OCS Report
MMS 87-0074

Shell Wilmington Canyon 587-1 Well

Geological & Operational Summary

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

1987

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ABSTRACT

The Shell Wilmington Canyon 587-1 well, in southeast Baltimore Canyon Trough, is about 90 miles offshore from southern New Jersey. The well, spudded on August 2 and completed on December 26, 1983, was drilled by the Discoverer Seven Seas drillship in 6,448 feet of water. Total depth of the well is 14,500 feet (below kelly bushing), and 8,004 feet of sediments and rock were penetrated beneath the sea floor.

Standard well logs were run, together with downhole while drilling and electromagnetic propagation logs. Cuttings samples were collected from 8,550 feet to the bottom of the drill hole. Two hundred and twenty-nine sidewall cores were obtained, and three conventional drill cores were cut in limestone intervals of the well.

The section penetrated by the 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 shelf-edge limestone cap, a shelf-edge limestone buildup, 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 shales and carbonate rocks, and kerogens are mostly terrigenous, gas-prone types.

Light-optical thermal alteration index values suggest borderline to fair maturity among Jurassic platform carbonates below 12,850 feet. However, petroleum geochemical analyses indicate that all rocks penetrated by the Shell 587-1 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
DST	drill stem test
FNL	from north line
FSL	from south line
FT	formation tester
FWL	from west line
H/C	hydrogen/carbon ratio
HEW	hydrocarbon evolution window
KB	kelly bushing
LS	limestone
MD	millidarcies
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
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 western Atlantic subsurface, 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 at 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 exploration well, the Shell 93-1, is almost 50 miles to the southwest of the 587-1 well, but it penetrated a continental clastic section that is approximately coeval and 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, Shell's exploration drilling provided the first samples of the buried carbonate buildup and associated other 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 by Shell Offshore, Inc., acccording 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 587 lease on December 27, 1984. Interpretations of the data contained in this report are those of the Minerals Management Service and may differ from those of Shell Offshore, Inc., and other company participants in the well.

OPERATIONAL SUMMARY

by

Khaleeq U. Siddiqui

The Shell Wilmington Canyon 587-1 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, and 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 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 Lease Sale 59, December 7, 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. The Shell 587-1 was part of a four-well program. The other three, the Shell 586-1, 372-1, 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, lithologic samples, core slabs, geologic information, and operational reports.

Drilling Program

Shell drilled the 587-1 well to a total depth (TD) of 14,500 feet. All depths in this report are in feet below kelly bushing (KB) elevation, unless otherwise stated. Drilling rates ranged from 0.2 to 46 feet per hour. Maximum borehole deviation from vertical is less than one degree.

Four strings of casing were set in the well, as shown in figure 3. The 48-inch casing was driven to 6,566 feet. The 30-inch casing was set at 6,752 feet with 720 sacks of cement; the 20-inch casing was set at 8,488 feet with 2,020 sacks of cement; the 13 3/8-inch casing was set at 10,746 feet with 925 sacks of cement. Class H cement was used for all casings.

At a depth of 8,550 feet, drilling was temporarily halted because of malfunctioning equipment. Overall, 22 days were spent for reparing the

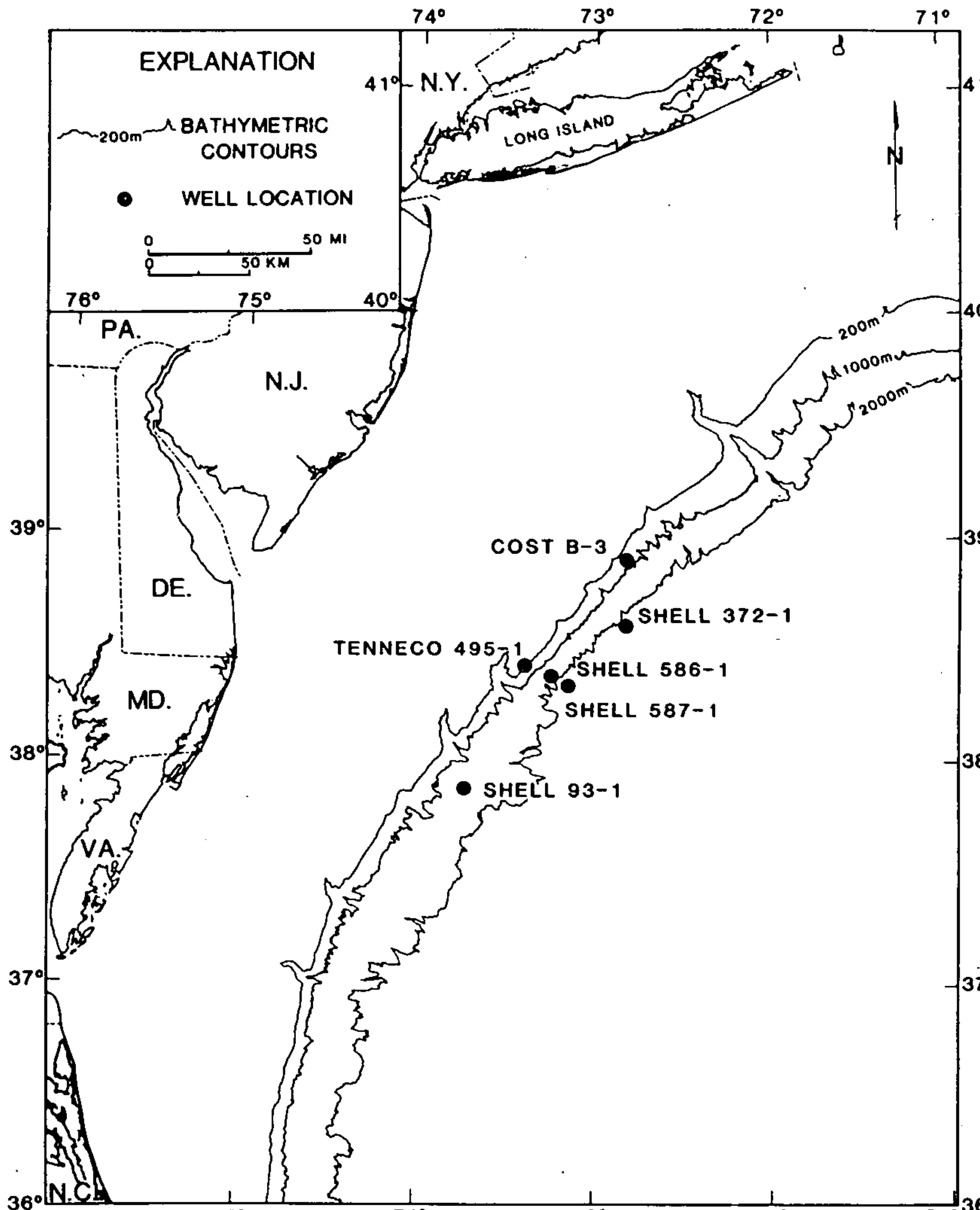


Figure 1.--Location map of a portion of the Mid-Atlantic offshore area showing the location of the Shell Wilmington Canyon 587-1 well and selected other wells.

Table 1.--Shell 587-1 well statistics

Well identification	API No. 61-104-00009 Lease No. OCS-A-0337
Surface location	Wilmington Canyon NJ 18-6 block 587, 4,921 ft FSL, 6,334 ft FWL Lat.: 38°22'52.327" N. Long.: 73°09'51.954" W. X = 660,330.59 m Y = 4,249,499.87 m
Bottom hole location	15.5 ft S.25°06'W. of surface location
Proposed total depth	14,500 ft
Driller's total depth	14,500 ft
Actual total depth	14,470 ft, measured
KB elevation	48 ft above sea level
Water depth	6,448 ft (6,496 below KB)
Spud date	August 2, 1983
Completion date	December 26, 1983
Final well status	Plugged and abandoned

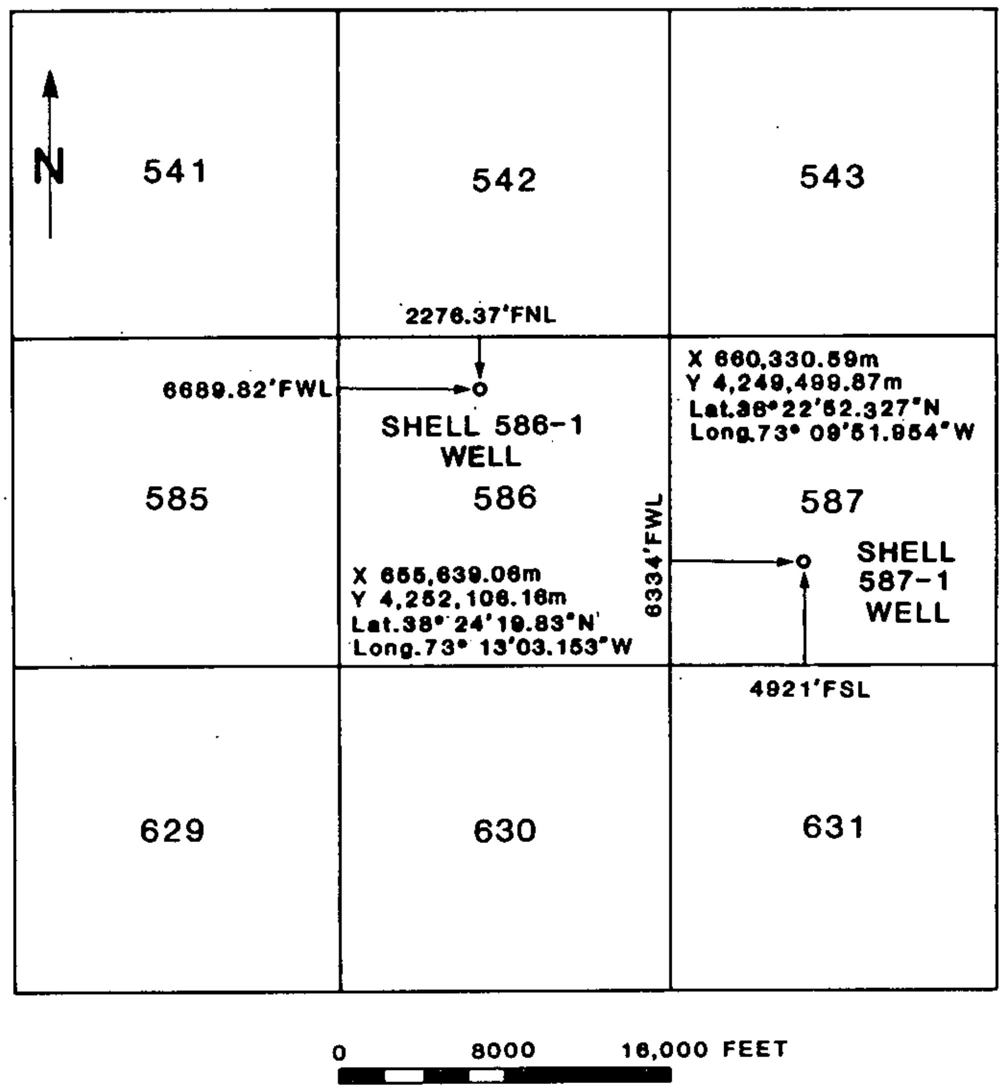


Figure 2.--Locations of the Shell 587-1 and 586-1 wells on OCS Wilmington Canyon NJ 18-6 protraction diagram.

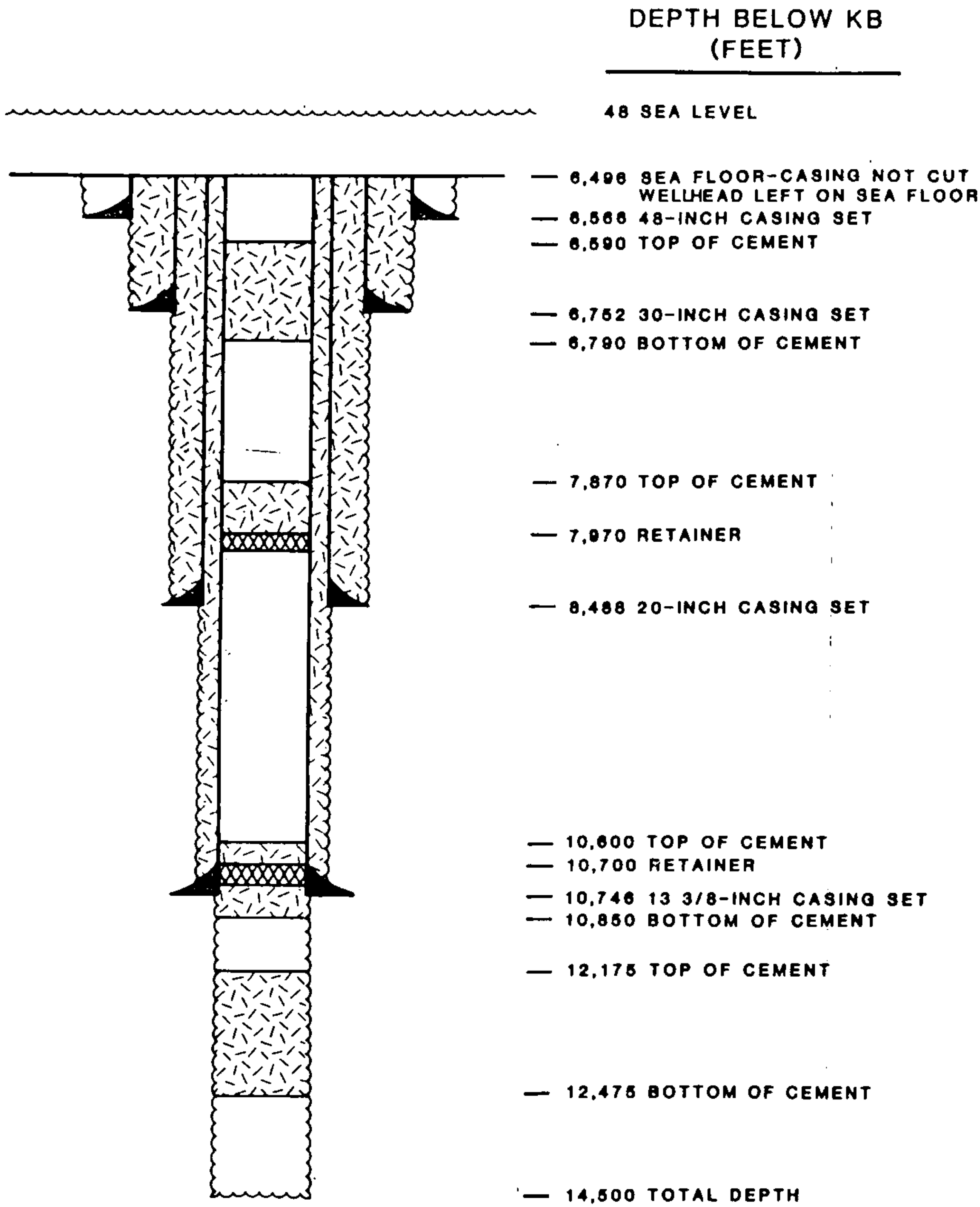


Figure 3.--Casing and abandonment program for the Shell 587-1 well.

following systems: blowout preventers, motion compensator, tensioners, multiplex electrohydraulic system, subsea television, and remote-operated vehicle. Drilling was also discontinued September 29 and 30, November 16 and 17, and December 25 and 26, 1983, because of bad weather conditions. Daily drilling progress is shown in figure 4.

The abandonment procedure is also shown in figure 3. Shell plugged back the well by setting a cement plug from 12,475 feet to 12,175 feet with 210 sacks of cement. A cement retainer, with 75 sacks of cement above and 110 sacks of cement squeezed below the retainer, was set at 10,700 feet. This plug was tested at 1,000 pounds per square inch (psi). A cement retainer was set at 7,970 feet. Cement could not be squeezed below the retainer, and 50 sacks were pumped on top of it. This plug was also tested at 1,000 psi. A cement plug was set from 6,790 to 6,590 feet with 140 sacks of cement. Several pieces of equipment--including drill pipe, pieces of "hang off" clamp, a beacon, and a transponder--were lost during operations and were abandoned on the sea floor.

Mud Program

Seawater and seawater gel with an average weight of 9.3 pounds per gallon (ppg) and an average viscosity of 80 seconds were used as drilling fluid to a depth of 8,550 feet. Seawater and freshwater gel with Drispac, having an average weight of 9 ppg and viscosity of 45 seconds, were used as drilling fluid to a depth of 10,780 feet. Mud weight was increased to 9.6 ppg at 10,945 feet, reached 9.7 ppg at 11,581 feet, and then dropped to 9.4 ppg at 14,084 feet and remained at that weight to the total depth of the well. The viscosity of the mud fluctuated between 45 and 120 seconds in the first 8,550 feet and averaged about 53 seconds for the remainder of the well. Mud pH averaged 11.5 with minor fluctuation. Chloride concentrations began at 12,000 parts per million (ppm), increased to 15,000 ppm at 10,460 feet, and dropped to 13,000 ppm at TD.

Samples and Tests

Three 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	11,012-11,042	30
2	11,551-11,581	14
3	14,470-14,500	27

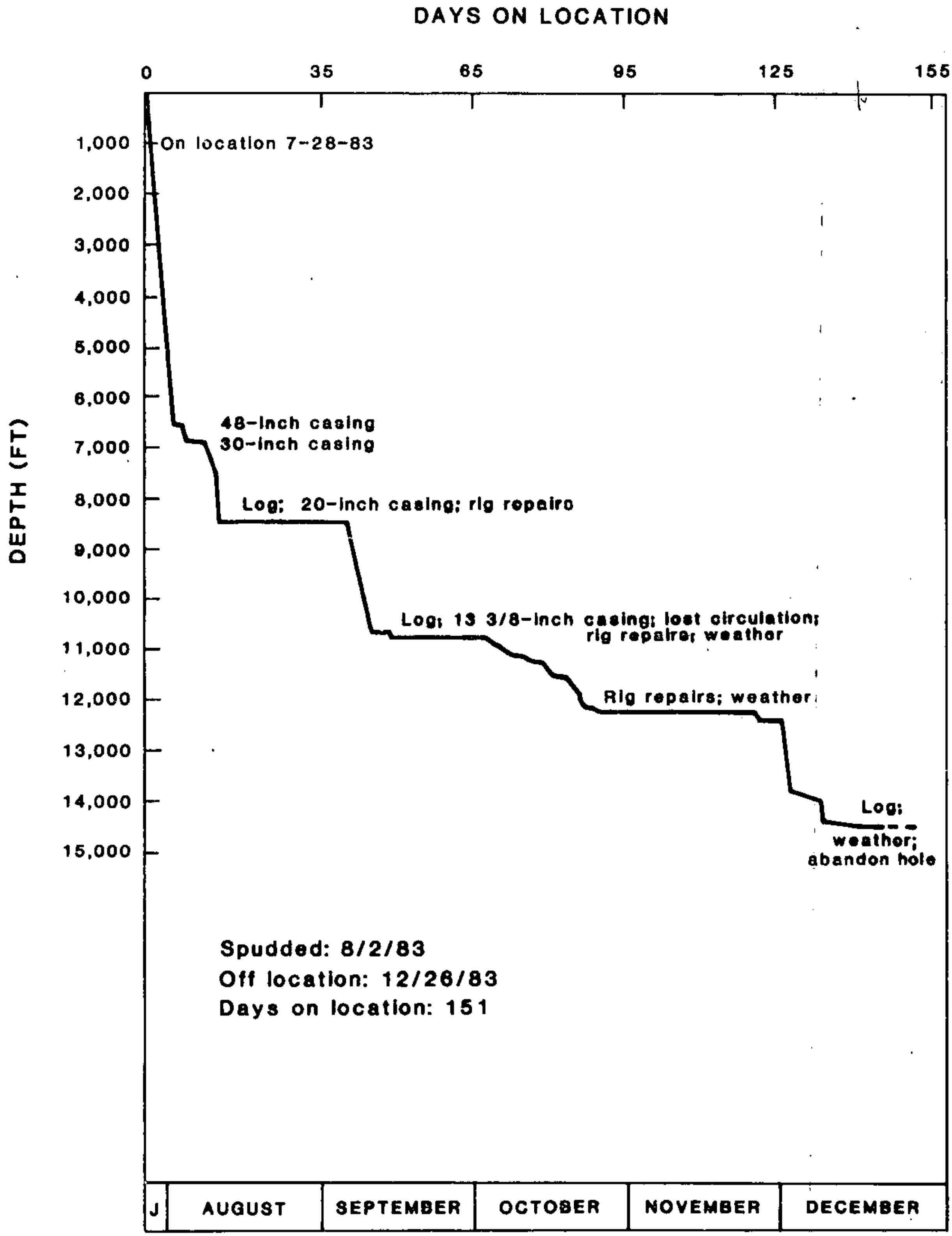


Figure 4.--Daily drilling progress for the Shell 587-1 well.

Of the 387 sidewall cores attempted, 229 were recovered. There were no drill stem tests made in this well. Well logs were run and are listed and discussed in the Formation Evaluation section of this report.

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 587-1 well. The WST verifies the 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 the sea floor (6,448 feet below sea level) and the deepest data, 14,412 feet (below sea level), two intervals are identified on the basis of relative interval velocities. The lower velocities of interval 1 are consistent with noncarbonate clastic lithologies, and the higher velocities of interval 2 suggest carbonates. These two depth intervals and their inferred lithologies generally agree with the lithology log.

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

DEPTH RANGE (feet)		6,448-10,951
INTERVAL VELOCITY RANGE	(feet/second)	5,040-9,618
AVERAGE INTERVAL VELOCITY	(feet/second)	6,790

These velocities suggest noncarbonate clastic lithologies with shale predominating.

- Interval 2 -- This section is identified on the basis of an abrupt velocity increase.

DEPTH RANGE (feet)		10,951-14,412
INTERVAL VELOCITY RANGE	(feet/second)	11,955-21,130
AVERAGE INTERVAL VELOCITY	(feet/second)	16,032

The high velocities of interval 2 suggest predominantly carbonate material. However, large variations among the velocities suggest interbedded lithologies, such as shale interbeds within limestone (see the lithology and petrology section, p. 13). The velocity increase from interval 1 to interval 2 is explained by shale overlying the paleoshelf-edge carbonate trend.

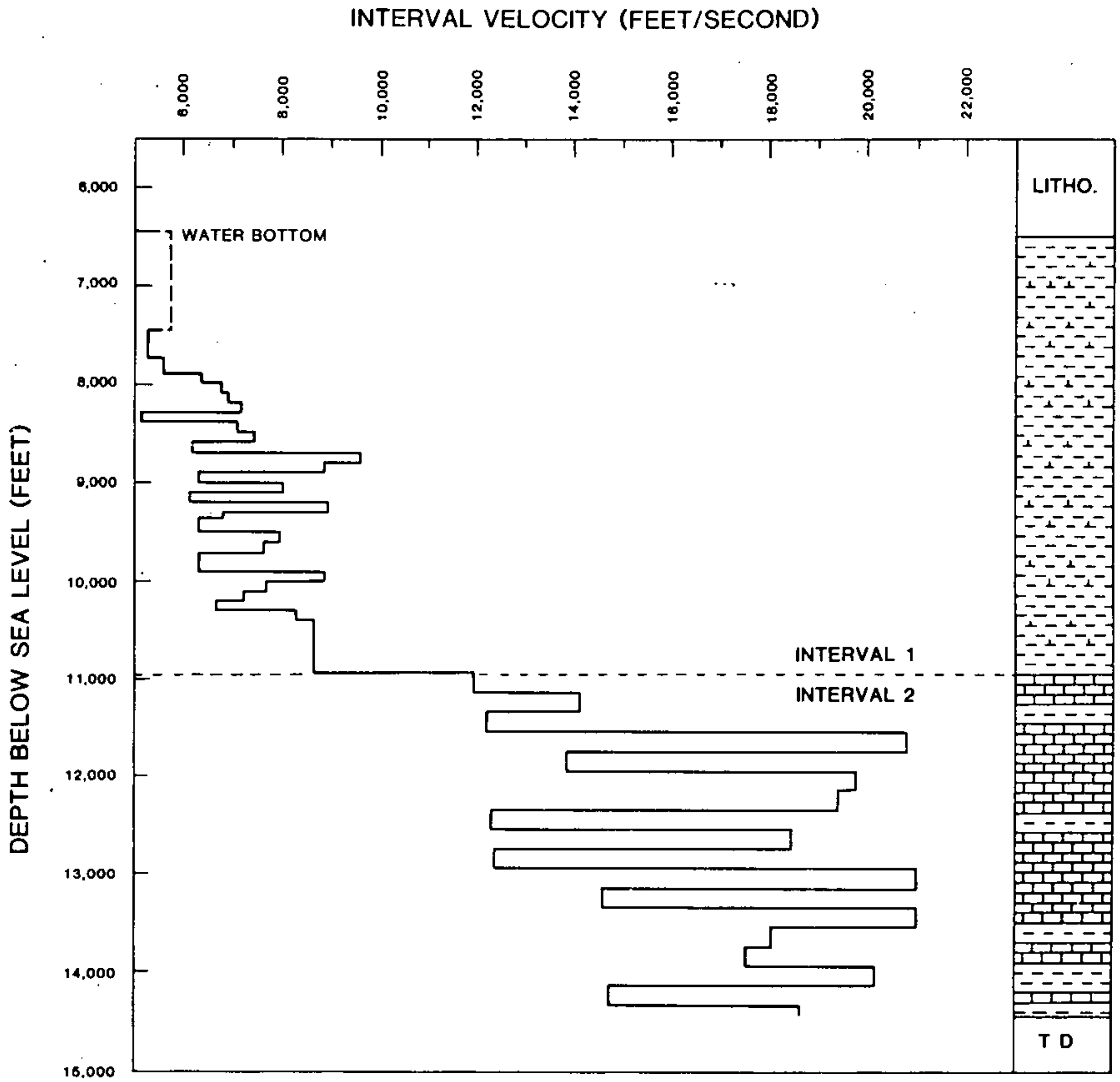


Figure 5.--Interval velocity profile of the Shell 587-1 well, with generalized lithologic column.

LITHOLOGIC AND PETROGRAPHIC DESCRIPTIONS

by

Gary M. Edson and George B. Carpenter

The Shell Wilmington Canyon 587-1 well penetrated the seaward margin of the Jurassic-lowermost Cretaceous paleoshelf-edge carbonate platform and the Lower Cretaceous paleoshelf-edge carbonate buildup. Correlation with the updip Shell 586-1 drill hole and integration of seismic analysis with geologic data have produced the facies framework shown in figure 6. The lithologies of the 587-1 well are grouped in this report according to this facies nomenclature. A lithologic column is shown in figure 7 (page 20).

Rock samples examined include drill cuttings, which were collected from 8,550 feet to total depth, 14,500 feet; three 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 the inclusion of 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.

o Argillaceous Facies (8,550-10,970 feet; Maestrichtian-Valanginian)

Lithologic interpretation is hampered by drilling difficulties, poor cuttings returns, and lack of wireline logs between 10,401 and 10,745 feet. Other impediments include the absence of conventional cores for the entire interval of 8,550 to 10,970 feet and of sidewall cores above 10,778 feet. However, well logs suggest that shale is the most abundant lithology. Sidewall cores and drill cuttings indicate that the shale contains limestone interbeds and that some of the shale is calcareous. Relatively lower natural gamma log values may indicate calcareous shale in the upper 2,400 feet of the interval and relatively higher values may indicate shale in the lowermost 200 feet.

The lost circulation zone, 10,400 to 10,750 feet (see page 31), is reliably represented only by the downhole logging while drilling (DLWD) log. The DLWD includes rate-of-penetration, natural gamma, resistivity, and conductivity data. The drilling rate is extremely variable through the zone with numerous 3- to 10-foot occurrences of very rapid penetration. The natural gamma amplitude is also quite variable over short intervals, suggesting interbedded lithologies. Resistivity amplitude is low (1.6-4.0 ohm-meters) but higher and more variable than for the presumed calcareous shales from 8,550 to 10,400 feet. In summary, this zone appears to consist of calcareous shale with thin (3- to 10-foot), porous limestone interbeds. The argillaceous facies occurs in all Baltimore Canyon Trough wells, which contain fine-grained, post-Valanginian sediments.

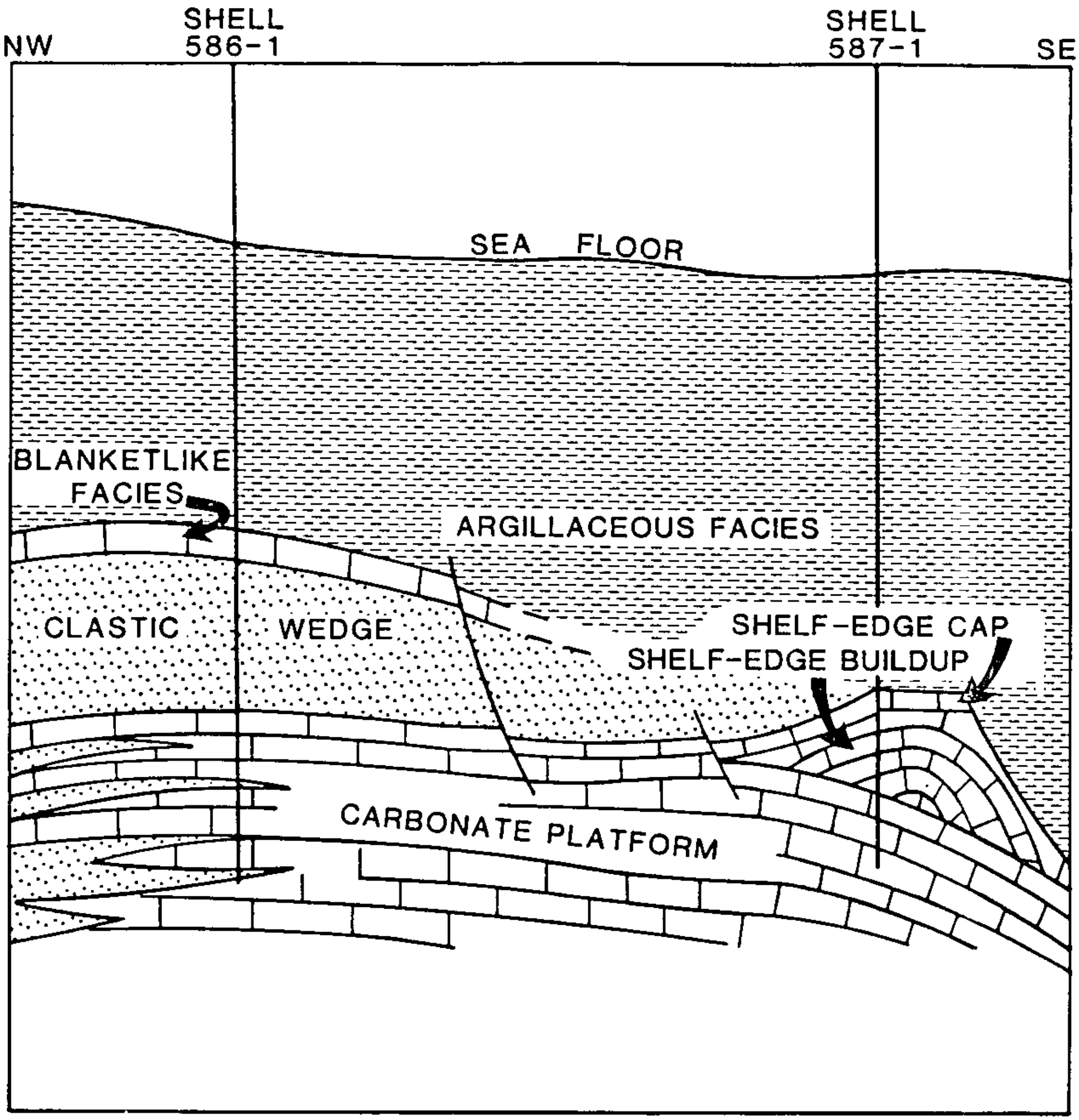


Figure 6.--Diagrammatic cross section through the Shell 586-1 and 587-1 wells.

Thin sections made from drill cuttings throughout the argillaceous facies interval include a few calcareous shale fragments, which contain coarse quartz silt and fine quartz sand grains, glauconite, pyrite, inertinite, and small amounts of mica and collophane. However, wackestone fragments, also containing quartz, glauconite, pyrite, inertinite, mica, and collophane, are much more abundant. Apparently, drilling and sampling operations tended to preserve the limestone and deplete the shale cuttings.

Effective porosity is inferred to be poor for the shales of this facies, but well log analysis (page 30) identified three intervals of high porosity, thought to be associated with limestone interbeds. Cuttings thin sections show some intraskeletal porosity within foraminifer chambers and minor intragranular solution voids in wackestone fragments. However, because of the lack of drill cores or sidewall cores, there is no specific information on the nature of the porosity within the potential reservoir intervals identified by log analysis and within the lost circulation zone.

o Paleoshelf-edge Carbonate Cap Facies (10,970-11,260 feet; Valanginian)

This thin, distinctive limestone unit forms a cap on the paleoshelf-edge carbonate buildup (fig. 6). Seismic interpretation indicates that the cap may also extend over the carbonate platform a short distance landward from the paleoshelf-edge buildup. The persistence of the cap along strike is problematical because the morphology of the paleoshelf-edge appears to vary. A capping unit of similar lithology and fossil biota overlies the paleoshelf-edge carbonate buildup in the Shell 372-1 drill hole, about 23 miles to the northeast, but there the cap appears to be Hauterivian in age.

The cap appears as a discrete limestone unit in well logs from the Shell 587-1 drill hole, with higher natural gamma and lower resistivity values than the underlying paleoshelf-edge buildup. The drilling rate was higher, averaging about 12 feet per hour, for the cap than for the upper portion of the buildup, which averaged about 6 feet per hour. Therefore, the cap appears to be softer and perhaps more porous than the buildup. Sidewall core descriptions identify calcareous shale, lime mudstone, wackestone, and packstone in this facies interval.

The first conventional drill core was cut from 11,012 to 11,042 feet, near the top of the cap. The core is chalky, light gray limestone that has a grainy appearance owing to abundant small (0.1-1 cm) medium gray bioclasts. Shaley intervals, 4 to 15 cm thick, that contain sand-sized limestone clasts occur every 150 to 250 cm, and a few small calcite crystal-lined vugs are scattered through the core. The chalky texture allows the core to be cut by a knife almost like soap.

Thin sections from this core show laminated and unlaminated bioclastic wackestone and packstone with minor anhydrite and gypsum and traces of dolomitization. Pyrite fills some intraskeletal voids. The bioclasts are angular and are mostly sand sized but range up to 1 cm in diameter. They represent a wide variety of fauna. By volume, the most abundant biota are hexactinellid fragments. Also abundant are bryozoans, ostracods, pelecypods, echinoderms, foraminifers, calpionellids, calcareous sponges, algae, and tubiphytes. The foraminifers include plentiful Epistomina and rare Lenticulina and Trocholina, together with numerous arenaceous uniserial and uniserial-biserial forms. Algae include abundant blue-green types, sparse dasycladaceans, and rare red forms.

Porosities observed in thin section range from zero to about 10 percent as interparticle and intraskeletal voids. Permeability appears to be poor because voids do not interconnect. Petrophysical analysis of 31 core plugs shows porosities of 8.8 to 26.0 percent, averaging 14.4 percent, and air permeabilities of 0.009 to 12.6 millidarcies (md), averaging 0.57 md.

- Paleoshelf-edge Carbonate Buildup Facies (11,260-12,500(?) feet; Valanginian)

In the vicinity of the Shell 587-1 well, this facies unit forms a raised rim along the seaward edge of the Jurassic-lowermost Cretaceous carbonate platform (fig. 6). According to seismic interpretation, the morphology of the paleoshelf edge varies along strike. However, lithologies and biota are similar for this facies unit in the Shell 587-1 well and the Shell 372-1 well, which is about 23 miles along strike to the northeast. The age of this unit may be the same in the two wells, but biostratigraphic control is poor, especially in the Shell 372-1 well.

The paleoshelf-edge buildup facies is seismically distinct from the underlying carbonate platform-edge facies. However, it is difficult to determine the extent to which these facies units are lithologically and biologically discrete. Cuttings samples are of poor quality, and core No. 2 is in the upper one quarter of the paleoshelf-edge buildup facies while core No. 3 is about 2,000 feet below the top of the platform-edge facies. The cores differ from one another, but it is not known how well they represent the facies units.

Further, the contact between the two facies units is indistinct; it is identified on the basis of an apparent lithologic change in the cuttings. The drilling rate is higher and the natural gamma and resistivity logs are more variable in amplitude for the carbonate platform-edge facies than the carbonate buildup facies. But the logs do not indicate a specific depth that definitely separates the two intervals. Descriptions of the 54 sidewall cores obtained from the paleoshelf-edge buildup facies identify grainstone, packstone, wackestone, and mudstone as the dominant lithologies.

Core No. 2, cut from 11,551 to 11,581 feet, is light gray, granular-appearing limestone with medium gray and beige lobate and tabular fossils several centimeters in diameter. The granularity is caused by very coarse sand-sized, well rounded carbonate clasts and bioclasts cemented at their points of mutual contact. The grains have chalky coatings that serve as the cement. Otherwise, intergranular space is empty and porosity is excellent. However, the chalky coatings also appear to occlude passageways so that permeability is poor. Vugs, as wide as 2 cm, are sparsely disseminated in the core. This core is also similar to core No. 1 in its pervasive chalkiness and softness.

Core thin sections show bioclastic grainstones and possible minor boundstones, altogether of coarser textures than those of core No. 1. Intergranular spar consists of minute, blocky, subhedral crystals as isopachous rims around clasts; coarse crystal mosaics filling interiors of some voids; and single crystals entirely filling other voids. The isopachous crystals and most of the coarse spar are calcite. The single-crystal, optically continuous areas and about 10 percent of the coarse spar mosaics are anhydrite. There are also occasional patches of finely crystalline dolomite. Intergranular porosity is locally excellent, ranging up to about 40 percent. A much smaller amount of intraskeletal porosity is evident. Visual porosity may average 10-15 percent overall, but permeability appears to be poor.

Petrophysical analysis of 14 core plugs shows porosities of 4.2 to 25.4 percent, averaging 12.2 percent, and air permeabilities of 0.046 to 156.0 md, averaging 15.4 md. Only one plug had relatively good permeability; otherwise, the average would be much lower.

Bioclasts are generally 0.5 mm to 1 cm in diameter and consist of coral, calcareous sponge, echinoderm, bryozoan, and pelecypod fragements, as well as abundant foraminifers and blue-green algae. Dasycladacean algae are in low abundance and red algae are very rare. Nearly all bioclasts are well rounded and have well developed micritic rinds.

The large metazoan fossils, many of which appear to be boundstone elements, are mostly stromatoporoids and subordinate communal corals. Extensive areas of the large fossils are recrystallized to calcite spar mosaics, and most external surfaces have well developed foraminifer and blue-green algae crusts. The lobate fossils are thumb sized, and the tabular fossils are comformable with bedding and are larger in diameter than the drill core (about 6 cm).

o <u>Carbonate Platform-edge Facies (12,500(?)-14,500 feet; Valanginian-Bathonian)</u>

The seaward edge of the Jurassic-lowermost Cretaceous platform is the foundation upon which the carbonate buildup formed (fig. 6). The uppermost portion of the platform is probably Lower Cretaceous; it is identified as Berriasian in the more shoreward Shell 586-1 well at 11,600 feet (Steinkraus and others, 1986). In the Shell 587-1 well, the platform top is designated as Valanginian (see fig. 7) owing to a lack of biostratigraphic control near 12,500 feet and to the Valanginian identification of the nearest overlying guide fossils.

Well logs suggest limestone with minor shale interbeds from 12,500 to 14,000 feet and interbedded limestone and shale from 14,000 to 14,500 feet. Within this facies interval, descriptions of 116 sidewall cores confirm these lithologies. The shales are calcareous and micaceous and have a petroliferous odor. The limestones are dominantly mudstone, wackestone, and packstone, according to the sidewall core descriptions.

The third conventional core was taken at the termination of the drill hole, from 14,470 to 14,500 feet. This limestone is light gray, highly stylolitized, dense, and microcrystalline with abundant sand- and pebble-sized clasts. In some short intervals the stylolites are so abundant that they interpenetrate, creating a "stylobreccia." The clasts occasionally form graded beds associated with apparent burrowed textures. The chalky weathering and porosity observed in the upper cores were not observed in the third core.

Conventional core thin sections show finely pelleted lime mudstone and wackestone with abundant stylolites, spar-filled fractures, patches of spar, and occasional blebs of pyrite. Thin sections also show finely laminated wackestone with less spar and with finely disseminated pyrite. The spar is calcite, dolomite, and minor anhydrite, and the spar patches are probably replacement of fossils. Locally, in intervals of several centimeters thickness, dolomite spar abundance increases and the lithology becomes apparent grainstone as a fabric replacing the original wackestone. Throughout the thin sections, micrite peloids are abundant, and some have thick, concentric micritic rinds. Few fossils are identifiable because of recrystallization, but tubiphytes, ostracods, calcareous sponge, blue-green and dasycladacean algae, and single specimens of *Trocholina* and *Epistomina* were recognized.

Negligible porosity was observed in thin section. Petrophysical analysis of 27 core plugs shows porosities of 1.0 to 2.5 percent, averaging 1.7 percent, and air permeabilities of 0.009 to 1.9 md, averaging 0.15 md.

BIOSTRATIGRAPHY

by

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

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. In addition, in United States Atlantic offshore wells 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 relies on the Jurassic palynostratigraphy of offshore eastern Canada (Bujak and Williams, 1977) because many of their palynomorph marker species are also present in the United States offshore Atlantic subsurface. Although the European stage equivalance 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).

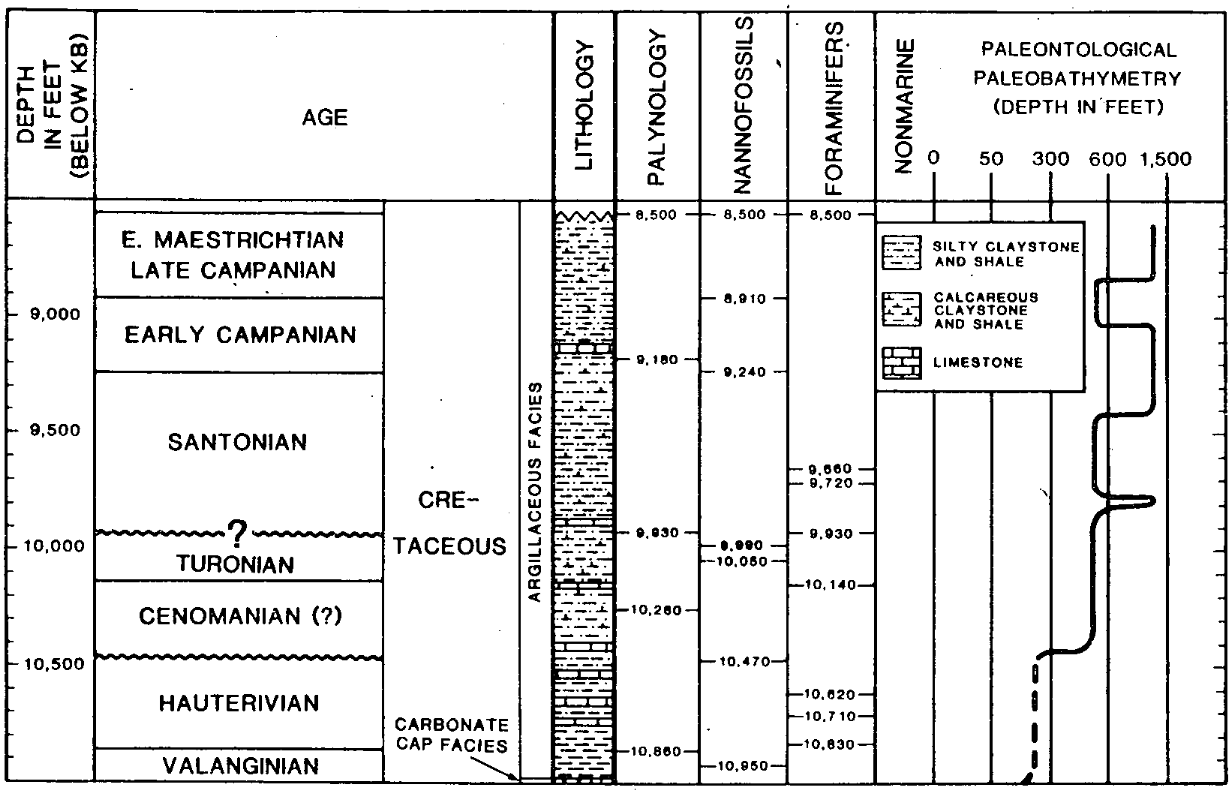
This investigation is based on examination of fossil dinoflagellates, spores, pollen, calcareous nannofossils, and foraminifers by the paleontological staff of the Atlantic Outer Continental Shelf Region Office of the Minerals Management Service (MMS). Palynological analyses were made from 70 slides prepared from 90-foot composite samples. Nannofossil studies were made from 198 slides representing 30-foot intervals. Foraminiferal analyses were based on 121 samples from 30-foot intervals. Micropaleontological analyses were based on drill cuttings collected from 8,550 to 14,500 feet (TD), except the foraminiferal studies, which were based on the interval of 8,550 to 13,020 feet. In addition, samples from the three conventional cores were examined.

Age determinations range from Late Cretaceous (early Maestrichtian) to Middle Jurassic (Bathonian). A major hiatus is indicated between the Cenomanian(?) at 10,140 feet and the Hauterivian at 10,470 feet. Possible Coniacian and Berriasian hiatuses may indicate two other unconformities. The biostratigraphic chart, figure 7, shows the highest occurrences of the marker fossils and probable locations of the unconformities.

Late Cretaceous

o Early Maestrichtian-late Campanian (8,550-8,910 feet)

The dinoflagellate Aeroligera senonensis (late Campanian-Eocene) occurs along with the nannofossil species Eiffellithus turriseiffeli and the foraminifers Globotruncana aegyptiaca and G. arca, indicating an early Maestrichtian



DEPTH IN FEET (BELOW KB)
AGE
LITHOLOGY
PALYNOLOGY
NANNOFOSSILS
FORAMINIFERS
NONMARINE
PALEONTOLOGICAL PALEOBATHYMETRY (DEPTH IN FEET)
0
50
300
600
1,500
9,000
9,500
10,000
10,500
E. MAESTRICHTIAN
LATE CAMPANIAN
EARLY CAMPANIAN
SANTONIAN
?
TURONIAN
CENOMANIAN (?)
HAUTERIVIAN
VALANGINIAN
CRE-
TACEOUS
ARGILLACEOUS FACIES
CARBONATE CAP FACIES
8,500
9,180
9,930
10,260
10,860
8,500
8,910
9,240
9,990
10,060
10,470
10,950
8,500
9,660
9,720
9,930
10,140
10,620
10,710
10,830
SILTY CLAYSTONE AND SHALE
CALCAREOUS CLAYSTONE AND SHALE
LIMESTONE

10970

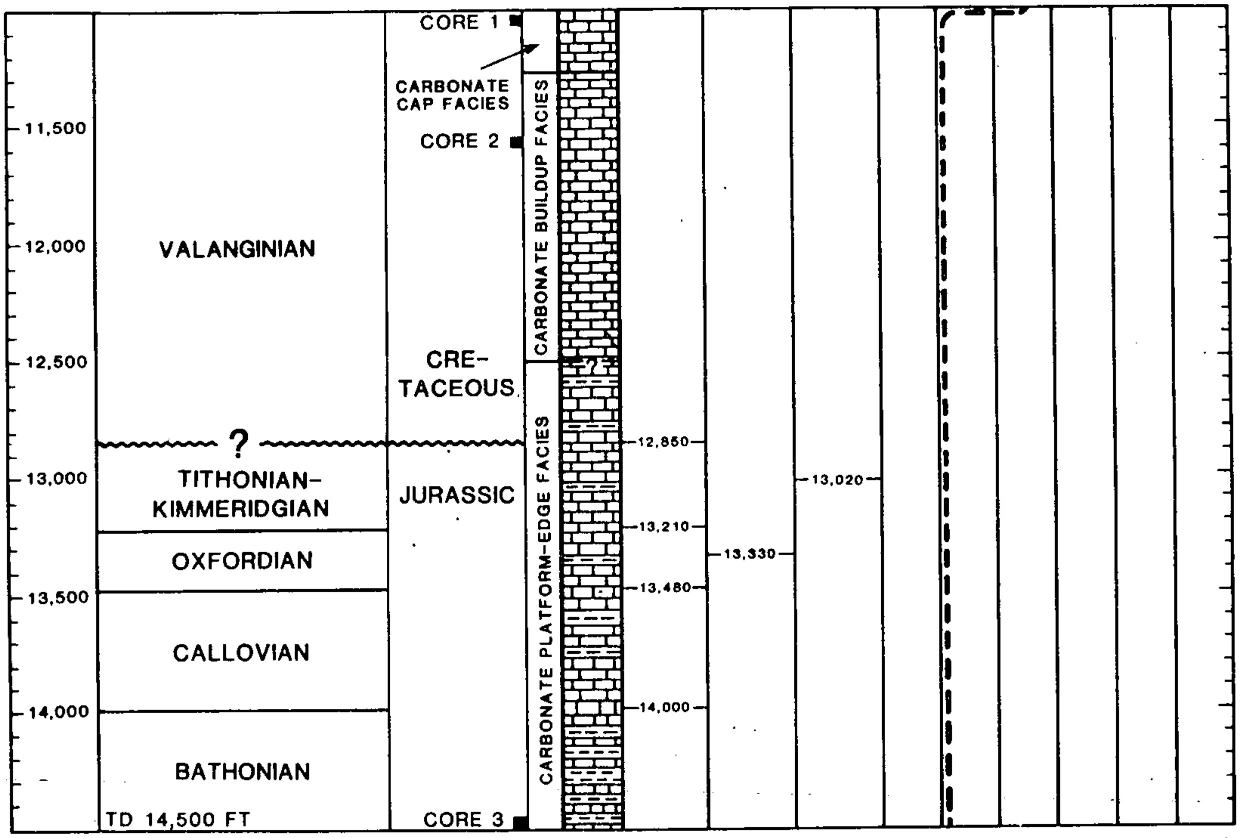


Figure 7.--Lithology, biostratigraphy, and paleobathymetry of the Shell 587-1 well. Lithologic breaks picked from well logs. Within columns, depths refer to uppermost occurrence of index fossils, listed in Biostratigraphy section. Stage tops based on paleontology. Paleobathymetric interpretations become less reliable with increasing well depth.

age at 8,550 feet. No microfossils diagnostic of the late Campanian were recognized.

o Early Campanian (8,910-9,240 feet)

The nannofossils Tetralithus ovalis and E. eximius (8,910 feet) indicate early Campanian. The dinoflagellate Achomosphaera sagena (9,180 feet) does not range above the Campanian.

o Santonian (9,240-9,930 feet)

The nannofossil Marthasterites furcatus (9,240 feet) and foraminifers G. sinuosa (9,660 feet) and G. renzi (9,720 feet) define a Santonian age for this interval. No microfossils of Coniacian age were found.

o Turonian (9,930-10,140 feet)

The foraminifer Praeglobotruncana stephanii and several specimens of the dinoflagellate Surculosphaeridium longifurcatum have their uppermost occurrence at 9,930 feet. Below this, the nannofossils Radiolithus planus (9,990 feet) and Corollithion achylosum (10,050 feet) occur, all indicating this interval is of Turonian age.

o Cenomanian(?) (10,140-10,470 feet)

One poorly preserved specimen of the foraminifer Rotalipora greenhornensis recorded at 10,140 feet may indicate a Cenomanian age for this level.

Paleontological data indicate that a major hiatus is present in the section below 10,140 feet, with no evidence of Albian, Aptian, or Barremian strata below the Cenomanian(?) at 10,140 feet and above the Early Cretaceous Hauterivian at 10,470 feet.

Early Cretaceous

o Hauterivian (10,470-10,860 feet)

Nannoconus colomi (10,470 feet) and the foraminifers Epistomina ornata (10,620 feet), Planularia crepidularis (10,710 feet), and Lenticulina saxonica (10,830 feet) all indicate Hauterivian age. The dinoflagellate species Oligosphaeridium perforatum has its uppermost occurrence at 10,260 feet, possibly indicating Hauterivian sediments at that somewhat shallower depth.

o Valanginian (10,860-12,850 feet)

The dinoflagellate Muderongia staurata (10,860 feet) and the nannofossils Bipodorhabus colligatus (10,910 feet) and Diadorhombus rectus (10,950 feet) indicate the Valanginian stage for this interval. No microfauna or flora of restricted Berriasian age were recovered.

Late Jurassic

o Tithonian-Kimmeridgian (12,850-13,210 feet)

The dinoflagellate species Ctenidodinium panneum and Muderongia sp. "A" both indicate late Kimmeridgian to early Tithonian age (12,850 feet). The foraminifer Epistomina uhligi (13,020 feet) is restricted to the Kimmeridgian.

o Oxfordian (13,210-13,480 feet)

The dinoflagellates Adnatosphaeridium aemulum and Hystrichogonyaulax cornigera at 13,210 feet both indicate the Oxfordian, which is further supported by the nannofossil Stephanolithion bigoti at 13,330 feet.

Middle Jurassic

o Callovian (13,480-14,000 feet)

The Callovian is indicated at 13,480 feet by the uppermost occurrences of Gonyaulacysta pectinigera and G. pachyderma (dinoflagellates).

o Bathonian (14,000-14,500 feet)

The uppermost occurrence of the Bathonian dinoflagellate marker species G. filapicata is at 14,000 feet. This species occurs intermittently to the deepest palynological sample examined (14,400 feet).

Paleobathymetric Summary

Foraminiferal assemblages indicate a fluctuating, relatively deepwater environment (perhaps 600 to 1,500 feet) at the following depth intervals: 8,550 to 8,820 feet, 9,030 to 9,420 feet, 9,780 to 9,810 feet. Moderate depths (perhaps 300 to 600 feet) are indicated at 8,820 to 9,030 feet, 9,420 to 9,780 feet, and 9,810 to 10,440 feet. The interval of 10,440 to 11,040 feet is uncertain with respect to foraminiferal paleobathymetry but appears, on the basis of lithologies, to represent a deeper marine environment than the underlying interval. A shallow, possibly lower salinity interval is inferred for 11,040 to 13,020 feet. Below 13,020 feet no diagnostic foraminifers were recognized, but shallow environments are probable to the bottom of the well, based on lithologies and sedimentary textures.

Palynology residues indicate higher energy with increased terrestrial detritus at the following intervals: 9,180 to 9,270 feet, 9,360 to 9,810 feet (barren), 11,190 to 11,270 feet, 11,380 to 11,470 feet (reworked zones), 11,470 to 11,920 feet (barren), 11,920 to 12,010 feet (reworked), and 12,010 to 12,760 feet (barren).

DEPOSITIONAL ENVIRONMENTS

by

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

The Shell Wilmington Canyon 587-1 well penetrated the Upper Jurassic-Lower Cretaceous paleoshelf-edge carbonate trend along the seaward margin of the Baltimore Canyon Trough. The carbonate trend strikes northeast-southwest but is narrow perpendicular to strike, being only a few miles in width (see fig. 6).

Four facies units were identified in the Shell 587-1 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 19), and inferred paleobathymetry is shown in figure 7. From bottom to top, the facies units are the carbonate platform edge, paleoshelf-edge carbonate buildup, paleoshelf-edge carbonate cap, and the argillaceous facies. The environments they represent are discussed in that order.

- Carbonate Platform-edge Facies (12,500(?)-14,500 feet; Valanginian-Bathonian)

Seismic profiles show that the Shell 587-1 well bottoms in the seaward edge of the Jurassic-Lower Cretaceous platform, schematically shown in figure 6. Cuttings and sidewall core lithologies are lime mudstone, wackestone, and packstone. Core No. 3, cut at the bottom of the well, is pelletal mudstone and wackestone. Well logs suggest that shale interbeds are more abundant near the bottom of the drill hole.

Paleobathymetric analysis (see fig. 7) suggests shallow inner neritic deposition, and primary sedimentary textures and lithologies resemble the bioturbated muds of intertidal flats. However, both of these inferences appear to be incorrect. Paleodepths are inconclusive because there are few diagnostic fossils in the interval. Seismic profiles show a platform edge, rather than flat-lying deposits. However, lithologic and petrographic textures imply a quiet depositional environment rather than the grainstones and ooliths that should be expected at the seaward edge of a carbonate bank. Finally, the seismic profiles show that the lower 2,000 feet of the Shell 587-1 well are in seaward-sloping sediments about one-quarter mile basinward of the paleoshelf-edge crest. It is concluded that the carbonate platform-edge facies unit consists of carbonate mud-dominated sediments deposited in quiet water slightly seaward of the edge of the platform.

- Paleoshelf-edge Carbonate Buildup Facies (11,260-12,500(?) feet; Valanginian)

This next higher facies interval represents a shoreward shift, to the crest of the platform edge, and an increase in depositional energy. The platform edge is progradational. At the drill hole location, dip-section seismic profiles show the bottom of this interval to be slightly seaward of the apparent crest and the top of the interval to be immediately landward of the crest. A morphologic evolution is also seen within the interval as the paleoshelf-edge carbonate buildup develops into a raised platform-edge rim. Limestone lithologies include grainstone, packstone, wackestone, and mudstone. Bioclastic grainstones appear to be most abundant, and they contain subintervals of stromatoporoids and corals as boundstone elements. Other than the boundstone subintervals, the upper one-quarter of this facies unit appears to be a passive bioclastic accumulation because it consists mostly of well rounded, coated bioclasts. Lithologic samples are inadequate to characterize the lower three-quarters of the unit.

In summary, this facies interval is interpreted to represent a shallow water, relatively high-energy environment at the seaward edge of the carbonate bank. It is thought to be a berm-like bioclastic buildup within which stromatoporoids, corals, and algae established themselves as minor boundstone elements. To use Embry and Klovan's (1971) terminology, some of these large metazoans form bindstone subintervals. The paleoshelf-edge carbonate buildup is identified as Valanginian. According to Vail and others (1977), a marine transgression occupies the upper portion of this stage. It therefore appears that bank aggradation kept pace with rising sea level. Perhaps the large metazoans and algae did not grow into a reefal framework because bioclastic debris accumulation was too rapid; instead the stromatoporoids and corals were smothered.

o <u>Paleoshelf-edge Carbonate Cap Facies (10,970-11,260 feet; Valanginian)</u>

This distinctive 290-foot-thick limestone unit appears to cap the paleoshelf-edge buildup, according to seismic profiles. Thin sections from core No. 1 show bioclastic wackestone and packstone with abundant hexactinellid fragments and tubiphytes. Based on sparse data, paleobathymetric analysis suggests shallow inner neritic environments for this facies interval. However, deeper water is inferred for the overlying argillaceous facies (see page 23).

Depositional water depth apparently increased as the cap unit was deposited. The wackstones and packstones of the cap and the absence of micritic coatings on the angular bioclasts suggest lower energy depositional environments than those of the underlying carbonate buildup. The hexactinellids may also indicate deeper water (although there are also shallow-water biota among the bioclasts). Altogether, it is concluded that the paleoshelf-edge cap facies represents a deepening environment near the end of the Valanginian stage, as the paleoshelf-edge carbonate buildup failed to keep pace with rising sea level.

o <u>Argillaceous Facies (8,550-10,970 feet; Maestrichtian-Valanginian)</u>

The lithologies of this interval are silty and sandy calcareous shale with silty and sandy wackestone interbeds (see page 13). The change from Valanginian and older limestone to latest Valanginian, or Hauterivian, and younger shale deposition would seem to indicate increased water depths. Paleobathymetric analyses confirm this interpretation; depositional water depths were perhaps 200 to 1,000 feet from Hauterivian to Maestrichtian times. Vail and others (1977) present this portion of the Cretaceous Period as a generally transgressive series of cycles, relative to Valanginian and older ages. The unconformity, defined paleontologically between the Hauterivian and Cenomanian Stages (see page 19), may be the result of erosion associated with marine regressions, the latest of which is at the middle of the Cenomanian Stage (94 to 93.5 MYBP) according to Vail and others (1977). Similarly, the Turonian-Santonian unconformity may be a result of Coniacian marine regression.

FORMATION EVALUATION [1]

Well "electric" logs were run in the Shell 587-1 well by Schlumberger Ltd. to provide information for stratigraphic correlation and for evaluation of formation fluids, porosity, and lithology. Table 3 identifies some of the logs.

Table 3.--Well logs

Log Type	Depth Interval (ft)
Induction Spherically-focused Log (ISFL)	6,743-8,540
Dual Induction Spherically-focused Log (DISFL)	8,478-10,401, 10,745-14,481
Natural Gamma (GR)	6,743-10,401, 10,745-14,481
Digital Induction Tool (DIT)	8,478-10,401, 10,745-14,481
Borehole Compensated (BHC) Sonic	6,743-10,401, 10,746-14,486
Proximity Log/Micrologr	10,746-14,484
Compensated Neutron Log (CNL)	10,746-14,486
Compensated Formation Density (FDC)	10,746-14,486
Lithodensity Tool (LDT)	10,746-14,486
Natural Gamma Spectrometry (NGT)	10,746-14,486
High-Resolution Dipmeter (HDT)	10,777-14,462
Caliper	8,478-10,401, 10,746-14,486

Exploration Logging, Inc. provided a formation evaluation ("mud") log for the interval of 8,550 to 14,470 feet, which includes a rate of penetration curve, lithologic sample descriptions, and a graphic representation of hydrocarbon shows. In addition, a drilling data pressure log (8,500 to

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

14,470 feet), a pressure evaluation log (8,560 to 14,500 feet), and a temperature data log (8,560 to 14,470 feet) were run. Downhole logging while drilling (DLWD) was used to provide continuous gamma ray, resistivity, and rate of penetration logs while the well was being drilled for the interval 6,820 to 14,470 feet. The DLWD experienced some malfunctioning, and all three types of logs are not present for all intervals.

The electric logs, together with the mud log and other available data, were analyzed to determine the thickness of potential reservoirs, average porosities, and feet of hydrocarbon present. Reservoir rocks with porosities of less than 5 percent were disregarded. A combination of logs was used in the analysis, but a more detailed lithologic and reservoir-property determination from samples, conventional cores, sidewall cores, as well as the incorporation of further test results, would be necessary to substantiate the estimates shown in table 4.

Table 4.--Well log interpretation

Depth Interval (ft)	Feet of Potential Reservoir (a)	Average Porosity (Sw) (%)	Water Saturation (%)	Feet of Hydrocarbon (b)
8,830-8,930	100	33	61	-
10,360-10,366	6	35+	100	-
10,485-10,746 (c)	30-85(?) (d)	20-35+(?)	50(?)	(?) (e)
10,976-11,258	240	15	-	-
11,388-11,530	126	11	-	-
11,530-11,586	56	17(f)	-	-
11,586-11,780	189	10	-	-
11,796-11,840	43	10	-	-
11,848-11,936	84	9	-	-
11,970-12,032	58	10	-	-
12,084-12,168	78	8	-	-
12,208-12,224	16	6	-	-
12,286-12,319	32	8	-	-
12,328-12,402	74	18	70	-
12,464-12,502	36	12	-	-
12,546-12,556	10	8	-	-
12,618-12,644	26	15	-	-
12,648-12,672	24	9	-	-
12,678-12,720	42	13	-	-
12,743-13,060	302	12	-	-
13,090-13,152	62	18	-	-
13,205-13,228	21	11	-	-
13,342-13,430	86	10	-	-
13,456-13,481	25	8	-	-
13,591-13,628	35	8	-	-
13,717-13,750	29	7	-	-
13,832-13,855	23	11	43	(g)
13,939-13,973	32	7	52	(h)
14,064-14,080	16	11	41	(i)

Table 4.--Well log interpretation--continued

a) Generally in beds > 10 ft thick and Ø > 5%.
b) Generally in beds > 10 ft thick, Ø > 5%, and Sw < 50%.
c) The interval of 10,401 to 10,746 ft was not logged except by the mud log and DLWD.
d) Rate of penetration data suggest a porous zone up to 85 ft thick.
e) At 10,627 ft, 522 units of gas detected. Zone not tested by DST or FT.
f) Maximum indicated porosity is 21% at 11,532-11,543 ft.
g) Two 5-ft zones, 2 units total gas, no SP, Sw/Sxo = 0.52, BVF = 0.05, PRI = 0.03, SWC = NS.
h) Two units total gas, poor SP, Sw/Sxo = 0.52, BVF = 0.04, PRI = 0.02, SWC = NS.
i) Two units total gas, Sw/Sxo = 0.52, BVF = 0.05, PRI = 0.03, SWC = NS.

The interval of 10,400 to 10,750 feet presented extreme drilling difficulties. This was a lost circulation zone, and drill cuttings sample returns were poor or nonexistent. Most of the interval was drilled with a floating mud cap, after which casing was immediately set to 10,746 feet. No wireline logs were run from 10,401 to 10,745 feet; however, the mud log shows shale with minor limestone and the DLWD did record this interval. Minerals Management Service (MMS) concludes that the zone of lost circulation is shale with limestone interbeds (see page 13) and that high porosity and permeability exist in the carbonates. The gas show of 522 units at 10,627 feet was detected during a short trip, during which the mud was cut from 8.8 to 8.2 ppg. The origin of the hydrocarbon could not be determined. No formation tests were run, and the show is assumed not to be significant.

Conventional Core Analysis

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

Table 5.--Conventional core properties

Core No.	Depth Interval (ft)	Lithology	Porosity Range (%)	Permeability Range (md)	Oil Volume Pore (%)
1	11,012-11,042	limestone	8.8-26.0	0.009-12.6	0.04-0.22
2	11,551-11,581	limestone	4.2-25.4	0.046-156.0	0.02-0.18
3	14,470-14,500	limestone	1.0- 2.5	0.009-1.9	---

Although porosities are good, permeabilities are poor for the first two cores. The 156 md permeability in core No. 2 is much higher than the next best value (23 md) among the core plugs. Altogether, effective porosities are low. Visual porosity estimates from thin sections range from zero to 10 percent for core No. 1, generally from 10 to 15 percent but as high as 40 percent for core No. 2, and negligable for core No. 3 (pages 16, 17, and 18). Log analysis indicates porosities averaging 15 percent and water saturation of 79 percent for the core No. 1 interval; 17 percent and 71 percent, respectively, for core No. 2; and negligable for core No. 3.

Sidewall Core Analysis

Two hundred and twenty-nine sidewall cores were recovered from this well and 25 limestone cores, from 11,010 to 13,385 feet, were analyzed by Shell. Porosity ranged in the limestone cores from 1.5 to 31.9 percent, averaging 19.2 percent, and permeability ranged from 0.02 to 14 md, averaging 1.3 md.

Dipmeter

Results of the high-resolution dipmeter survey were recorded on a dipmeter arrow plot from 10,777 to 14,462 feet. Possible structural anomalies may be present at 11,060, 11,190, 11,550, 12,400, and 13,360 feet. Dip directions and magnitudes in the well are shown in table 6.

Table 6.--Dipmeter results

Interval (ft)	Direction	Magnitude
10,777-11,050	northwest	1-14°
11,050-11,600	west	3-21°
11,600-12,150	east	2-27°
12,150-13,300	northwest	1-23°
13,300-14,462	southeast	2-52°

Hydrocarbon Shows

Table 7 lists all shows of hydrocarbon encountered in the well. The gas show at 10,627 feet is judged not to be significant. No formation tests were taken in the well.

Table 7.--Summary of hydrocarbon shows

[ø, porosity in percent; K, permeability in millidarcies; O_p, oil pore in percent; Sw, water saturation in percent; C, carbon; NS, no show]

Depth Interval	Drilling Break ft/hr	Sample Description (Mud Log)	Total Gas back-ground	Total Gas inter-val	Chroma-tography	Cutt. Gas	Conventional Cores[1]	ø	K	O_p	Sidewall Cores [1]	ø	K	O_p	Well Log Interp.	ø	Sw
8,830–8,930	---	shale, very calcareous	7	7	C_{1-2}	1									8,830–8,930	33	61
10,105–10,135	50–75	shale	5	9	C_1	1											
10,360–10,380	50–70	shale	5	5	C_1	1									10,360–10,366	35+	100
10,485–10,620	35–50	limestone, hard	5	5	C_{1-2}	1									10,480–10,627	20–35+	
10,627				522(2)													
10,635–10,730	20–40	limestone/shale(?) lost circulation zone	2	2	C_1	1									10,627–10,780	20–35+	?
11,010–11,040	---	limestone	2	2	C_1	1	11,012–11,042	8.8–26	0.009–12.6	0.04–0.22	11,000–11,050			NS	11,010–11,040	15	79
											11,514			NS			
11,545–11,590	10–30	limestone, hard	2	2	C_1	1	11,551–11,581	4.2–25.4	0.046–156.0	0.02–0.18	11,576	5	0.04		11,530–11,586	17	71
											12,332			NS			
12,345–12,380	10–35	limestone, hard	2	6	C_{1-2-3}	12					12,335	1.5	0.02		12,328–12,402	18	70
											12,342			NS			
											12,352			NS			
13,830–13,850	20–30	limestone, hard	2	2	C_{1-2-3}	---					13,840			NS	13,832–13,855	11	43
											13,845			NS			
13,970–13,985	20–30	limestone, hard	2	2	C_{1-2-3}	---					13,940			NS	13,939–13,973	7	52
											13,951			NS			
14,090–14,110	20–30	limestone, hard	2	2	C_{1-2-3}	---					13,969			NS	14,064–14,080	11	41
											14,070						
14,125–14,145	17–25	limestone, hard	2	2	C_{1-2-3}	---									14,127–14,147	5	100
14,240–14,260	15–22	limestone, hard	2	2	C_{1-2-3}	---					14,250			NS	14,238–14,253	9	54
14,295–14,300	20–23	limestone, hard	2	2	C_{1-2-3}	---					14,349			NS	14,320–14,328	3	100

1. No oil bulk or gas bulk values were reported from the data provided.
2. Detected during a short trip.

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 587-1 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). Percentage 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 Upper Cretaceous interval, from the first available sample at 8,550 feet to 10,470 feet (see fig. 7), is dominated by woody and coaly kerogen (fig. 8b).

Within the Lower Cretaceous interval, 10,470 to 12,850 feet, herbaceous, woody, and coaly kerogens together account for most of the organic matter. Results are questionable from 10,400 to 10,750 feet because this is the zone in which mud circulation was lost during drilling. In the upper portion of the interval, 10,470 to 11,470 feet, algal abundance increases but reaches a maximum of only about 15 percent of total kerogen. From 11,470 to 12,310 feet, woody and coaly kerogen types are about 80 percent and algal types are present only in trace quantities.

Slides from the Lower Cretaceous and Upper Jurassic interval of 12,310 to 13,490 feet show an increase of algal kerogens to about 5 percent and an increase of herbaceous kerogens to about 35 to 40 percent. A large proportion of the herbaceous fraction is degraded, unstructured terrestrial material that is difficult to classify.

The remaining section, below 13,490 feet, is Middle Jurassic, and the kerogen is about evenly distributed among herbaceous, woody, and coaly types. Algal kerogen is present only in trace quantities. Much of this material is also degraded, but a few dinoflagellates are recognizable.

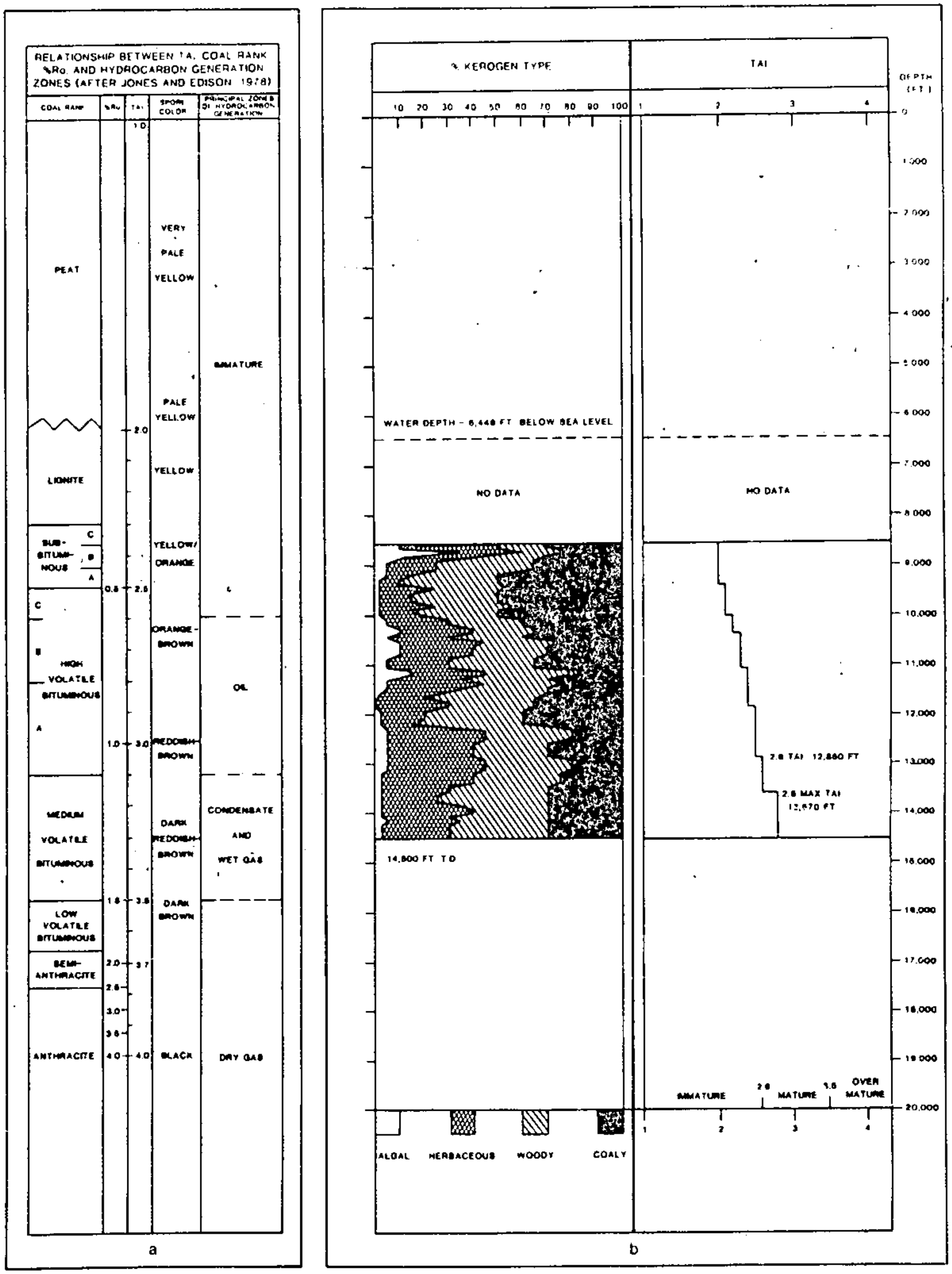


Figure 8.--Thermal maturity and hydrocarbon generation (a) and kerogen analysis for the Shell 587-1 well (b).

Of all the drill cuttings samples, organic material of marine origin is abundant only in a slide from 8,640 feet. Terrestial kerogen, indicating gas-prone organic matter, dominated all other slides. However, the organic richness at all depths tested is generally only in the poor-to-fair range according to petroleum geochemical analysis (see pages 39 to 41).

Thermal Maturity

Kerogen thermal maturities from the Shell 587-1 well were estimated by observing palynomorph color (see fig. 8b). Indigenous palynomorphs with colors indicating borderline maturity (2.6 TAI) were observed in samples below the top of the Upper Jurassic section (12,850 feet). A color change corresponding to a TAI value of 2.8 occurs in Middle Jurassic samples beginning at 13,570 feet. This value exceeds borderline maturity but is less than peak-potential maturity. Samples from 13,570 feet to total depth, 14,500 feet, indicate no greater maturity.

Conclusions

Kerogens observed in all sample slides except one are dominantly of terrigenous origin, indicating that if petroleum were generated, it would likely be gas. The exceptional sample, within the Upper Cretaceous shales at 8,640 feet, contains sufficient algal kerogen to be considered a possible oil source. However, a 2.0 TAI value at this depth indicates insufficient thermal maturity to have generated hydrocarbons.

Borderline maturity (2.6 TAI) is indicated among Upper Jurassic samples, but this value may be insufficient to generate hydrocarbons from terrigenous source rocks. Within Middle Jurassic rocks, at 13,570 feet and below, TAI was estimated at 2.8. Therefore, the Middle Jurassic section appears to have the best potential for gas generation. However, petroleum geochemical analyses may better define thermal maturity, and for the Shell 587-1 well, the geochemical onset of intense generation appears to be deeper than the bottom of the drill hole (see fig. 10).

PETROLEUM GEOCHEMISTRY

by

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The objectives of this study are (1) to examine and define the source-rock characteristics of the stratigraphic intervals in the Shell Wilmington Canyon 587-1 well that may have potential for generating oil and natural gas, (2) to determine the 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 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 39 well cuttings samples for their C_{15}+ characteristics and 236 gas samples from well depths of 8,550 to 14,480 feet. 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 gilsonite-like and tar-like solid to semisolid 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. 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 587-1 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 Upper and Lower Cretaceous shales, 8,550 to 10,970 feet, have total organic carbon values that range from 0.1 to 0.75 weight percent. Such values are in the

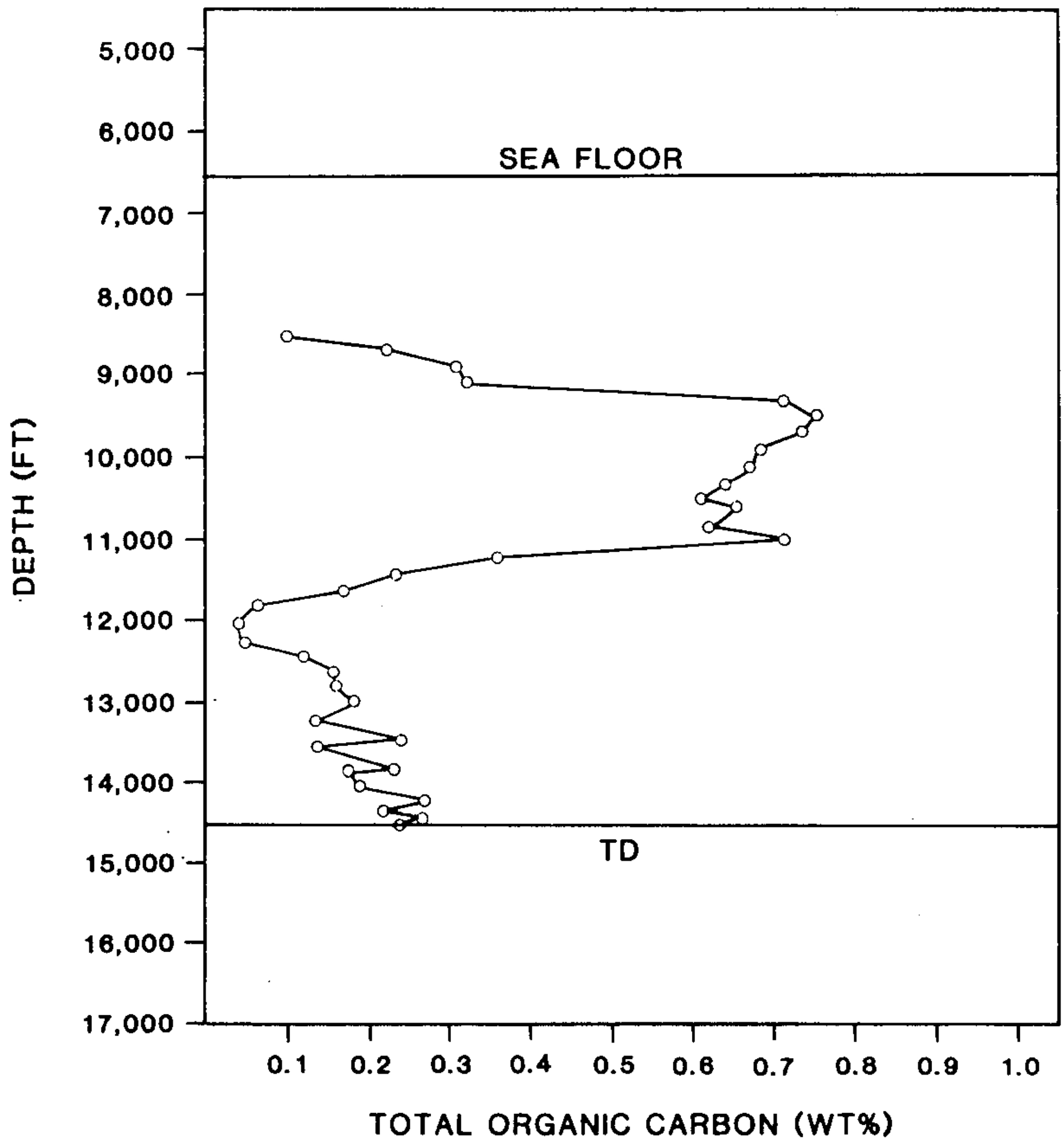

Figure 9.--Total organic carbon content of rocks in the Shell 587-1 well.

the poor to fair range for argillaceous source beds. Lower Cretaceous rock samples, 10,970 to 12,850 feet, have total organic carbon values that range from 0.04 to 0.71 weight percent. These values are considered to be in the poor to fair category because these cuttings are calcareous shale, thought to represent interbeds within the limestone interval. The Upper and Middle Jurassic limestones, 12,850 to 14,500 feet, have total organic carbon values that range from 0.13 to 0.27 weight percent. Such values are within the poor to average range for carbonates. The total solvent-extractable hydrocarbons (100 to 300 ppm) for the Lower 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 128 to 1,472 ppm and 10 to 40 ppm, respectively.

The abnormally high solvent 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 carefully cleaned by washing and picking, the source rock potential of the Lower Cretaceous and Upper to Middle Jurassic lithologies in the Shell 587-1 well 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 hydrogen/carbon (H/C) ratios of the Upper and Lower Cretaceous shales and limestones, 8,550 to 12,850 feet, range from 0.38 to 0.80. The Jurassic section from 12,850 feet to the total well depth of 14,500 feet contains organic matter with H/C ratios that vary from 0.29 to 0.47, 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 587-1 well are consistent with the light-optical descriptions of organic matter types reported (page 35).

Thermal Maturity

The geothermal gradient for the Shell 587-1 well was determined from well bore temperatures taken at four depths with an assumed ambient temperature of 60°F. The gradient was determined to be 0.97°F/100 feet. This value is lower than anticipated, given a geothermal gradient of 1.25°F/100 feet for the Continental Offshore Stratigraphic Test (COST) B-3 well and 1.26°F/100 feet 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 587-1 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 the Shell 587-1 well gradient is compared with the gradients of the Shell 586-1 and Tenneco 495-1 wells. There appears to be a progression (from the 587-1 to the 586-1 to the 495-1 well) of increasing geothermal gradients that 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 587-1 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 include vitrinite reflectance (%R_o) and thermal alteration index (TAI) techniques. On the basis of a geothermal gradient of 0.97°F/100 feet, the theoretical threshold of intense oil generation (TIOG) should occur at a depth of about 16,500 feet, relative to sea level, or at about 10,000 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 11,000 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 12,850 feet below sea level or at a sediment thickness depth of about 6,350 feet. Vitrinite reflectance (%R_o) values of 0.40 to 0.50 were reported in the interval of 12,850 to 14,560 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. The apparent inconsistency may be caused by reworked kerogens. 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 587-1 well did not exceed a value of 2.8 even at the bottom of the well. Although the burial depths for the onset of petroleum generation (according to the thermal chemical-kinetics model) and the TAI light-optical and vitrinite reflectance results do not agree, it is clear that the PZOF is interpreted to occur at a burial depth below the stratigraphic section penetrated.

The molecular gases examined in the Shell 587-1 cuttings samples were the C_1 to C_4 (methane through butane) "head-space" components and the C_4 to C_7 (butane through heptane) detailed gasoline-range species (table 8). The average concentration of the total methane through butane molecular species was generally about 500 ppm for the entire stratigraphic section, or about 6 times less than that of the Shell 586-1 well. Exceptions to this value are samples from 8,500 to 9,500 feet, where total concentrations ranged as high as 16,500 ppm, and samples from 10,500 to 11,000 feet and 14,000 to 14,500 feet, where values ranged up to 2,000 ppm. The shallowest gas is believed primarily to be biogenic methane. The highest percentage of gas

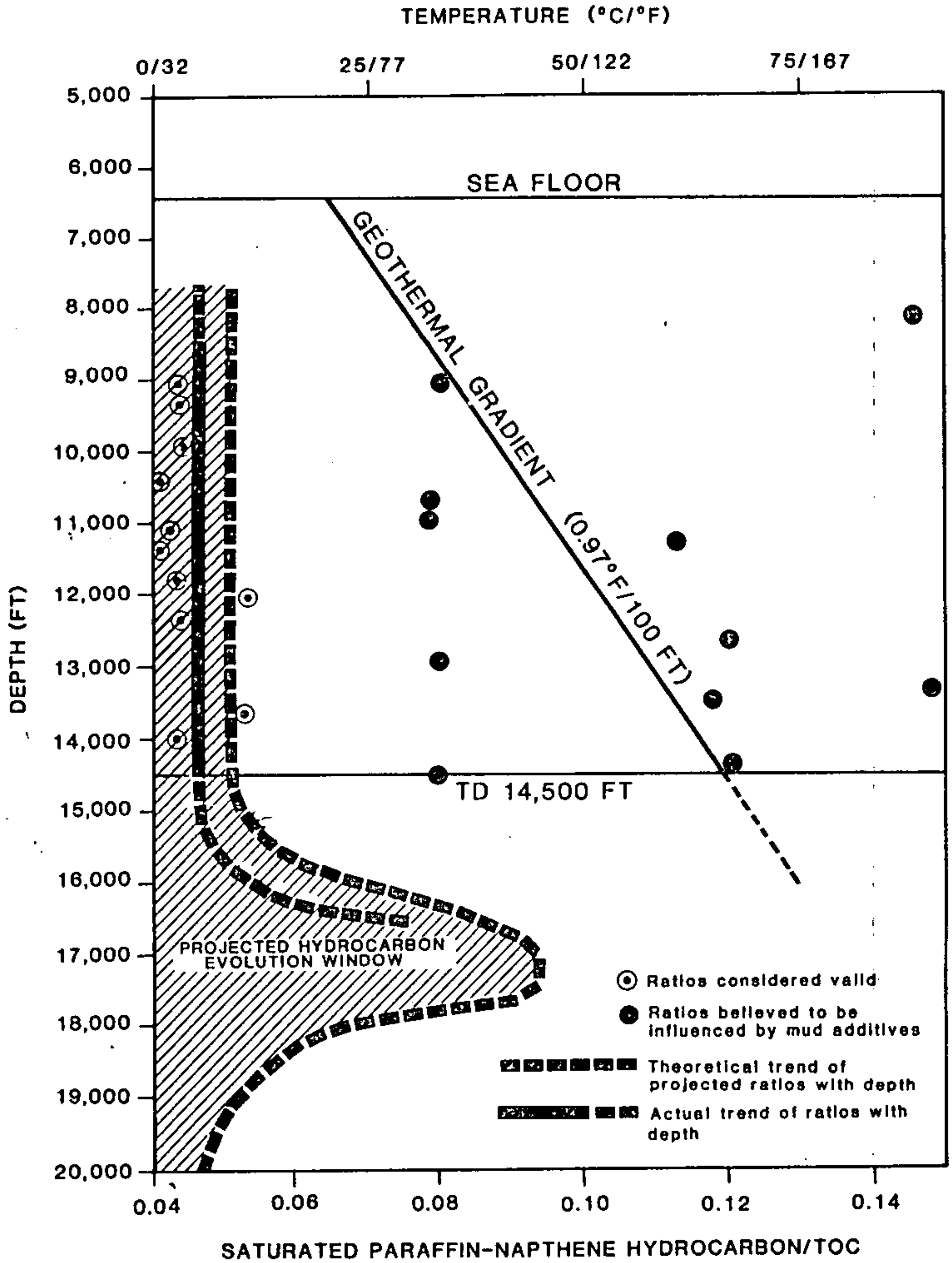

Figure 10.--Hydrocarbon evolution window and geothermal gradient for the Shell 587-1 well.

wetness (75 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 10,500 to 12,000 feet. A second maximum (40 percent) was found to be present at about 14,000 to 14,500 feet. The higher homologs may indicate that petrogenic thermal generation processes are active at greater burial depths. The low gas concentrations in the Shell 587-1 well are discouraging with regard to possible source bed quality in the vicinity of the Jurassic-Cretaceous shelf edge. However, the higher C_1 to C_4 concentrations and the 50 to 60 percent gas wetness of the source beds tested in the Shell 586-1 well behind the shelf edge are encouraging.

The trends of the isopentane-to-n-pentane and n-butane-to-isobutane ratios suggest that low-grade thermal maturation processes are active at burial depths of about 8,000 feet, as indicated by the increase of permanent 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, as well as the predominantly Type III, gas-prone organic matter in the Cretaceous and Upper Jurassic units.

Time-Temperature Burial Model

Time-temperature burial model relationships for the Shell 587-1 well (fig. 11) are based on stratigraphic tops and thicknesses described on pages 19 through 23. The geothermal gradient (0.97°F/100 feet) 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 within the temperature range of 50°C and 110°C, it appears that only Bathonian rocks at the bottom of the well may have approached the onset of petroleum generation within the Quaternary Period. All overlying Middle Jurassic and younger units have not entered the PZOF and, therefore, are not considered to be potential source rocks. These conclusions are consistent with the molecular geochemical determinations made for thermal maturity (see fig. 10) and are somewhat more pessimistic than the light-optical (TAI) determinations (see fig. 8).

The burial history model of the stratigraphic section represented in the Shell 587-1 well suggests the presence of two periods of relatively rapid subsidence and burial: 135 to 121 MYBP and 86 to 78 MYBP. The intervals from 121 to 86 MYBP and 78 to 0 MYBP are believed to be periods of reduced sedimentation and slower subsidence. This sedimentation-burial history, coupled with a low geothermal gradient of 0.97°F/100 feet, suggests a low to moderate time-temperature burial history for the Upper to Middle Jurassic stratigraphic units encountered in the Shell 587-1 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. The Shell 587-1 well is located seaward of the axis of the East Coast Magnetic Anomaly and therefore may be seaward of the transition crust. Those depositional sites that contain Lower Cretaceous and Upper to Middle Jurassic sediments and that are located nearest to the transition crust zone will most likely have had the higher heat flows.

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-C_4	iC_5/ n-C_5
8,000-8,500	0-80	---	---	---
8,500-9,000	3,500-16,500	2-3	0.10-0.80	2.0-8.0
9,000-9,500	500-2,400	2-7	0.10-0.15	1.5-3.5
9,500-10,000	400-500	4-9	0.25-0.40	3.5-7.0
10,000-10,500	400-700	5-25	0.38-0.90	0.80-2.3
10,500-11,000	300-2,000	10-72	0.60-0.85	0.60-0.9
11,000-11,500	200-400	20-60	0.60-0.75	0.80-0.9
11,500-12,000	200-500	12-18	0.65-0.80	1.0-1.5
12,000-12,500	200-800	12-18	0.65-0.85	1.2-1.8
12,500-13,000	200-800	12-18	0.50-0.75	0.80-2.0
13,000-13,500	100-400	14-16	0.30-0.60	1.0-4.54
13,500-14,000	100-400	15-23	0.30-0.50	0.80-4.5
14,000-14,500	800-2,000	22-38	0.20-0.60	0.80-1.1

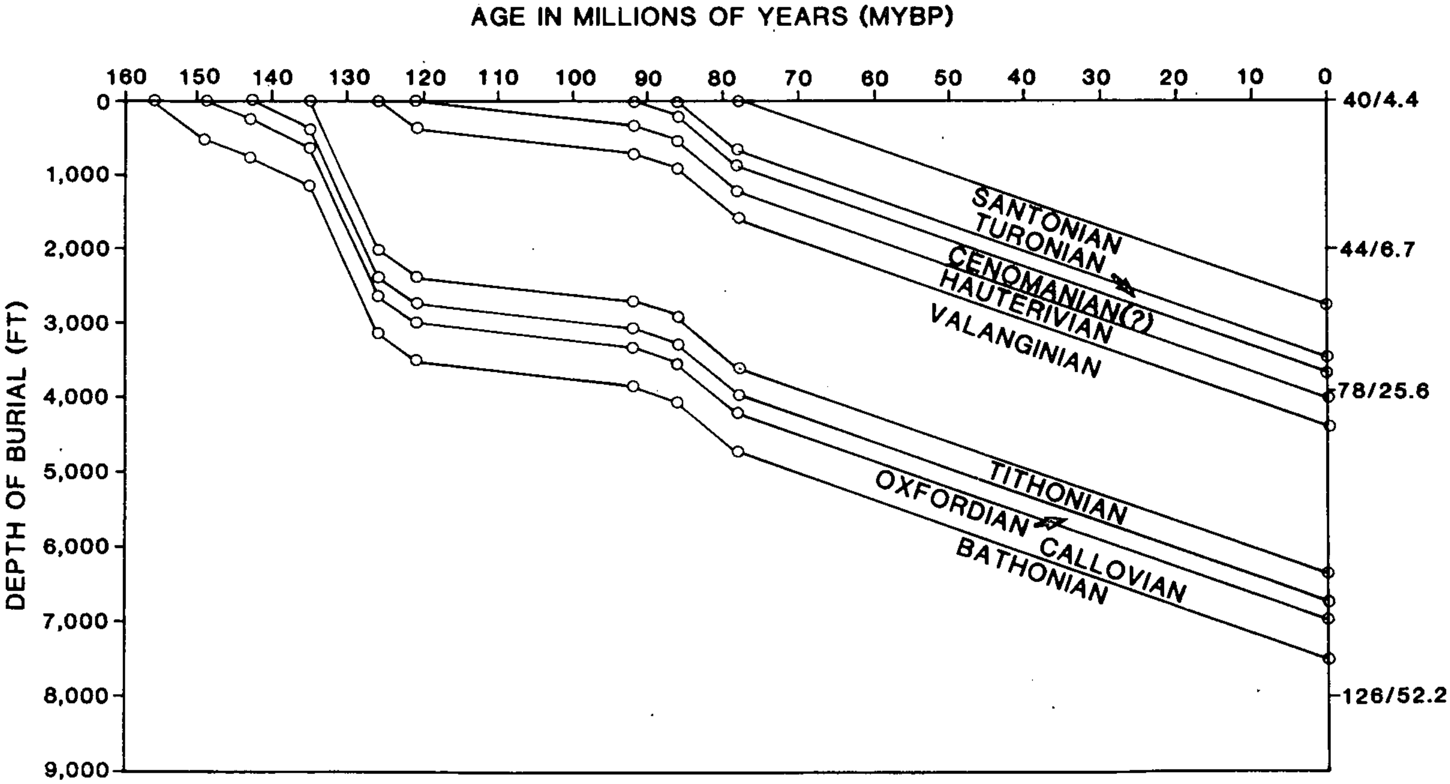

Figure 11.--Time-temperature burial profile for the Shell 587-1 well. Age scale is from Van Hinte (1976 a,b).

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1987—181-410/60024