range from Late Cretaceous (Campanian) to Early Cretaceous (Hauterivian). A hiatus between the Albian and Hauterivian at 10,976 feet indicates an unconformity. This well is characterized by sparse faunal and floral assemblages. The Coniacian stage was not recognized. The biostratigraphic chart (fig. 7) shows the highest occurrences of the marker fossils and probable location of the unconformity.

### Late Cretaceous

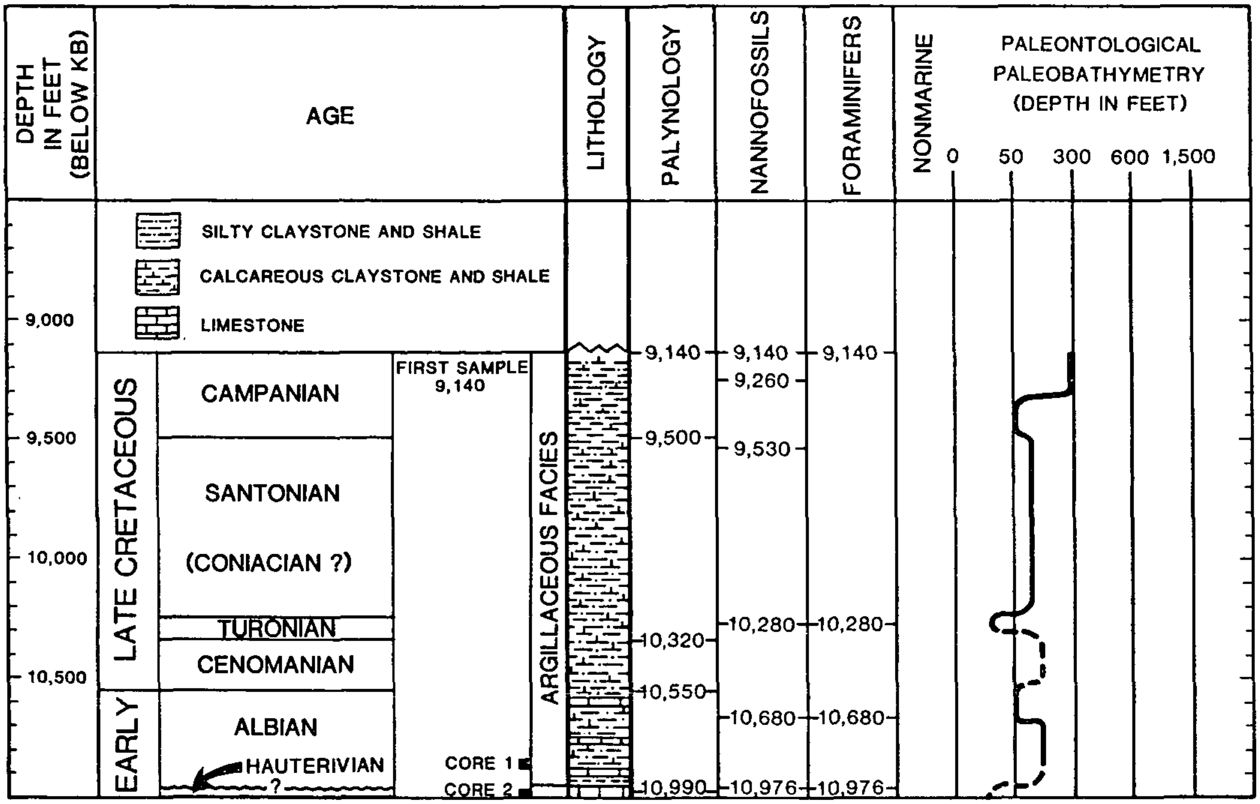
° Campanian (9,140-9,500 feet)

Campanian nannofossil, dinoflagellate, and foraminifer species identified in the first sample at 9,140 feet are *Tetralithus pyramidus*, *Spinidinium echinoidea*, and *Globotruncana stuartiformis*, respectively. The Campanian nannofossil *Eiffellithus eximius* was identified at 9,260 feet.

On the basis of the benthic foraminiferal genera *Gyroidinoides*, *Tritaxia*, *Epistominella*, and *Spirillina*, the upper part of this interval is considered to represent water depths of perhaps 100 to 500 feet and the lower part to represent depths of about 40 to 200 feet.

° Santonian (9,500-10,280 feet)

The upper limit of the Santonian is identified by the presence of the dinoflagellate *Chatangiella tripartita*. The nannofossil *Marthasterites furcatus* is present at 9,530 feet.


DEPTH IN FEET (BELOW KB)
AGE
LITHOLOGY
PALYNOLOGY
NANNOFOSSILS
FORAMINIFERS
NONMARINE
PALEONTOLOGICAL PALEOBATHYMETRY (DEPTH IN FEET)
0
50
300
600
1,500
SILTY CLAYSTONE AND SHALE
CALCAREOUS CLAYSTONE AND SHALE
LIMESTONE
9,000
9,500
10,000
10,500
LATE CRETACEOUS
EARLY
CAMPANIAN
SANTONIAN
(CONIACIAN ?)
TURONIAN
CENOMANIAN
ALBIAN
HAUTERIVIAN
?
FIRST SAMPLE 9,140
CORE 1
CORE 2
ARGILLACEOUS FACIES
9,140
9,500
10,320
10,550
10,990
9,140
9,260
9,530
10,280
10,680
10,976
9,140
10,280
10,680
10,976

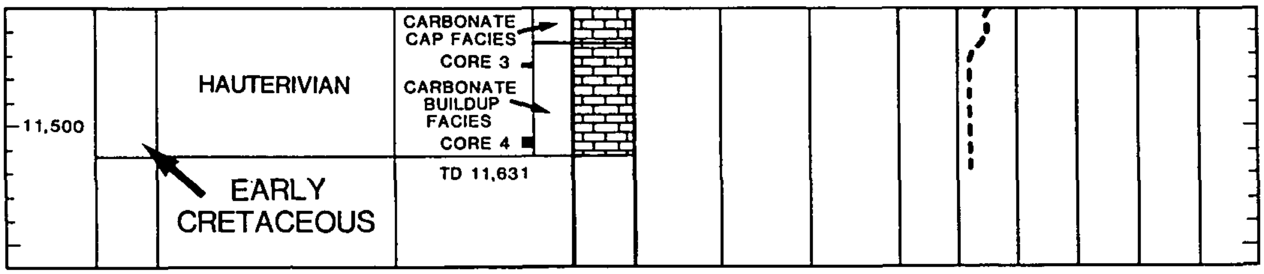



Figure 7.--Lithology, biostratigraphy, and paleobathymetry of the Shell 372-1 well. Lithologic breaks picked from well logs. Age tops based on paleontology. Within palynology, nannofossil, and foraminifer columns, depths refer to uppermost occurrence of index fossils, listed in biostratigraphy section. Paleobathymetric data become less reliable with increasing depth.

A benthic foraminiferal assemblage of Gyroidinoides, Tritaxia, and Lenticulina, with Gyroidinoides occasionally being the dominant form, suggests that this interval represents water depths of 50 to 300 feet, and perhaps occasionally less than 50 feet.

° Turonian (10,280-10,320 feet)

The nannofossil Radiolithus planus and the foraminifer Praeglobotruncana stephanii are present at 10,280 feet.

The foraminifers Heterohelix and Pseudotextularia plexus indicate that this interval represents water depths of less than 50 feet.

° Cenomanian (10,320-10,550 feet)

The highest Cenomanian marker recognized is the dinoflagellate Cribroperidinium orthoceras at 10,320 feet.

The environment of deposition for this interval is questionable but may represent water depths of 50 to 300 feet by the presence of the foraminifers Gavelinella and Gavelinopsis combined with the planktonic foraminiferal genera Pseudotextularia and Heterohelix.

## Early Cretaceous

° Albian (10,550-10,976 feet)

The highest Albian marker that is considered to be in place is the dinoflagellate Astrocysta cretacea. The nannofossil species Braarudosphaera stenorhetha and the foraminiferal species Haplophragmoides sp. "3" of Ascoli (1976) are present at 10,680 feet.

Because of the increase in Lenticulina spp. and the decline of Pseudotextularia and Heterohelix, the upper half of the section may represent water depths of 40 to 200 feet and the lower portion appears to indicate depths of 50 to 300 feet.

° Hauterivian (10,976-11,631 feet, TD)

The highest Hauterivian identification is based on the uppermost appearance of the planktonic foraminiferal species Hedbergella planispira, the benthic foraminifer Lagena hispida, and the nannofossil Nannoconus colomi. The dinoflagellate Oligosphaeridium perforatum is present between 10,990 feet and 11,620 feet. No index fossil "tops" were identified below 10,990 feet. Therefore, it is possible that a portion of this interval may be Valanginian, which would be consistent with the Shell 587-1 well where this age is inferred for the paleoshelf-edge carbonate buildup (Cousminer and others, 1987).

Paleobathymetric interpretations for this interval are uncertain, owing to recrystallization of the limestone and scarcity of diagnostic fossils. Further, fossil evidence is contradictory, such as the Trocholinas and rare hexactinellid fragments, which are generally assumed to indicate very shallow water and deeper water, respectively. However, the grainstone textures and abundant coated grains below 11,150 feet probably reflect fairly high-energy depositional environments. Therefore, perhaps the interval of 11,150 to 11,631 feet represents a very shallow environment, typical of a reefal carbonate platform rim.

## Depositional Environments

by

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

The Shell Wilmington Canyon 372-1 well tested limestones of the Upper Jurassic-Lower Cretaceous paleoshelf-edge carbonate trend. However, only 671 feet of the buried limestone units were penetrated by this well, and the oldest stage reached is the Lower Cretaceous Hauterivian or, possibly, Valanginian.

Three facies units are identified in the well from rock samples, well logs, and seismic profiles. These units are described in the lithology and petrography section (page 13), and a diagrammatic dip cross section is shown in figure 6. Ages of these units are reported in the biostratigraphy section (page 19), and inferred paleobathmetry is shown in figure 7. From bottom to top, the facies units are the paleoshelf-edge carbonate buildup, the paleoshelf-edge carbonate cap, and the argillaceous facies. The environments they represent will be discussed in that order.

### ° Paleoshelf-edge Carbonate Buildup Facies (11,150-11,631 feet; Hauterivian)

The most seaward portion of the Upper Jurassic-lowermost Lower Cretaceous continental shelf consists of a narrow carbonate platform at the seaward margin of Baltimore Canyon Trough (see fig. 6). Minerals Management Service regional seismic studies show that the platform is oriented northeast-southwest, bracketed between the submarine deltaic deposits of the ancient Hudson River to the northeast and the ancient Delaware River to the southwest. The paleoshelf undergoes a landward facies change from platform carbonates to terrigenous clastic basin-fill sediments (Edson and others, 1986). The carbonate platform is the foundation upon which the paleoshelf-edge carbonate buildup accumulated as a discontinous raised rim.

Paleobathymetric analysis of the carbonate buildup is inconclusive because of the near absence of in-place foraminifers, but other paleontological and petrographic evidence suggests shallow-water and relatively high-energy depositional settings. This evidence includes grainstone textures and coated clasts and bioclasts, Epistomina, rudists, stromatoporoids, solitary and communal corals, and blue-green algae and encrusting foraminifers. Trocholina probably indicate low-energy, nearshore brackish water environments. These benthic foraminifers, common in core No. 4, were probably transported seaward during storms and incorporated in the paleoshelf-edge carbonate buildup mostly as coated grains. However, also in core No. 4, indications of a pelagic environment are supplied by calpionellids. The mixture of inferred depositional environments may result from fluctuations in sea level and reworking of the clastic sediments.

Foraminifers and nannofossils are generally in low abundance among drill cuttings throughout the interval. Their scarcity may be due to high biologic density on the paleoshelf-edge rim and consequent high carbon dioxide concentrations in the water column. Microscopic calcareous tests were therefore dissolved unless protected by immediate burial, containment within fecal pellets, or coating by micrite rinds.

Oxidized organic detritus is seen among samples, especially palynology slides, suggesting shallow, high-energy, well-oxygenated environments (and/or postdepositional oxidation from emergence and weathering). Oxidation of the organic matter helps explain the low organic content (see page 39) of these rocks despite the observed abundance of blue-green algae.

The cross sectional shape of the paleoshelf-edge carbonate buildup (see fig. 6) itself suggests a shallow-water reefal or detrital accumulation. This interpretation is confirmed by the presence of bioclastic detritus, grainstones, and coated grains; the environmental affinities of much of the biota; the general absence of microscopic calcareous tests; and the evidence of oxidation. Nevertheless, indications of nearshore shallow and pelagic environments indicate sediment transport, sea level fluctuation, and extensive in-place reworking of detritus.

Although the paleoshelf-edge carbonate buildup appears to be mostly a passive detrital accumulation, it contains large metazoan fossils, some of which are interpreted to be boundstone elements. Large metazoan fossils are especially abundant in core No. 4. Many corals and stromatoporoids, ranging up to 10 centimeters in size, are lobate or irregular in shape and may be clasts. However abundant stromatoporoids with algae and foraminifer crusts indicate bindstone subintervals (Embry and Klovan nomenclature, (1971). It appears that frame-building biotic communities became established on the shelf-edge rim but were soon covered by rapidly accumulating bioclastic debris.

° Paleoshelf-edge Carbonate Cap Facies (10,960-11,150 feet; Hauterivian)

This thin (190 feet thick), seismically, lithologically, and biologically distinct unit forms a cap that drapes over the underlying paleoshelf-edge carbonate buildup. Analysis of seismic profiles indicates that the cap may extend a short distance (a mile or less) landward over the top of the carbonate platform behind the buildup (see fig. 6).

The cap unit in the 372-1 well is bioclastic wackestone and packstone and has finely laminated, shaley subintervals containing bioclasts and micrite clasts, mostly of sand-grain size. Core No. 2 contains abundant hexactinellids, which are generally considered to have deeper water affinity than the reefal fauna of the underlying buildup. Pelagic evidence is again supplied by abundant calpionellids. Foraminifers are plentiful in this interval, including Trocholina, which were likely transported from shoreward, brackish environments. Other marine benthic biota, such as rudists and stromatoporoids which may suggest shallow marine environments, are in low abundance. It is concluded that the paleoshelf-edge carbonate cap represents a deeper environment at deposition than the underlying carbonate buildup unit. The cap appears to have been deposited below wave base (wackestones, packstones) but well within the photic zone (abundant blue-green algae). The shaley subintervals appear to indicate periods of low sedimentation within which periodic storms provided bioclasts and micritic grains.

° Argillaceous Facies (9,140-10,960 feet; Campanian-Aptian)

Paleobathymetric analysis (see fig. 7) indicates fluctuating but deepening marine environments through this interval. The dominance of calcareous and silty claystone and shale lithologies (see page 13) suggest greater water depths.

## Summary

As with other east coast offshore wells, the Shell 372-1 provides data which indicate deepening marine environments in the Cretaceous Period. Although there is evidence of fluctuating sea level, biostratigraphic control is poor in this well, and specific transgressions and regressions are not identifiable. The Aptian-Barremian unconformity, overlying the bentonite(?) subinterval at the top of the paleoshelf-edge carbonate cap (see page 19), may indicate a great drop in sea level. Within the limits of biostratigraphic control, this hiatus may correlate with the Aptian major marine regression documented by Vail and others (1977) and evident in other Baltimore Canyon wells.

## FORMATION EVALUATION[1]

Well ("electric") logs were run in the Shell Wilmington Canyon 372-1 well by Schlumberger Ltd. to provide information for stratigraphic correlation and for evaluation of formation fluids, porosity, and lithology. Table 3 identifies some of these logs.

Table 3.--Wireline logs

| Log type | Depth Interval (ft) |
|---|---|
| Dual-induction spherically focused log (DISFL) | 9,094-11,613 |
| Natural gamma (GR) | 9,094-11,613 |
| Borehole-compensated (BHC) sonic | 9,094-11,613 |
| Compensated neutron log (CNL) | 10,275-11,614 |
| Lithodensity tool (LDT) | 10,275-11,614 |
| Natural gamma spectroscopy (NGT) | 10,275-11,614 |
| High-resolution dipmeter (HDT) | 10,275-11,616 |
| Caliper | 9,094-11,613 |

Exploration Logging, Inc., provided a formation evaluation ("mud") log, which includes lithologic sample descriptions, a rate of penetration curve, and a graphic representation of hydrocarbon shows (9,135-11,586 feet). In addition, a drilling data pressure log, a pressure evaluation log, and a temperature data log were run. Newer and more experimental logging procedures included electromagnetic propagation and downhole logging while drilling (DLWD). The latter was used to provide continuous gamma ray, resistivity, conductivity, and rate of penetration logs from 7,300 feet to total depth while the well was being drilled. The DLWD tool experienced some malfunctioning, and the resistivity and conductivity data are absent for several intervals.



The well logs, together with the mud log and other data, were analyzed to estimate the thickness of potential reservoirs, as well as average indicated porosities and water saturations. These estimates are shown in table 4. No hydrocarbon accumulations are inferred. A combination of logs was used in order to maximize reliability of the conclusions; however, detailed lithologic and petrophysical studies of well cuttings, conventional cores, and sidewall cores are necessary to confirm the estimates made from well logs.

[1] Based on a 1983 Minerals Management Service in-house report by Renny R. Nichols

Table 4.--Well log interpretation

| Depth interval (ft) | Potential reservoir thickness (ft) (a) | Average porosity (%) | Water saturation (Sw, %) |
|---|---|---|---|
| 9,710-9,720 | 10(?) | 35+ | 100 |
| 10,864-10,893 | 29 | 13(?)(b) | 92 |
| 10,989-11,017 | 10(?) | 2(?)(c) | 98 |
| 11,176-11,190 | 14(?) | 4(?)(d) | 77 |
| 11,214-11,225 | 11 | 32(e) | 23(?) |
| 11,252-11,263 | 11 | 4(f) | 55 |
| 11,538-11,562 | 22 | 5(g) | 61 |

a) Generally in beds > 10 feet thick and porosity (Ø) > 5%.
b) Sonic Ø = 35%+ but core No. 1 (10,864-10,984 ft) Ø = 13%.
c) Density Ø = 11%, sonic Ø = 2%, core No. 2 (10,975-11,006 ft) Ø = 1.4%.
d) Density Ø = 9%, sonic Ø = 4%, rate of penetration (11,170-11,190 ft) 12-16 ft/hr.
e) Density Ø = 32%, sonic Ø = 5% but 11,224-11,233 ft (daily drilling report) and 11,214-11,225 ft (DISFL) had complete lost circulation (cavern) and no show.
f) Density Ø = 9%, sonic Ø = 4%, core No. 3 (11,252-11,264) Ø = 5.2%.
g) Density Ø = 8%, sonic Ø = 5%, core No. 4 (11,563-11,593 ft) Ø = 2.6%.

Fourteen sidewall cores were obtained and described by Shell Offshore from depths of 10,952 to 11,551 feet. Two cores, from 10,952 and 10,956 feet, consisted of clay which may be devitrified volcanic ash, according to company reports. The remaining twelve cores are limestone, except one, which is dolomite. Limestone lithologies include grainstones, packtones, and lime mudstones.

Four conventional cores were taken in this well (table 5). Petrophysical laboratory data indicate that limestone porosites are generally very low in the 372-1 well, and petrographic examination of thin sections (see pages 16 and 17) confirms the analyses. However, apparently there are zones of good carbonate porosity. Well log analysis identified the interval of 11,214 to 11,225 feet (see table 4) as being porous, and Shell Offshore reported a drilling break at 11,165 feet, lost circulation at 11,224 feet, and a cavern at 11,233 feet.

Table 5.--Conventional core properties

| Core no. | Depth interval (ft) | Lithology | Porosity(%)(a) low | Porosity(%)(a) high | Porosity(%)(a) mean | Permeability(md)(b) low | Permeability(md)(b) high | Permeability(md)(b) mean |
|---|---|---|---|---|---|---|---|---|
| 1 | 10,864-10,894 | silty shale | 1.6 | 16.4 | 13.1 | 0.022 | 0.54 | 0.19 |
| 2 | 10,975-11,006 | limestone | 0.4 | 2.4 | 1.4 | 0.005 | 2.9 | 0.22 |
| 3 | 11,252-11,264 | limestone | 3.8 | 6.1 | 5.2 | 0.011 | 0.17 | 0.040 |
| 4 | 11,563-11,593 | limestone | 0.8 | 6.2 | 2.6 | <0.01 | 0.13 | <0.02 |

a) Core No. 1, 31 analyses; No. 2, 29 analyses; No. 3, 8 analyses; No. 4, 23 analyses.
b) Data from only nonfractured plugs. Core No. 1, 15 analyses; No. 2, 26 analyses; No. 3, 7 analyses; No. 4, 23 analyses.
Source: porosity and permeability data reported by Shell Offshore, Inc., from core plug petrophysical analyses.

No significant hydrocarbon shows were indicated among well cuttings. Within limestones two units of gas ($C_{1-2}$) were recorded from 11,140 to 11,150 feet and three units ($C_{1-2-3}$) from 11,280 to 11,300 feet. Neither of these shows is appreciably greater than background gas readings.

## OPTICAL KEROGEN ANALYSIS

by

Charles E. Fry

To determine the type and thermal rank of kerogen contained in cuttings samples of the Shell Wilmington Canyon 372-1 well, 26 kerogen and 26 palynology slides were examined with a microscope. 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 Hunt, 1979, and Bayliss, 1980). The percentage of each type present is estimated from the prepared 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. 8; Jones and Edison, 1978). Colors displayed by the organic matter can indicate the degree to which the kerogen has been thermally altered (Staplin, 1969).

Assignment of kerogen types and thermal maturity to correct well intervals depends on recognizing whether material is indigenous to the level sampled. Rock chips caved from higher in the hole, as well as reworked and redeposited older sedimentary components, will give false results. Further, oxidation associated with high-energy depositional environments can alter the appearance of kerogens, leading to incorrect judgments about maturity.

Microscopic interpretations of kerogen type and thermal maturity complement petroleum geochemical analyses (see page 37) in determining the petroleum source rock potential of a well and of specific lithologic intervals.

### Kerogen Types

Within the argillaceous facies of the Shell 372-1 well, 9,140 to 10,960 feet (see page 13), algal kerogen abundance generally averages about 10 percent; herbaceous, about 25 percent; woody, about 35 percent; and coaly, about 30 percent (fig. 9a).

More specifically, from 9,140 to 9,320 feet (Campanian), algal kerogen abundance is 20 percent, herbaceous is 20 percent, woody is 30 percent, and coaly is 30 percent. From 9,320 to 10,320 feet (Campanian through Turonian), kerogens are more terrestrial in composition. Algal kerogen is 10 percent; herbaceous, 25 percent; woody, 35 percent; and coaly, 30 percent. From 10,320 to 10,630 feet (Cenomanian and Albian), algal kerogen ranges from 15 to 25 percent, herbaceous kerogen is 20

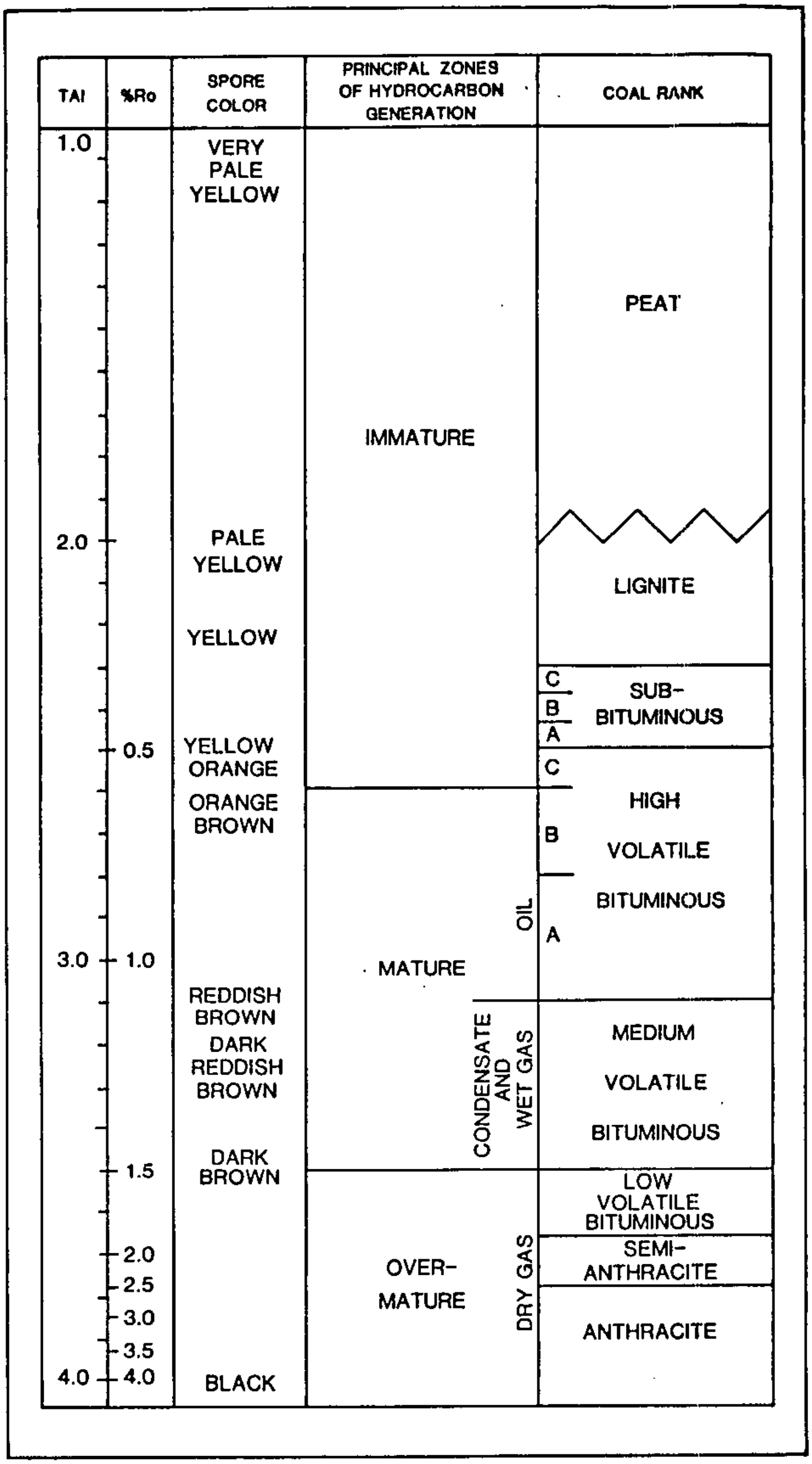



Figure 8.--Relationships among TAI, %Ro, spore color, hydrocarbon generation, and coal rank (after Jones and Edison, 1978).

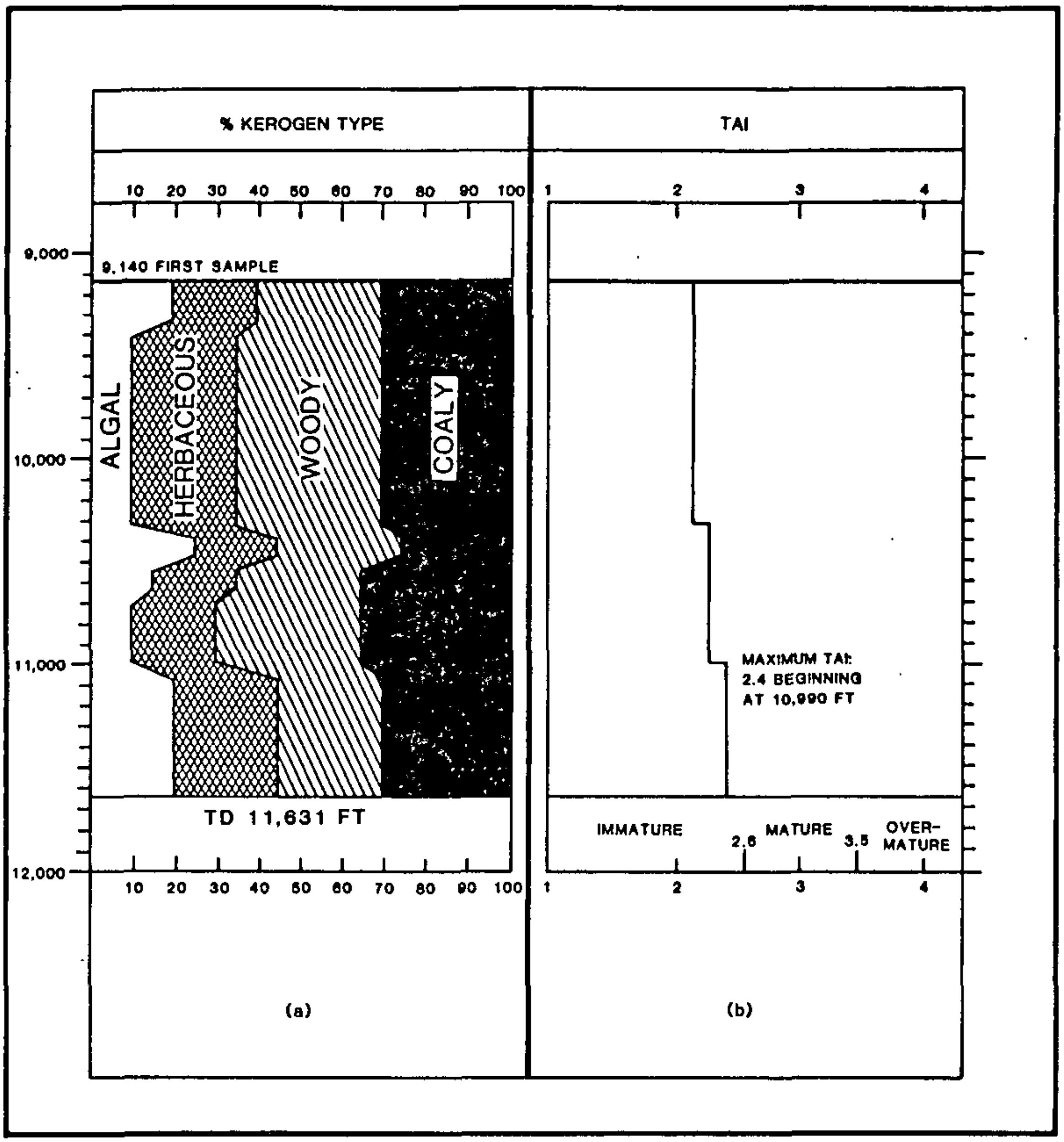



Figure 9.--Kerogen analysis (a) and thermal maturity (b) for the Shell 372-1 well.

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percent, woody kerogen is 30 percent, and coaly kerogen varies from 25 to 35 percent. Slides from 10,630 to 10,990 feet (Albian) display 10 percent algal, 20 percent herbaceous, 35 percent woody, and 35 percent coaly kerogens.

Within the limestone (cap and buildup) facies units, 10,960 to 11,631 feet (TD), algal kerogens are generally more abundant than in the argillaceous facies. The Hauterivian section, from 10,990 to 11,631 feet (TD), contains 20 percent algal kerogen, 25 percent herbaceous kerogen, 25 percent woody kerogen, and 30 percent coaly kerogen. The interval top of 10,990 feet is the upper limit of a sampling interval and is therefore different than the top of the facies unit, 10,960 feet, picked more accurately from well logs.

## Maturity

Only slight changes of palynomorph color were evident from the highest sample, beginning at 9,140 feet, to the total depth of the well. Dinoflagellates are yellow, becoming more orange-yellow with increasing depth, so that indicated TAI values are 2.2 from 9,140 to 10,320 feet, 2.3 from 10,320 to 10,990 feet, and 2.4 from 10,990 to 11,631 feet (TD) (fig. 9b). Although inferred thermal maturity increases with depth, the stratigraphic section penetrated by the Shell 372-1 well appears to be too immature for petroleum generation.

## Discussion

Algal kerogen is present throughout rock units of the well and is most abundant in three intervals: 9,140 to 9,320, 10,320 to 10,630, and 10,990 to 11,631 feet. However, woody and coaly kerogens predominate and are always more than 55 percent of total kerogens present. Therefore, any petroleum source beds would more likely produce gas than oil. Nevertheless, the maximum TAI value of 2.4 indicates that these beds are thermally immature and unlikely to have generated petroleum. The combination of terrestrial kerogens and low maturity values suggests poor source bed potential for rocks penetrated by the Shell 372-1 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 372-1 well that may have potential for generating oil and natural gas, (2) to determine time-temperature-burial depth relationships for the onset of thermal maturation, and (3) to evaluate the influence of any mud additives on source rock measurements.

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

## Analytical Methods and Procedures

The MMS petroleum geochemistry staff analyzed 10 well cuttings samples for their $C_{15}$+ characteristics and 57 gas samples from well depths of 9,140 to 11,631 feet. The unwashed cuttings samples were first analyzed by the "head-space" procedure to determine the concentration of $C_1$ to $C_4$ light hydrocarbons present in one-quart cans, which were 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. Metal fragments, rubber, plastic, fibers, and walnut husks were removed from the cuttings by hand. Gilsonite-like and tarlike substances, reported to be probable mud additives by Shell, were also picked from the samples. The samples were then examined with a binocular microscope. They were then divided into aliquots for gasoline-range hydrocarbon analysis, total organic carbon analyses, Soxhlet solvent extraction and liquid-column chromatography, and high-resolution glass capillary gas chromatographic analyses of the saturated paraffin-naphthene hydrocarbon fractions. Details of these methods and procedures are described in Miller and others (1979, 1980, 1982).



## Results and Discussion

### Source Rock Quality and Type

The source rock potential of the Shell 372-1 well is shown in figure 10, which depicts the richness of source beds penetrated by the well. The argillaceous facies, sampled over the interval of 9,140 to 10,900 feet, has total organic carbon (TOC) values that range from 0.40 to 0.88 weight percent. Such values are in the poor to fair range for claystone and shale

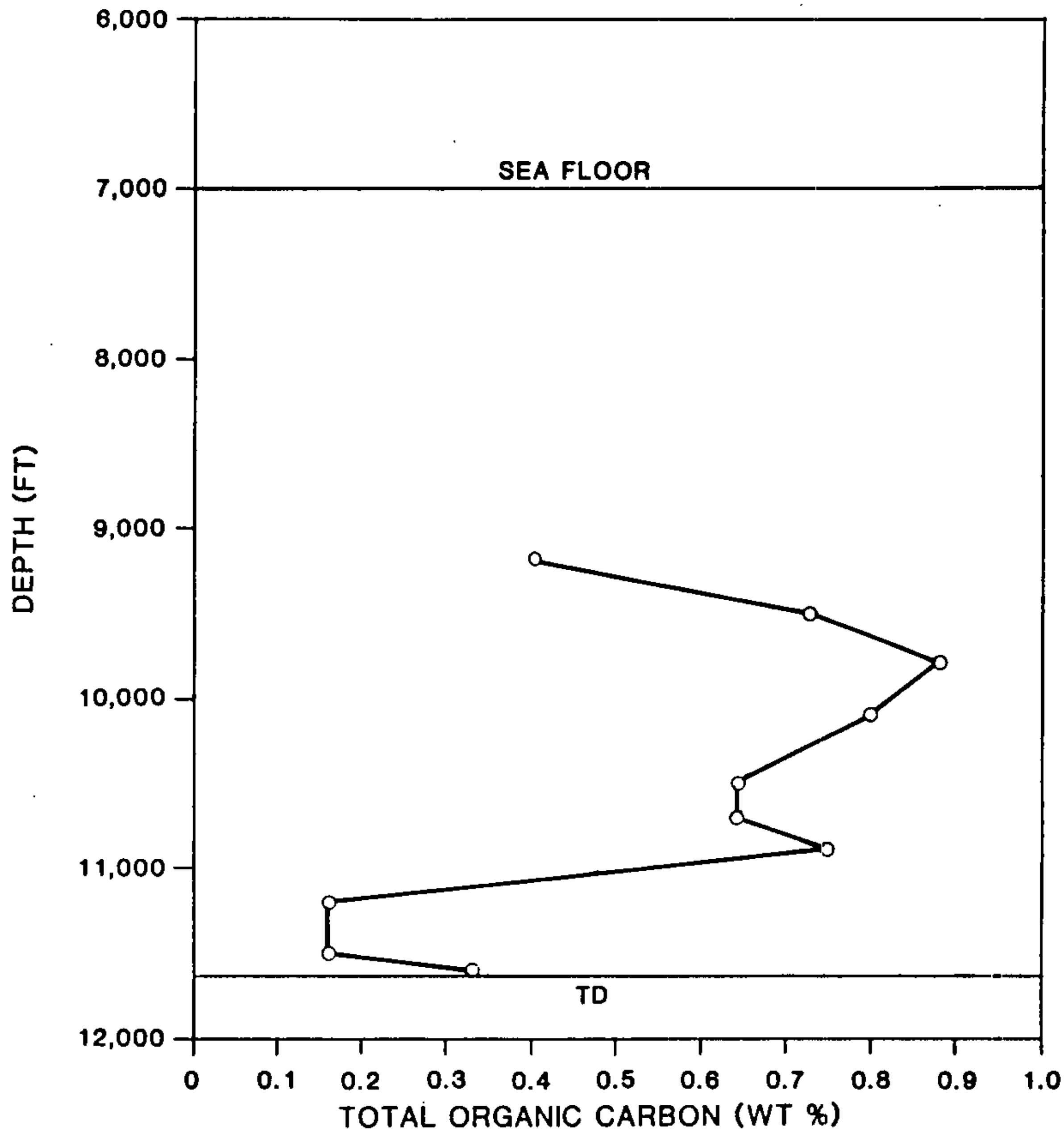


Figure 10.--Total organic carbon content of rocks in the Shell 372-1 well.

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source beds. The limestone interval (cap and buildup facies), sampled at 11,200, 11,500, and 11,600 feet, has TOC concentrations ranging from 0.16 to 0.33 weight percent. Such amounts are in the poor to fair range for carbonate source beds. Among the cuttings samples for the entire well, total extractable hydrocarbons range from 14 to 255 ppm (paraffin-naphthenes range from 10 to 225 ppm and aromatics range from 4 to 30 ppm, table 6) and are also in the poor to fair source rock categories.

Apparently contamination by mud additives is not a significant problem in the Shell 372-1 well. The low extractable hydrocarbon values and their molecular distributions indicate that hydrocarbon contaminants among the cuttings samples were effectively reduced by washing and hand picking. Among the 10 samples analyzed by chromatography, 3 may be faintly contaminated by refined hydrocarbon additives, indicated by slightly elevated saturated paraffin-napthene to total organic carbon ratios (see fig. 12).

Table 6.--Solvent-extractable organic matter from Shell 372-1 well samples

[Results in parts per million (ppm) from Soxhlet solvent extraction and liquid column chromatography. NSO, nitrogen, sulfur, and oxygen compounds.]

| Sample depth (ft) | Total extractable organic matter | Total extractable hydrocarbons | Aromatic hydrocarbons | Paraffin & napthene hydrocarbons | NSO |
|---|---|---|---|---|---|
| 9,200 | 236 | 195 | 10 | 185 | 41 |
| 9,500 | 96 | 37 | 7 | 30 | 59 |
| 9,800 | 81 | 39 | 4 | 35 | 42 |
| 10,100 | 211 | 134 | 24 | 110 | 77 |
| 10,500 | 300 | 255 | 30 | 225 | 45 |
| 10,700 | 105 | 44 | 9 | 35 | 61 |
| 10,900 | 119 | 77 | 7 | 70 | 42 |
| 11,200 | 49 | 14 | 4 | 10 | 35 |
| 11,500 | 62 | 30 | 15 | 15 | 32 |
| 11,600 | 220 | 135 | 20 | 115 | 85 |

## Types of Organic Matter

Organic matter in rocks sampled by the well is predominately of the hydrogen-lean, gas-prone variety. Within the sampled portion of the argillaceous facies, 9,140 to 10,900 feet, hydrogen/carbon (H/C) ratios vary from 0.41 to 1.03 (fig. 11). The largest ratio, from the sample at 10,700 feet, is the only one greater than 0.75. In the three geochemical samples within the carbonate (cap and buildup) facies units, the H/C ratios range from 0.56 to 0.73. Among all samples, molecular gas chromatographic and elemental signatures are consistent and suggest that the organic matter contained in the rocks of this well is mostly of the terrestrial type III variety. These results are also consistent with the light-optical kerogen identifications reported by Fry (see p. 33).

## Thermal Maturity

Molecular geochemical evidence indicates that the entire stratigraphic section penetrated by the Shell 372-1 well is thermally immature for petroleum generation. The hydrocarbon evolution window (HEW) for liquids and condensates is a function of the temperature sensitivity of the ratio of paraffin-naphthene $C_{15}$+ hydrocarbons to total organic carbon. The ratios are very low among all samples analyzed (fig. 12), thereby suggesting that the threshold of intense oil generation (TIOG) occurs considerably deeper than the total depth of the well. The immaturity of the organic matter is also indicated by optical kerogen analysis (see page 36). A maximum TAI value of 2.4 (immature) occurs between 10,990 feet and the bottom of the well.



The depth of thermally mature kerogens can be projected from the estimated geothermal gradient. However, the stratigraphic section penetrated by the Shell 372-1 well is too shallow to establish an adequate thermal gradient from downhole temperature data. Therefore a gradient of 1°F/100 feet is assumed (fig. 12), on the basis of those of the Shell 587-1 and 586-1 wells, which are about 22 miles to the southwest (Miller and others, 1986, 1987). (Relative to the Upper Jurassic-Lower Cretaceous paleoshelf edge, the 587-1 well is on strike with the 372-1, and the 586-1 is about 3 miles shoreward.)

Assuming a geothermal gradient of 1°F/100 feet, the projected TIOG should occur at a sediment burial depth near 9,000 feet or about 16,000 feet below KB. This projected depth far exceeds the bottom of the Shell 372-1 well, which is 11,631 feet below KB. The maximum temperature in the well was recorded as a bottomhole temperature of 100°F.

Geothermal gradients associated with the seaward margin of the Baltimor Canyon Trough are lower than expected. There may be a shoreward progressi of increasing heat flow, illustrated by the Shell 587-1 well (0.97°F/100 feet), the Shell 586-1 well (1.0°F/100 feet), and the Tenneco 495-1 well (1.26°F/100 feet). The COST B-3 well, approximately on strike with the Tenneco well, also has a higher geothermal gradient (1.25°F/100 feet). Regionally, the highest heat flows may be associated with the "transiti crust" between the continental sialic and the oceanic basaltic crusts i the vicinity of the COST B-3 and Tenneco 495-1 wells.

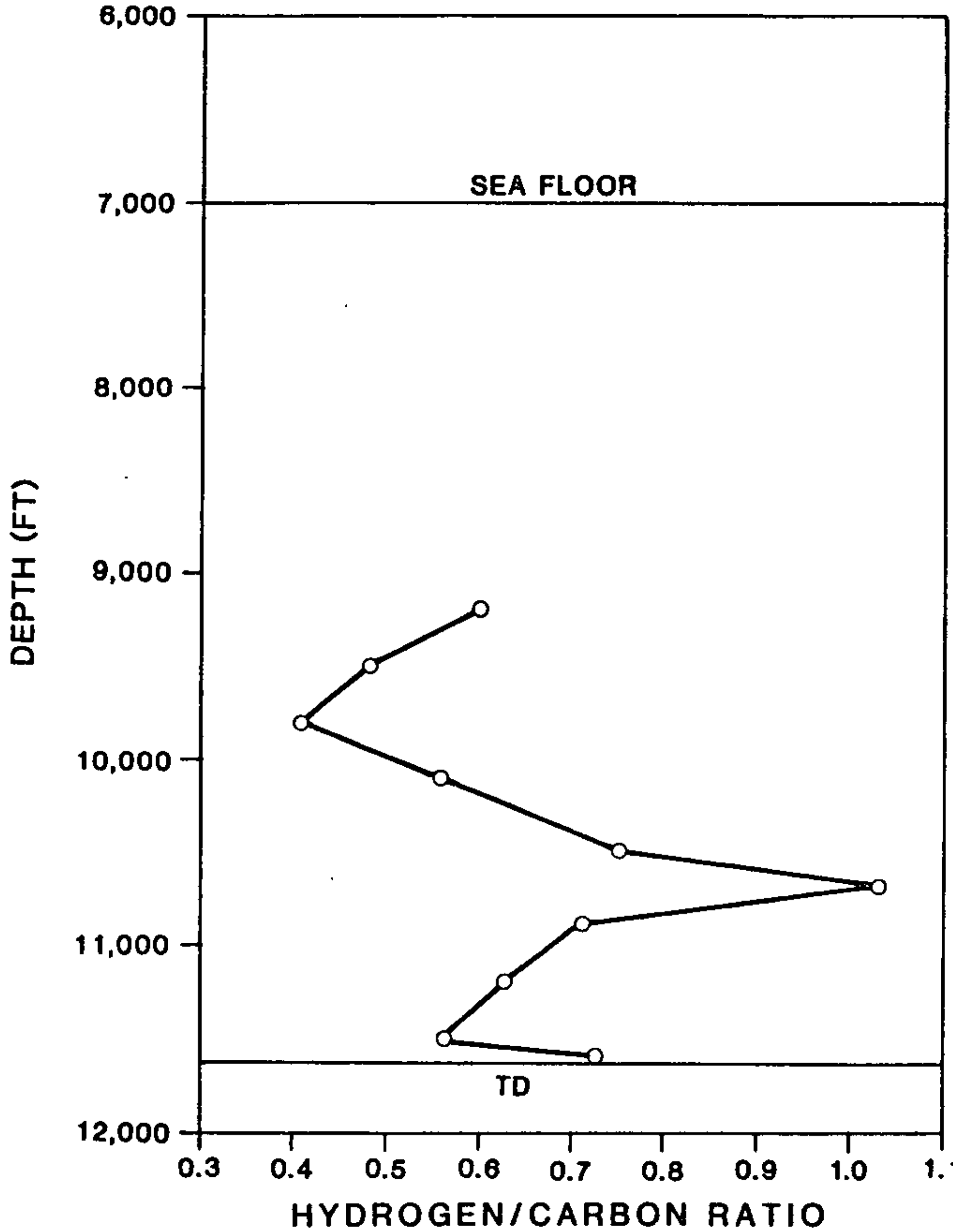


Figure 11.--Hydrogen-to-carbon ratio for organic matter of the Shell 372-1 well.

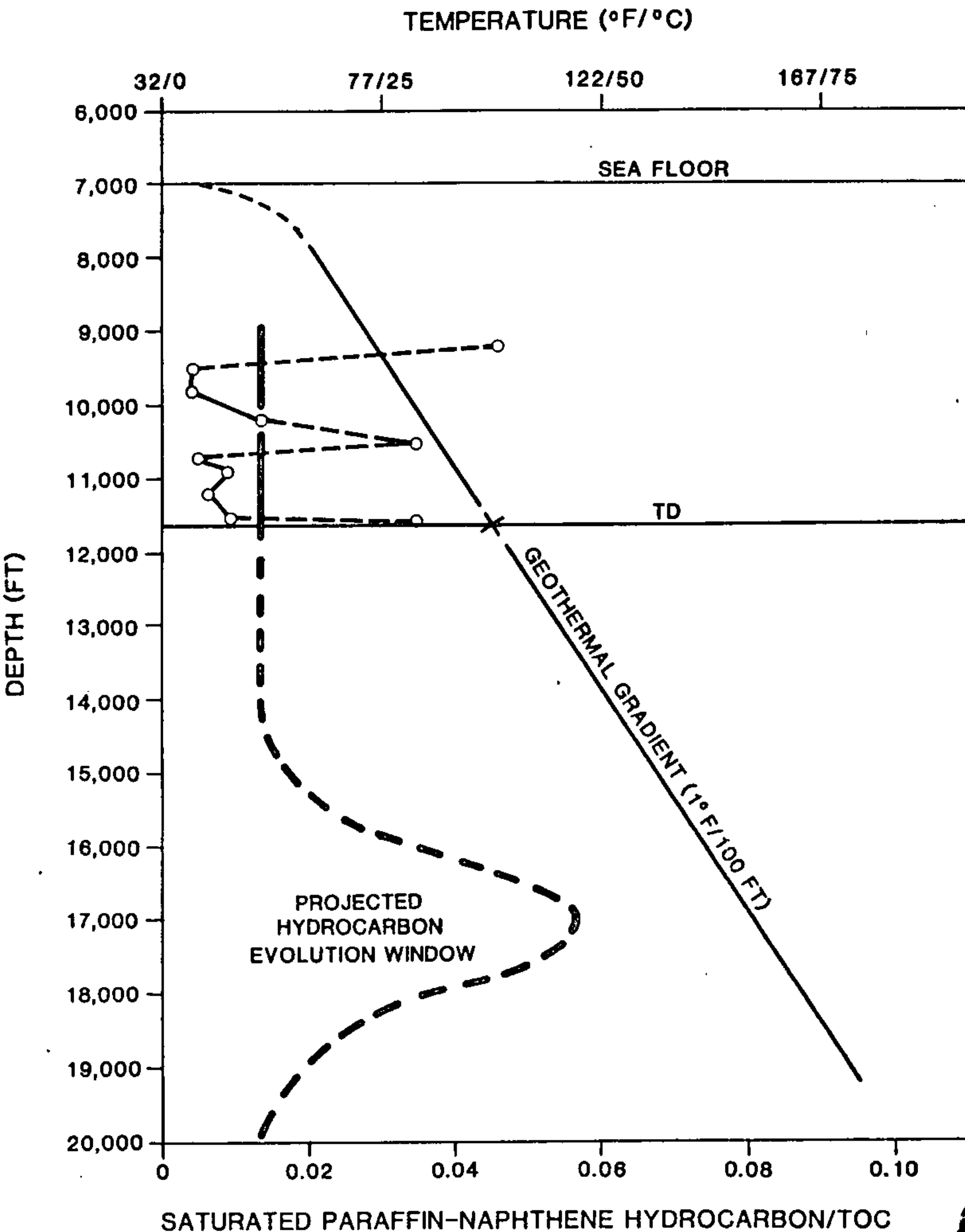


Figure 12.--Projected hydrocarbon evolution window, geothermal gradi and ratio of saturated paraffin-naphthene hydrocarbon-to-t organic carbon for the Shell 372-1 well.

Molecular gases, $C_1$–$C_4$ (methane through butane), analyzed as "headspace" components, average about 1,000 ppm for samples throughout the well section (fig. 13a). Higher concentration values were detected at about 10,000 feet and about 11,300 feet ranging up to 4,400 and 3,500 ppm, respectively. The samples from these two depths can be distinguished from one another on the basis of gas wetness. Gas wetness is defined as the ratio of the ethane, propane, and butane concentration to that of methane in a unit volume of gas. Gas wetness percentages were low (5 percent or less) at 10,000 feet, but at about 10,500 feet they began to increase, reaching 75 percent at 10,900 feet (fig. 13b). The shallower gas occurrence, at 10,000 feet, is believed to be biogenic methane. In the deeper occurrence, at 11,300 feet where the gas wetness is as much as 40 percent, the higher molecular homologs may indicate that petrogenic hydrocarbon gases are forming at greater burial depths and are migrating into the overlying Lower Cretaceous rocks. However, the low total gas concentrations may imply that the more deeply buried possible source beds are of poor quality.

## Time-Temperature-Burial Model

The time-temperature-burial model for the sedimentary section penetrated by the Shell 372-1 well (fig. 14) is based on the biostratigraphic determinations of the Minerals Management Service paleontological staff (see page 19), the Cretaceous time scale of Van Hinte (1976), and an assumed geothermal gradient of 1°F/100 feet. This gradient is also assumed to have been relatively constant for the last 140 million years. On the basis of chemical kinetics concepts that predict thermal generation of hydrocarbons from kerogen and the principal phase of oil generation within the temperature range of 50°C and 110°C, it is clear that the Lower Cretaceous section of the Shell 372-1 well has not approached the TIOG.

The time-temperature-burial profile also indicates uniform basinal subsidence and sediment accumulation through most of the Cretaceous Period represented by the sampled section of the well. However, increased subsidence and sedimentation are evident from 86 to 78 million years before the present (Coniacian-Santonian). This increase is also indicated by the Shell 587-1 time-temperature-burial model (Miller and others, 1987).

The time-temperature-burial history of the Shell 372-1 well indicates a fairly constant rate of burial and moderate-to-low subsidence. These factors, coupled with low heat flow, suggest poor petroleum source potential. However, Shell tested only the carbonate cap and the uppermost portion of the carbonate buildup within this shallow well. The underlying thick Valanginian section, penetrated in the Shell 586-1 and 587-1 wells (Miller and others, 1986, 1987), reflects much greater rates of sedimentation and subsidence in addition to somewhat higher temperatures. In general, the stratigraphic section deeper than that sampled by the 372-1 well may have somewhat better petroleum source rock potential.

If kerogen types and concentrations are adequate, heat flow is the major factor in determining source potential for offshore United States Atlantic basins (in addition to timing of burial, reservoir formation, and

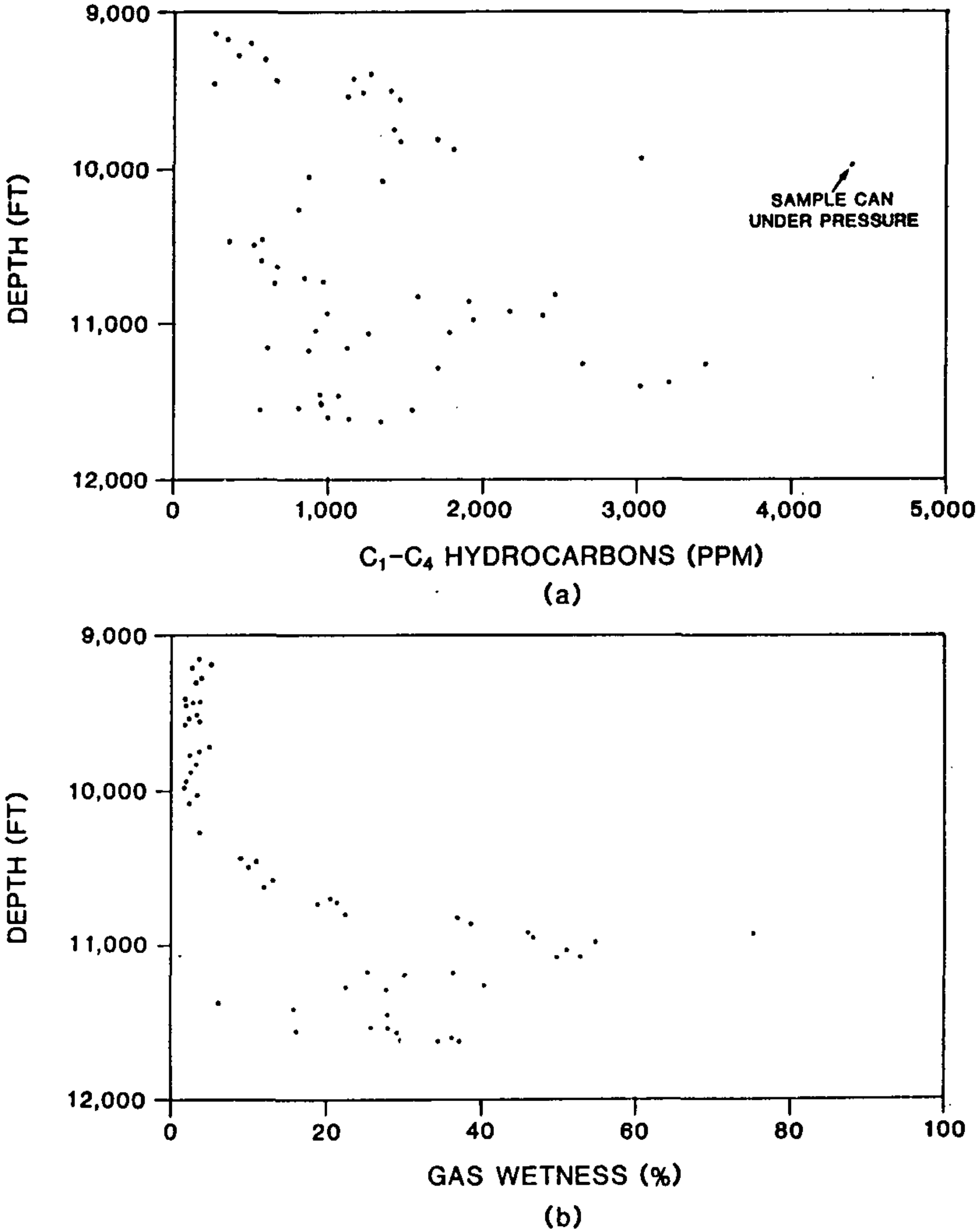


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Figure 13.--Total $C_1$-$C_4$ hydrocarbons (a) and gas wetness (b) of samples from the Shell 372-1 well.

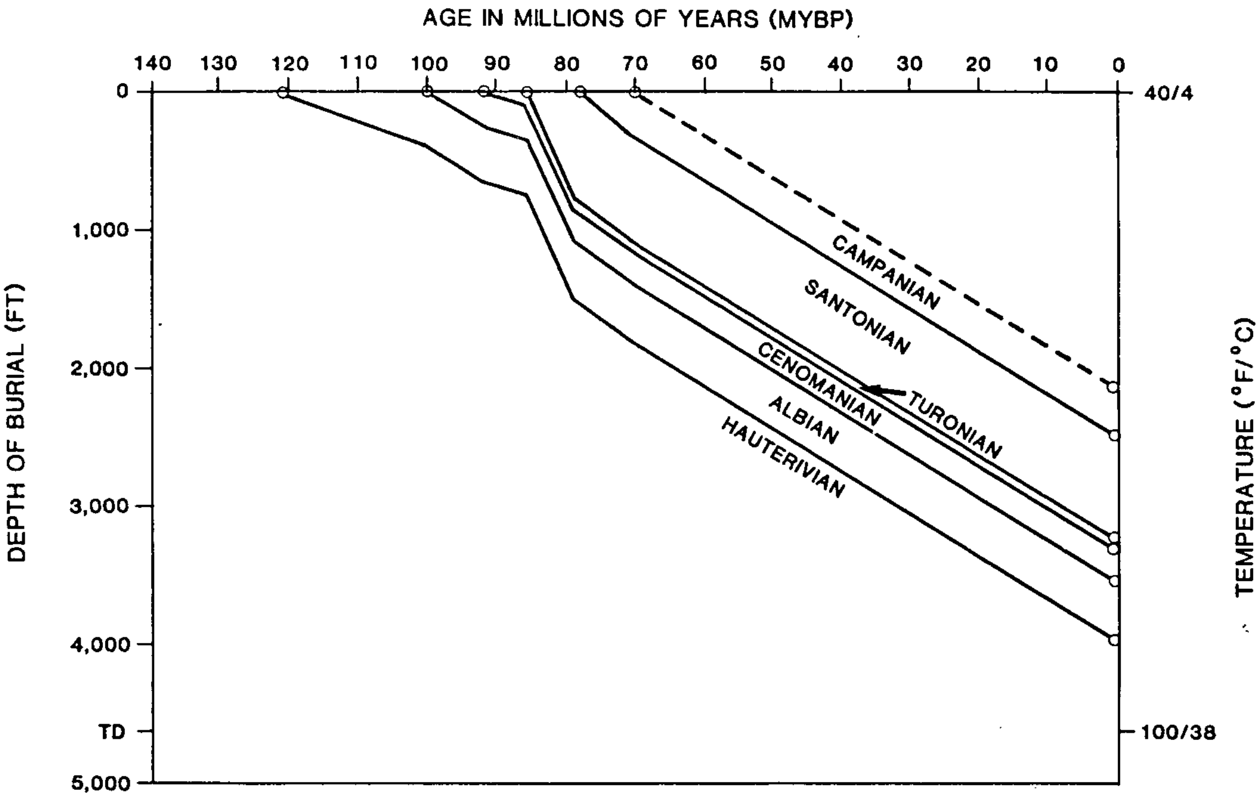


Figure 14.--Time-temperature-burial profile for the Shell 372-1 well. Age scale is from Van Hinte (1976).

petroleum generation, and migration). Proximity to heat sources, such as igneous bodies, is an important exploration consideration. Further, the "transition crust" between the continental sialic and oceanic basaltic crusts, which may be associated with the East Coast Magnetic Anomaly, may be the zone of highest heat flow. Within this zone, Jurassic and Lower Cretaceous sediments may have their highest thermal maturities in an otherwise cool passive margin.

The petroleum source rock potential of the Upper Jurassic-Lower Cretaceous carbonate paleoshelf edge appears to be poor in the vicinity of Shell's three-well carbonate exploration program. However, the reservoir potential is good. Therefore, future Mesozoic carbonate exploration in the Atlantic will probably concentrate on areas of higher heat flow, as well as areas where possible rich organic beds are adjacent to the carbonate trend.

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