OCS Report
MMS 2000-035

TENNECO LYDONIA CANYON BLOCK 187 No. 1 WELL

Geological and Operational Summary

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ABBREVIATIONS

API	--	American Petroleum Institute
bbl	--	barrels
BOP	--	Blowout preventer
CNL	--	Compensated neutron log
CPI	--	Carbon Preference Index
COST	--	Continental Offshore Stratigraphic Test
DST	--	drill stem test
EQMW	--	equivalent mud weight
FDC	--	compensated formation density log
FEL	--	from east line
FNL	--	from north line
FSL	--	from south line
FWL	--	from west line
k	--	permeability
KB	--	kelly bushing
LS	--	limestone
m	--	meter (s)
md	--	millidarcy
MYBP	--	million years before present
OCS	--	Outer Continental Shelf
ppf	--	pounds per foot
ppg	--	pounds per gallon
ppm	--	parts per million
psi	--	pounds per square inch
R_O	--	vitrinite reflectance
SS	--	sandstone
Sw	--	water saturation
TAI	--	thermal alteration index
TD	--	total depth
TIOG	--	threshold of intense oil generation
TOC	--	total organic carbon
UTM	--	Universal Transverse Mercator
ϕ	--	porosity

INTRODUCTION

The Tenneco Lydonia Canyon (LC) Block 187 No. 1 well was the fifth of eight industry wildcat wells drilled offshore from Massachusetts on Georges Bank in 1981 and 1982. Spudded on March 12, 1982, the well is about seven miles southeast of the Continental Offshore Stratigraphic Test (COST) G-2 well and 140 miles east-southeast of Nantucket Island. The well was drilled by a semisubmersible rig in 300 feet of water on the continental shelf, about 20 miles west of the shelf edge.

Tenneco Oil Exploration and Production Company (Tenneco) was the designated operator of the well, and the company's drilling targets were Jurassic limestones and dolomites at about 10,000 feet and deeper. Although Tenneco interpreted seismic data as showing a faulted anticline, the company also believed the targets to be stratigraphic. Reservoir facies were modeled as shallow-water, high-energy, porous carbonates, enhanced by dolomitization with increasing depth. Oil was anticipated to a depth of about 15,000 feet and gas below that.

On August 14, 1982, the *Cape Cod Times* published a front-page news story under the headline, "Offshore rigs reportedly locate significant finds of natural gas." In part, this story was apparently based on two 950-unit gas shows encountered in the Tenneco well during drilling at 14,310 to 14,360 feet. Subsequent well tests did not yield significant flows of hydrocarbons, and petrophysical and petrographic study of sidewall cores showed negligible effective porosity. Although some gas was generated in this part of Georges Bank Basin, the rocks targeted and tested by the Tenneco LC Block 187 No. 1 well are apparently not of reservoir quality. The well was plugged and abandoned as a dry hole at a total depth of 18,127 feet on August 21, 1982.

This report relies on geologic and geophysical data provided to the Minerals Management Service (MMS) by Tenneco, according to Outer Continental Shelf (OCS) regulations and lease stipulations. The data were released to the public after the LC Block 187 lease No. OCS-A-0182 was relinquished on January 28, 1985. Interpretations of the data contained in this report are those of MMS and may differ from those of Tenneco. Depths are relative to kelly bushing unless otherwise stated.

The material contained in this report is from unpublished, undated MMS internal interpretations. No attempt has been made to provide more recent geologic, geochemical, or geophysical interpretations or data, published or unpublished.

This report is initially released on the MMS Internet site **http://www.gomr.mms.gov**, and, together with the other Georges Bank well reports, on a single compact disk (CD). At a later date, additional technical data, including well "electric" logs will be added to the CD.

OPERATIONAL SUMMARY

The Tenneco Lydonia Canyon (LC) Block 187 No. 1 well (figure 1) was drilled by the *Alaskan Star* semisubmersible drilling rig to a total depth of 18,127 feet with Tenneco Oil Exploration and Production Company as operator. The well's location, within the lease block, is shown in figure 2. Daily drilling progress is shown in figure 3. Well and drilling information are summarized in table 1. Drilling stipulations required the operator to provide MMS with well logs, lithologic samples, core samples, geologic information, and operational reports.

The well was spudded on March 12, 1982, in 300 feet of water. The casing program is shown in figure 4. The surface hole was drilled to 590 feet, and the 30-inch casing was set at 578 feet and cemented with 185 sacks of H-12 percent gel and 399 sacks of Class H cement. Pressure tests were conducted, and the blowout preventer and marine riser were installed and connected.

The section from the 30-inch casing shoe to a depth of 1,345 feet was drilled in 7.9 hours with one bit. Rates of penetration ranged from 55 to 550 feet/hour, averaging 95.55 feet/hour. The section consisted of soft clay. A 9.1- to 9.3-ppg equivalent lignosulfonated mud system was used. No background or connection gasses were recorded. The 16-inch casing was set at 1,290 feet using 950 sacks of H-12 percent gel and 700 sacks of class H cement with 2 percent calcium chloride. No leak-off test was performed.

The section from the 16-inch casing shoe to 5,025 feet was drilled in 92.5 hours with two bits. Rates of penetration ranged from 12 to 850 feet/hour, averaging 43.2 feet/hour. Rocks penetrated were clays and coarse-grained sandstones. Biogenic gas ran as high as 15 units during the first 2,000 feet; background then dropped to one to three units. Lignosulfonate mud with weights ranging from 9.1 to 9.3 ppg was used. With equipment problems, two weeks were required to ream the hole to 22 inches, and the 13 3/8-inch casing was run to a depth of 4,976 feet and set with 1,628 sacks of 12.9-ppg H-12 percent gel and 500 sacks of 16.4-ppg H-75 percent CFR-2 and 14 percent D-Air2.

The section from the 13 3/8-inch casing shoe to 14,450 feet was drilled in 922.9 hours with 16 bits. Rates of penetration averaged 10.2 feet/hour, and background gas was 10 to 15 units in clastics and 30 to 60 units in carbonates. The mud system was a 9.3- to 11.8-ppg lignosulfonate. The 9 5/8-inch casing was set to 14,409 feet, and cemented with 2,600 sacks of H-8 percent gel with 1,175 sacks H-35 percent SSA-1 and 0.01 FR-2 cement. A leak-off test was performed to 17.04 ppg equivalent. The section from the 9 5/8-inch casing shoe to total depth of 18,127 feet was drilled in 454.3 hours with 9 bits and an average rate of penetration of 8.1 feet/hour. Initially, the lignosulfonate mud was 11.8 ppg and it was increased to 13.8 ppg.

Seven gas shows, ranging from 23 to 950 units, were encountered in drilling the well (see **Formation Evaluation** chapter). The well was perforated at three intervals: 13,650 to 13,660 feet, 13,664 to 13,686

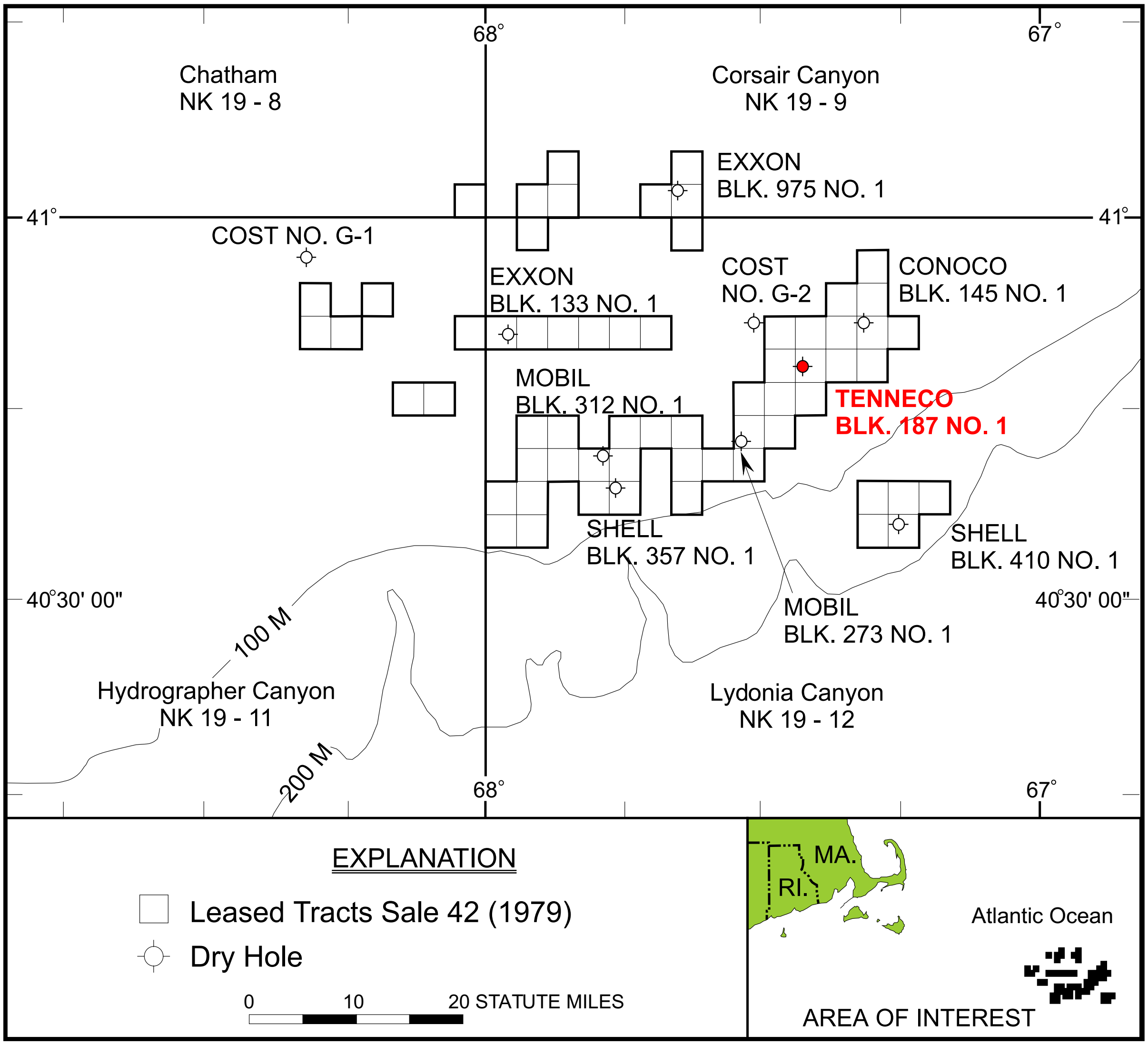

Figure 1. Map of the North Atlantic offshore area showing well locations. The Tenneco Lydonia Canyon Block 187 No. 1 well is highlighted in red. Bathymetry is in meters.

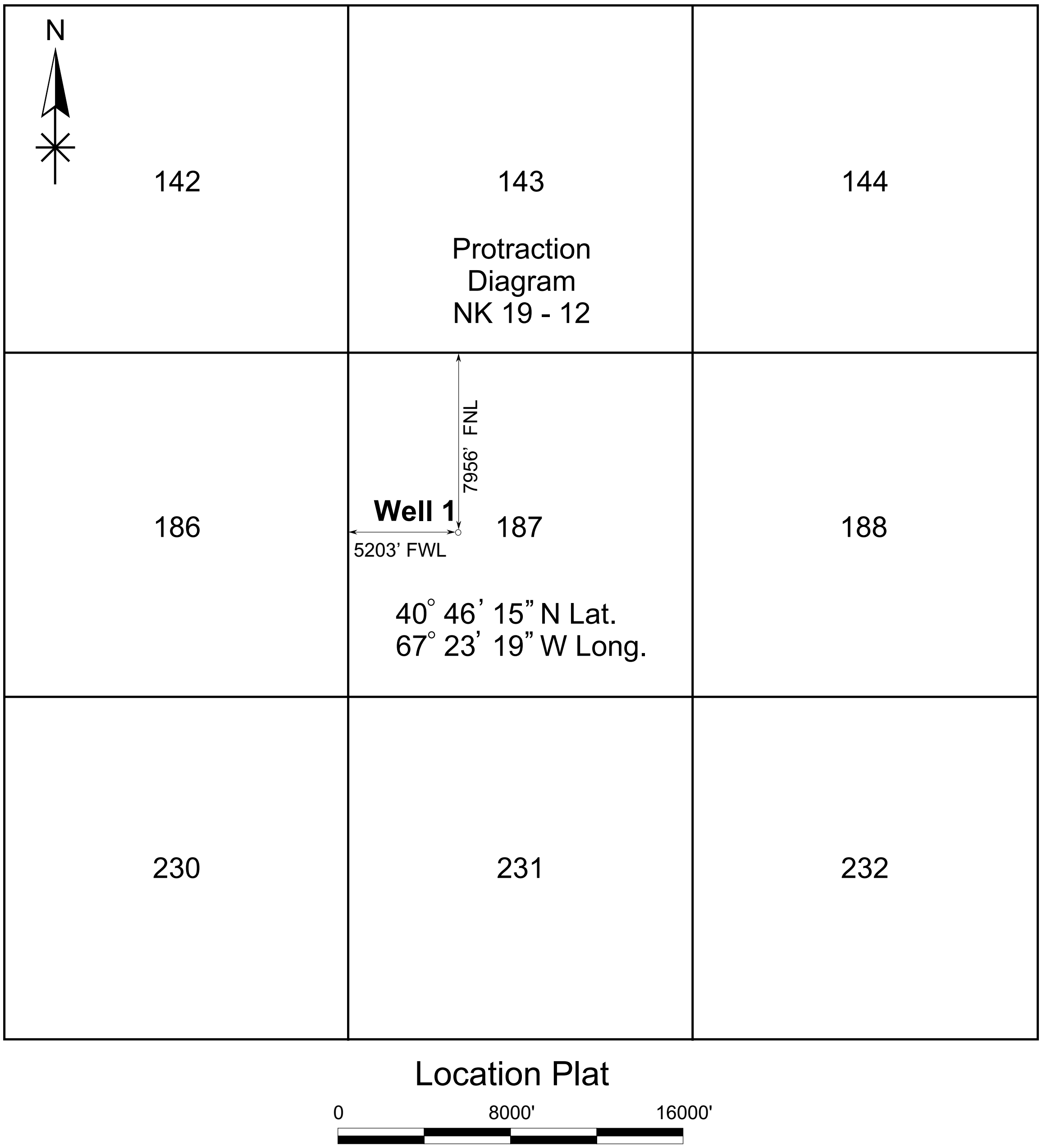

Figure 2. Location plat for the Tenneco Block 187 No. 1 well on the OCS Lydonia Canyon NK 19-12 protraction diagram.

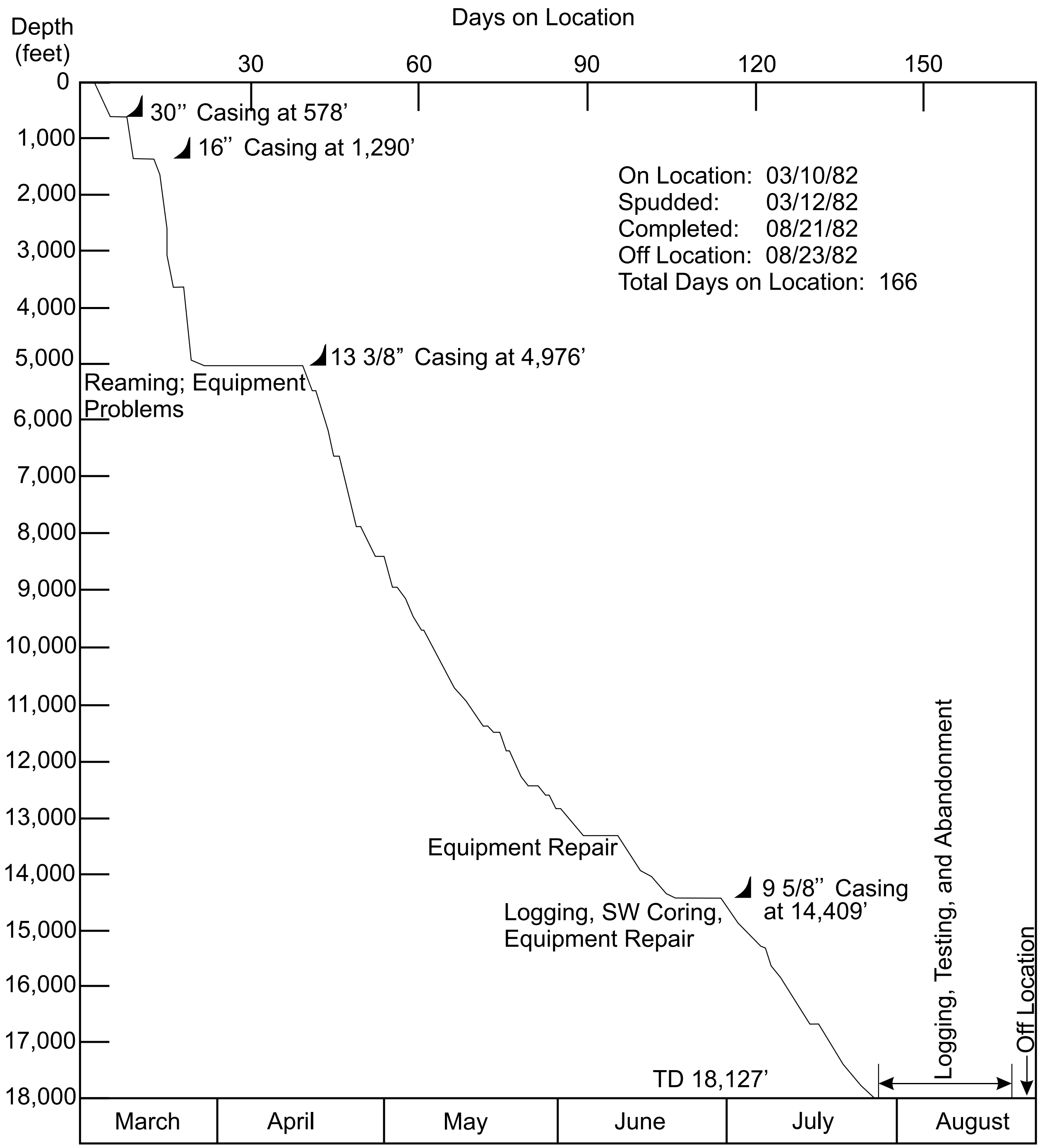

Figure 3. Daily drilling progress for the Tenneco Lydonia Canyon Block 187 No. 1 well.

Table 1. Well statistics

Well identification:	API No. 61-040-00005 Lease No. OCS-A-0182
Surface location:	Lydonia Canyon NK19-12 Block 187 7,956 feet FNL 5,203 feet FWL Latitude: 40° 46' 15" N Longitude: 67° 23' 19" W UTM coordinates: X = 635,986 m Y = 4,514,375 m
Bottomhole location:	106.62 feet N and 79.1 feet E of surface location
Proposed total depth:	21,000 feet
True vertical depth:	18,127 feet
Measured depth:	18,127 feet
Kelly bushing elevation:	83 feet
Water depth:	300 feet
Spud date:	March 12, 1982
Reached TD:	July 28, 1982
Off location:	August 23, 1982
Final well status:	Plugged and abandoned

Note: All well depths indicated in this report are measured from the kelly bushing, unless otherwise indicated. Mean sea level is the datum for the water depth.

feet, and 14,338 to 14,355 feet. A test of the deepest interval was a failure. With reverse circulation, 1,100 units of gas were recovered from the well in a combined test of the upper two perforated intervals; however, well pressure quickly dissipated. Well pressure information is given in the **Formation Evaluation** chapter.

The first plug was set at 16,474 feet to total depth with 638 sacks of cement; however, the drill pipe became stuck, and was cut off at 16,069 feet. Three retainers were set below 14,000 feet that were defective or otherwise not used for cementing. A second cement plug was set with 100 sacks from 13,534 to about 13,800 feet. The 9 5/8-inch casing was cut

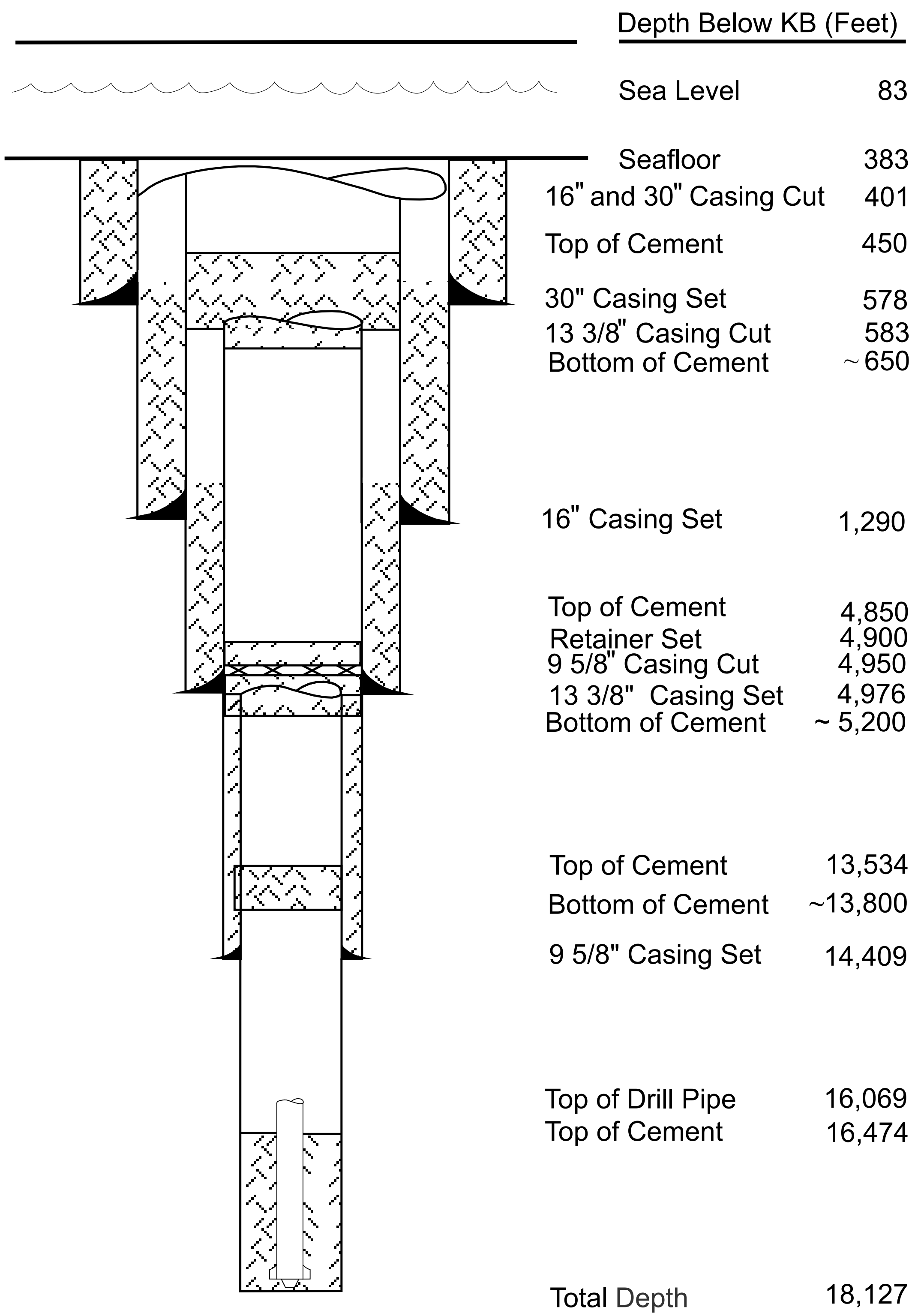

Figure 4. Casing diagram for the Tenneco Lydonia Canyon Block 187 No. 1 well.

at 4,950 feet, a retainer was set at 4,900 feet, and a cement plug set from 4,850 to about 5,200 feet with 250 sacks. The 13 3/8-inch casing was cut at 583 feet and a cement plug set at 450 to about 650 feet with 584 sacks. The 30- and 16-inch casings were cut at 401 feet (18 feet below mudline). The blowout preventer, wellhead, and guidebase were retrieved.

Anchors were pulled and the *Alaskan Star* moved off location on August 23, 1982. John Chance and Associates ran a post-abandonment sidescan-sonar survey.

WELL VELOCITY PROFILE

Seismograph Services Corp., Birdwell Division, ran a velocity checkshot survey between 800 and 18,115 feet in the Tenneco LC Block 187 No. 1 well. The checkshot data, together with that for the other nine wells drilled on Georges Bank, were given to Velocity Databank, Inc. at their request after all leases had been relinquished or had expired. Velocity Databank calculated interval, average, and RMS velocities, plotted time-depth curves, and tabulated the data. Table 2 presents well depth in feet, two-way travel time, and the calculated interval velocities for the Tenneco LC 187 No. 1 well. Figures 5 and 6 show interval velocity, average velocity, and RMS velocity plotted against depth and against two-way travel time. All depths are subsea.

Table 2. Well velocity data

Depth (Feet)	Two-way Travel Time (Seconds)	Interval Velocity (Feet/Sec.)	Average Velocity (Feet/Sec.)	RMS Velocity (Feet/Sec.)
300	0.120	5,000	5,000	5,000
1,227	0.452	5,584	5,429	5,435
1,447	0.512	7,333	5,652	5,690
1,767	0.608	6,666	5,812	5,855
2,127	0.718	6,545	5,924	5,966
2,317	0.768	7,599	6,033	6,085
2,517	0.814	8,695	6,184	6,262
3,027	0.944	7,846	6,413	6,503
3,497	1.054	8,545	6,635	6,745
3,917	1.142	9,545	6,859	7,000
4,087	1.174	10,624	6,962	7,124
4,297	1.220	9,130	7,044	7,209
4,557	1.274	9,629	7,153	7,328
4,717	1.304	10,666	7,234	7,422
5,057	1.368	10,624	7,393	7,602
5,187	1.392	10,833	7,452	7,669
5,347	1.424	9,999	7,509	7,729
5,517	1.452	12,142	7,599	7,838
5,667	1.474	13,636	7,689	7,955
5,817	1.498	12,499	7,766	8,048
5,967	1.526	10,714	7,820	8,105
6,117	1.552	11,538	7,882	8,175
6,267	1.578	11,538	7,942	8,241
6,417	1.604	11,538	8,001	8,305
6,567	1.630	11,538	8,057	8,366
6,717	1.654	12,499	8,122	8,441
6,887	1.680	13,076	8,198	8,532
7,017	1.704	10,833	8,235	8,568
7,142	1.726	11,363	8,275	8,610

continued

Table 2. Well velocity data--*continued*

Depth (Feet)	Two-way Travel Time (Seconds)	Inteval Velocity (Feet/Sec.)	Aveage Velocity (Feet/Sec.)	RMS Velocity (Feet/Sec.)
7,317	1.754	12,500	8,343	8,685
7,467	1.778	12,499	8,399	8,748
7,617	1.800	13,636	8,463	8,824
7,767	1.826	11,538	8,507	8,869
7,917	1.850	12,499	8,558	8,925
8,067	1.872	13,636	8,618	8,995
8,217	1.896	12,499	8,667	9,048
8,367	1.918	13,636	8,724	9,113
8,517	1.944	11,538	8,762	9,150
8,667	1.968	12,499	8,807	9,198
8,742	1.980	12,500	8,830	9,222
8,888	2.006	11,230	8,861	9,251
9,194	2.048	14,571	8,978	9,390
9,649	2.112	14,218	9,137	9,572
9,907	2.148	14,333	9,224	9,671
10,417	2.212	15,937	9,418	9,908
10,827	2.262	16,399	9,572	10,097
11,317	2.314	18,846	9,781	10,375
11,817	2.372	17,241	9,963	10,596
12,252	2.422	17,400	10,117	10,780
12,565	2.454	19,562	10,240	10,940
12,822	2.490	14,277	10,298	10,995
12,905	2.498	20,750	10,332	11,040
13,417	2.550	19,692	10,523	11,283
13,567	2.564	21,428	10,582	11,363
14,257	2.632	20,294	10,833	11,680
14,417	2.646	22,857	10,897	11,767
14,917	2.692	21,739	11,082	12,007
15,417	2.742	19,999	11,245	12,200

A lithologic column is also shown in figure 5, and five velocity intervals are indicated, which generally correlate with lithologic intervals penetrated by the well:

Table 3. Well velocity intervals

Interval	Depth Range (feet)	Interval Velocity Range (feet/second)	Average Interval Velocity (feet/second)
I	0-2,400	6,545-7,599	7,036
II	2,400-5,400	7,846-10,833	9,649
III	5,400-9,000	10,714-13,636	12,314
IV	9,000-12,800	14,218-19,562	16,501
V	12,800-18,128	14,277-22,857	20,198

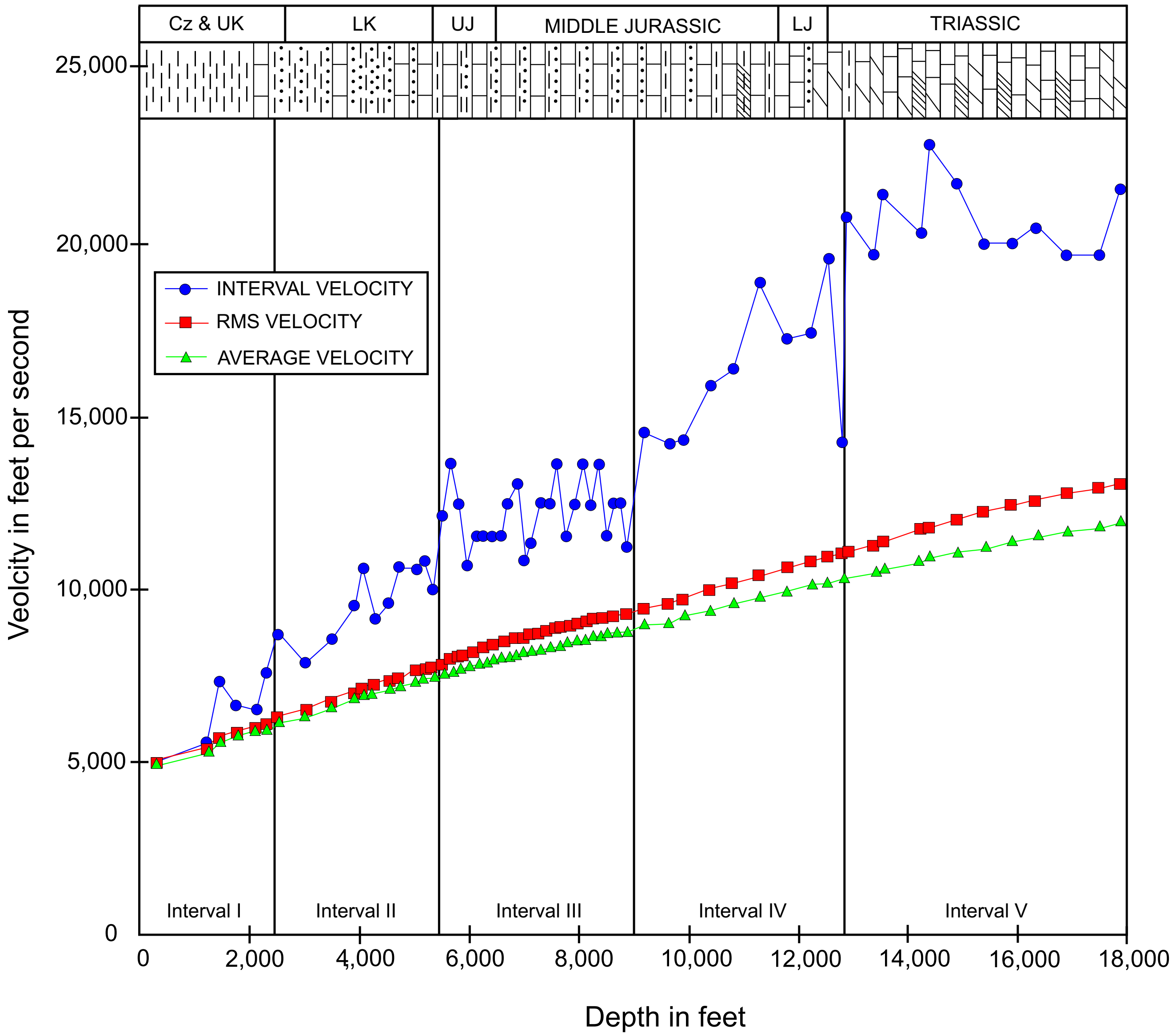

Figure 5. Well velocity profile for the Tenneco Lydonia Canyon Block 187 No. 1 well, plotted against depth, with biostratigraphic ages and generalized lithologies. Intervals are explained in text.

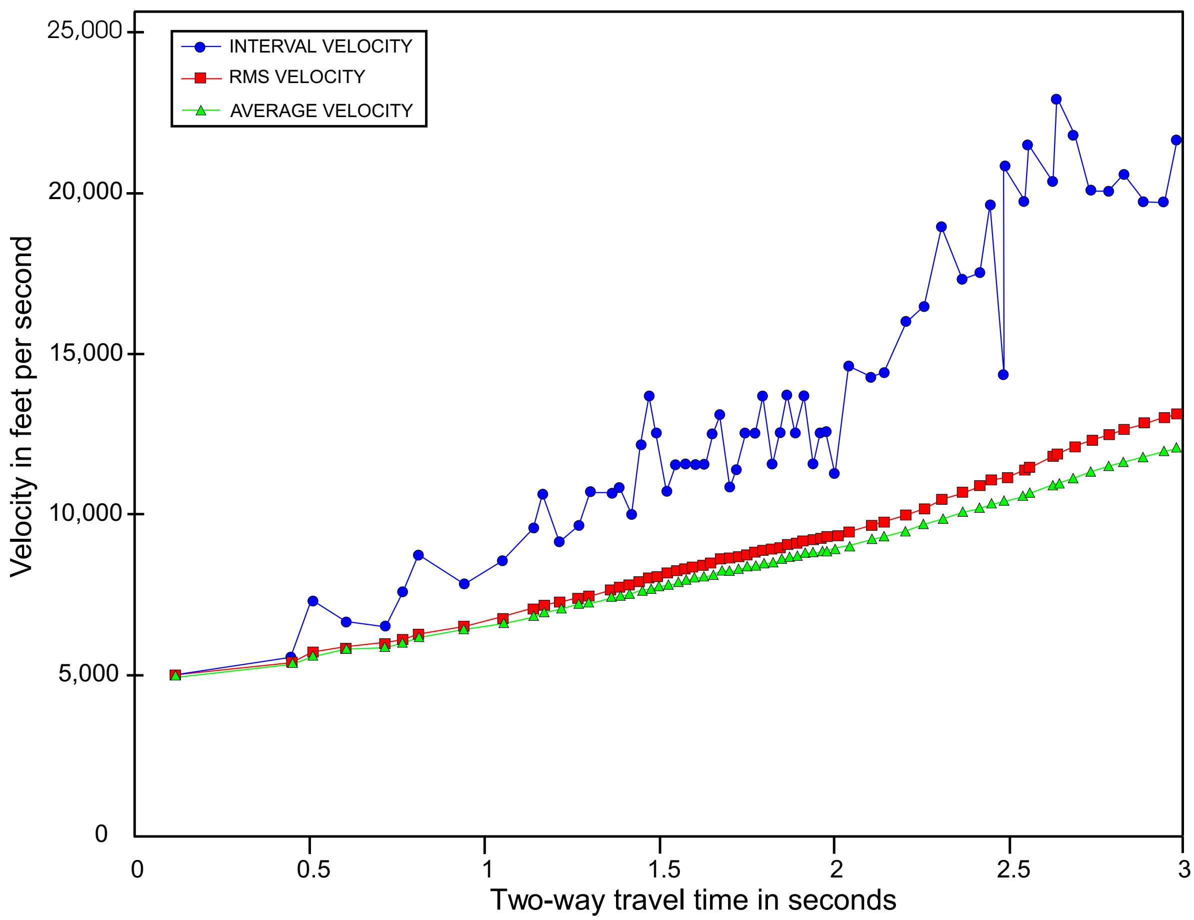

Figure 6. Well velocity profile for the Tenneco Lydonia Canyon Block 187 No. 1 well, plotted against two-way travel time.

Interval I This interval is identified on the basis of low interval velocities, averaging about 7,000 feet per second. (The first reading of 5,000 feet per second at 300 feet is for the water column only.) Interval I includes Cenozoic and Upper Cretaceous lithologies dominated by shale.

Interval II This interval is identified on the basis of somewhat higher velocities, averaging about 9,600 feet per second, and it generally agrees with Lower Cretaceous mixed lithologies.

Interval III This interval produces velocities averaging about 12,300 feet per second, representing Middle and Upper Jurassic mixed lithologies that are probably over half limestone.

Interval IV This interval is identified by high interval velocities, averaging about 16,500 feet per second. The velocity increase likely reflects a larger proportion of limestone, as well as greater depth. This interval represents Lower and Middle Jurassic section.

Interval V The deepest interval averages over 20,000 feet per second, which is appropriate to deep limestone, dolomite and anhydrite. This interval represents Triassic section.

LITHOLOGIC INTERPRETATION

Taken and adapted from R. C. Bowser, MMS internal report

Geologic samples from the Tenneco LC 187 No. 1 well were collected at 30-foot intervals from 1,340 to 4,940 feet, and 10- foot intervals from 4,940 to 18,127 feet. Sample quality appeared to be good throughout the well. The physical formation log, sidewall cores, and well "electric" logs provided additional lithologic control.

The lithologic descriptions of this report are interpretations derived mainly from examination of drill cuttings, supplemented by thin section studies. Depths of lithologic boundaries are adjusted with reference to electric and mud logs. All depths are from kelly bushing. Rocks penetrated are divided into gross lithologic-stratigraphic units, and a lithologic column appears as figure 7.

The interval from 1,340 to 1,850 feet is light-gray to gray-green, slightly calcareous clay. Sand and glauconite present in the clay increase between 1,340 and 1,550 feet. An increase in fossils occurs between 1,550 and 1,850 feet. Present also are traces of muscovite, chalk, and pebbles.

The interval from 1,850 to 2,240 feet is light-gray to gray calcareous clay. Present also are traces of glauconite, sand, muscovite, pyrite, and fossil fragments.

The interval from 2,240 to 2,600 feet is sandstone, clay, and limestone. The sandstone grains are clear to frosted, subrounded to subangular, and medium to very fine. The clay is light gray to gray and calcareous. Present also in this section are traces of glauconite, chert, and fossil fragments. The limestone is white to light gray, microcrystalline and oolitic or pelletal.

The interval from 2,600 to 2,800 feet is sandy clay with orange chert and fossil fragments. The sand grains are clear to white to gray, subrounded to subangular, and fine to medium. From 2,800 to 3,230 feet the section is light gray to gray, calcareous clay with traces of pyrite and glauconite.

The section between 3,230 to 3,620 feet is light-gray to gray calcareous clay, with traces of sand, glauconite, muscovite, chert, and fossil fragments.

The interval from 3,620 to 3,800 feet is calcareous sandstone, with traces of siltstone, lignite, shale, glauconite, pyrite, and fossil fragments. The sandstone is poorly consolidated with clear-to-white and rounded-to-subrounded grains.

From 3,800 to 4,020 feet the section is red-to-brown-to-gray calcareous siltstone, with traces of limestone, muscovite, lignite, and shale.

From 4,020 to 5,100 feet the section consists of sandstone, siltstone, and shale. The sandstone grains are clear to white, rounded to subrounded, and medium sized. The siltstone is light gray to gray and calcareous. The upper 350 feet of the interval is gray to dark-gray, moderately firm, blocky, calcareous shale. A small interval of white to light-gray, microcrystalline, pelletal

Figure 7. Columnar chart of the lithology, biostratigraphy, and paleobathymetry of the Tenneco Lydonia Canyon Block 187 No. 1 well. Lithologic interpretations from examination of cuttings; lithologic breaks picked from well logs. Within columns, depths refer to uppermost occurrence of index fossils listed in Biostratigraphy chapter. Stage tops based on paleontology. Biostratigraphy and bathymetric interpretations become less reliable with increasing depth.

limestone is present at 4,070 feet. Present also in this interval are traces of pyrite, muscovite, and a stringer of lignite at 4,580 feet.

The section from 5,100 to 5,370 feet is tan-gray cryptocrystalline and pelletal limestone and “reefal” bioclastic limestone containing algae, corals, and rudistids interbedded with sand and siltstone. Shale is abundant from 5,300 to 5,360 feet.

The interval from 5,370 to 5,730 feet is light-gray to gray calcareous clay with some white-to-gray limestone toward the bottom. Siltstone is interbedded throughout the section. Present also are traces of sand, lignite, glauconite, muscovite, and fossil fragments.

The interval from 5,730 to 6,200 feet consists of clay, siltstone, and limestone. Gray, unconsolidated, and calcareous clay, interbedded with siltstone, is present from the top of the interval to 5,970 feet. The siltstones, from 5,970 to 6,080 feet, are gray to brown gray and calcareous. From 6,080 to 6,200 feet, the limestone is white to dark gray and interbedded with shale. Present also are traces of pyrite, fossils, and glauconite.

The interval from 6,200 to 9,330 feet consists of interbedded limestone, shale, and sandstone. The limestone is white to gray, variably oolitic and pelletal, cryptocrystalline, and interbedded with shale. Between 7,000 and 7,100 feet, interbedded shales and sandstones gradually replace the limestone. This lithology continues for approximately 1,400 feet and contains lignite stringers. From 8,550 through 9,330 feet, cryptocrystalline limestone with interbedded shale and sandstones is present.

From 9,330 to 10,410 feet, the section consists of white-to- gray oolitic, cryptocrystalline limestone with interbedded calcareous shales and calcareous sandstones. The shales are gray to brown and moderately hard. The sandstone grains are clear to white, fine, and medium to well sorted. Traces of fossils, pyrite, and glauconite exist throughout the section.

The interval from 10,410 to 11,910 feet contains a dark- to light-gray variably oolitic and pelletal, cryptocrystalline limestone with interbedded calcareous shales. The shales are dark gray to black and moderately hard. At 10,680 feet an orange-to-brown soft anhydrite bed is present, and at 11,000 feet there is a stringer of lignite.

The interval from 11,910 to 13,460 feet is white-to-tan-to-light-gray, microcrystalline-to-cryptocrystalline limestone interbedded with dolomite, oolitic limestone, sandstone, and siltstone. Gray microcrystalline dolomite, interbedded with anhydrite, is abundant from 12,950 to 13,360 feet. Between 12,650 and 12,880 feet, the sandstone is red to brown with subrounded to rounded grains. Between 12,930 and 13,330 feet, the siltstone is reddish gray to reddish brown and calcareous. Lignite stringers occur at 12,350 feet, 12,580 feet, and 12,900 feet.

The interval from 13,460 to 18,127 feet consists of limestone and dolomite with limestone predominant in the upper portion of the section and dolomite predominant in the lower. Anhydrite interbeds occur sparingly among the limestone and dolomite. The limestone is light to dark gray, microcrystalline, and variably oolitic. The dolomite is white to light gray and microcrystalline to cryptocrystalline. The anhydrite is soft and variably crystalline. Several lignite stringers and small interbeds of siltstone are also present.

POTENTIAL RESERVOIR ROCKS

Several gas shows were detected during the drilling of Tenneco LC Block 187 No. 1 well. All were in Middle Jurassic to Triassic rocks, and most were in limestone (see the **Formation Evaluation** chapter of this report). Lower Jurassic and older rocks are considered marginally thermally mature to mature (see the **Petroleum Geochemistry** chapter of this report). The zones from 13,615 to 14,325 feet that were shot, acidized, and tested, failed to produce flows of hydrocarbon.

The sidewall core petrophysical analysis for the interval from 9,269 to 18,020 feet shows a porosity range from 5.1 to 22.3 percent and a permeability range of less than 0.1 to 35 millidarcies. However, most permeabilities are less than one millidarcy. No conventional cores were cut in the well. Log analysis yields CNL/FDC porosities that compare well to the sidewall cores down to about 14,000 feet. Below this depth, the indicated log porosities are substantially lower.

BIOSTRATIGRAPHY

Taken and adapted from H. L. Cousminer, W. E. Steinkraus, and R. Hall, MMS internal report

The following biostratigraphic and paleoenvironmental interpretations of the Tenneco LC Block 187 No. 1 well are based on spores, pollen, dinoflagellates, foraminfera, and calcareous nannofossils from well cutting samples. The palynological analysis is based on slides prepared from composite 90-foot samples. Nannofossil data are compiled from 172 slides representing composite 30-foot intervals. The foraminferal biostratigraphy is based on study of 204 slides and also from composite 30-foot intervals.

Two factors limit the reliability of the paleontologic data. (1) 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 (last) appearances of species are used. (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 U. S. offshore Atlantic wells, biostratigraphic control is poor in pre-Late Jurassic strata. Calcareous nannofossils and foraminifera are sparse. Palynomorphs are more common, but their biostratigraphic distribution is not fully documented with reference to the European type-stage localities.

This investigation 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 U. S. offshore Atlantic subsurface. Although the European stage equivalence of many species is not fully resolved, several species have recently been documented in European type sections (Woollam and Riding, 1983; Riding, 1984; Davies, 1985).

No samples are available above the 1,340-foot depth in the well. The Carnian (Late Triassic) is identified at 16,690 feet. Below 16,780 feet, the samples are barren to total depth of 18,127 feet.

Figure 7 shows the depths of all tops based on age-significant palynomorphs, nannofossils, and foraminifera, and also shows paleobathymetric interpretations. All depths are measured from kelly bushing.

MESOZOIC

CRETACEOUS

Late Cretaceous

Campanian (1,340 to 1,430 feet)

The top of the Campanian is based on the highest occurrence of Appendicisporites tricornatatus.

Santonian (1,430 to 1,790 feet)

A Santonian age is indicated by the highest occurrence of the dinocyst Xenascus ceratioides. This interpretation is supported by the highest occurrence of the nannofossil Marthasterites furcatus at 1,520 feet and the planktonic foraminifera Marginotruncana renzi at 1,730 feet. An outer shelf environment of deposition is indicated for this interval.

Turonian (1,790 to 2,120 feet)

The nannofossil Radiolithus planus marks the Turonian top. This age is supported by the foraminifera Praeglobotruncana gibba, P. praehelvetica, and P. stephanii at 1,830 feet. The nannofossil Corollithion achylosum at 1,940 feet also indicates the Turonian.

Cenomanian (2,120 to 2,600 feet)

Two planktonic foraminifera Rotalipora cushmani and R. greenhornensis, the benthonic species Gavelinopsis cenomanica, and the nannofossil Corollithion kennedyi all indicate a Cenomanian top at 2,120 feet. The dinocyst species Litosphaeridium siphoniphorum at 2,420 feet also indicates a Cenomanian age. From 1,730 feet to 2,240 feet, the foraminiferal and nannofossil assemblages indicate an outer shelf environment of deposition.

Eary Cretaceous

Albian (2,600 to 2,780 feet)

The dinoflagellate Hexasphaera asymmetrica indicates the top of the Albian. This interpretation is supported by the highest occurrence of the species Ornamentifera balticata at 2,690 feet. An inner shelf depositional environment is indicated.

Aptian (2,780 to 3,680 feet)

The highest occurrence of the dinoflagellate species Cyclonephelium attadalicum at 2,780 feet indicates an Aptian age. Below this, three nannofossil species occur: at 3,500 feet, Nannoconus globulus; 3,530 feet, N. "ashgeloni"; and 3,620 feet, Micrantholithus obtusus. An inner shelf depositional environment is indicated. Foraminiferal data suggest an Aptian top at 2,210 feet based on the benthonic species Lenticulina nodosa. However, within this interval, 2,210 to 3,920 feet, specimens of the Albian foraminifera Ticinella occur. These, along with the other microfossil data, suggest that L. nodosa is reworked at 2,210 feet.

Barremian (3,680 to 4,400 feet)

The dinoflagellate species Deflandrea perlucida and Pseudoceratium pelliferum occur at 3,680 feet. P. pelliferum does not range above the Barremian on the Scotian Shelf. The highest occurrence of the foraminifera Choffatella decipiens is at 3,920 feet and also indicates a Barremian age. An inner shelf depositional environment is indicated. Below 3,950 feet, the foraminiferal tops are depressed in comparison with the palynologic and nannofossil data and may reflect caving. Thus, based on foraminifera, the Hauterivian top is at 5,180 feet (highest occurrence of Planularia crepidularis and Lenticulina saxonica); the Valenginian top is at 5,270 feet (highest occurrence of Everticyclammina virguliana).

Hauterivian (4,400 to 4,940 feet)

The highest occurrence of the spores Trilobosporites sp. 1, T. sp. 2, T. domitus, and T. bernissartensis at 4,400 feet marks the top of the Hauterivian. The nannofossil species Nannoconus colomi at 4,700 feet also indicates Hauterivian.

Valanginian (4,940? to 5,120 feet)

Very abundant specimens of the dinoflagellate species Oligosphaeridium asterigerum occur at 4,940 feet (also in the Shell LC Block 410 No. 1 well at 5,800 feet), which may indicate a Valanginian top. However, Polystephanephorus sarjeantii is also present and generally does not range above the Berriasian. The difference between the dinoflagellate and foraminiferal data may be the result of caving or sedimentary reworking and incorporation of older material.

Berriasian (5,120 to 5,480 feet)

The nannofossil Polycostella senaria and the dinoflagellate species Occisucysta evittii occur at 5,120 feet, indicating the top of the Berriasian. The uppermost part of the interval (5,120 to 5,180 feet) was deposited in an inner shelf environment. From 5,180 to 5,270 feet, a middle shelf environment of deposition is indicated with middle to inner shelf conditions in the lower part of the interval. Bioclastic "reefal" limestone cutting fragments contain algae, coral, and rudistids in the upper portion of the Berriasian section.

JURASSIC

Late Jurassic

Tithonian (5,480 to 5,750 feet)

The highest occurrence of the dinoflagellate species Ctenidodinium panneum and Glossodinium dimorphum occurs at 5,480 feet, together with the nannofossil Zygodiscus noeli, indicating the top of the Tithonian. The dinoflagellate Gonyaulacysta cladophora at 5,660 feet and the foraminiferan Epistomina stellicostata also indicate Tithonian age. A middle to inner shelf environment of deposition is indicated by the biotic assemblage, as well as pelletal and micritic limestone, sandstone, and shale cutting fragments.

Kimmeridgian (5,750 to 5,930 feet)

The dinoflagellates species Gonyaulacysta longicornis, G. nuciformis, and G. perferans have highest occurrences at 5,750 feet, indicating the top of the Kimmeridgian. A middle to inner shelf environment of deposition is indicated. Lithologies are similar to the previous interval.

Oxfordian (5,930 to 6,380 feet)

The highest occurrence of the dinoflagellate species Adnatosphaeridium emulum indicates Oxfordian age at 5,930 feet. The nannofossil Stephanolithion bigoti at 6,170 feet is also indicative of the Oxfordian. Lithologies are similar to the previous interval.

Middle Jurassic

Callovian (6,380 to 7,100 feet)

The dinoflagellate species Valensiella ovulum and Gonyaulacysta aldorfensis have their highest occurrence at 6,380 feet, indicating a Callovian age. At 6,470 feet, a new species of Adnatophaeridium has its highest occurrence. This species was first noted in the Exxon LC Block 133 No. 1 well at approximately 8,300 feet. Lithologies are interbedded micritic, peloidal and oolitic limestones, gray shale, and sandstone. An inner to middle shelf environment of deposition is indicated. Based on the highest occurrence of the foraminiferan Alveosepta jaccardi, a Kimmeridgian top was noted at 7,070 feet. In comparison with the palynologic and nannofossil data outlined above, this top is probably depressed due to caving.

Bathonian (7,100 to 10,060 feet)

The highest occurrence of the dinoflagellate species Gonyaulacysta filapicata signifies a Bathonian age at 7,100 feet. Ctenidodinium continuum is also present. Lithologies are like the previous interval, except that shale is more abundant. An inner to middle shelf environment is indicated.

Bajocian (10,060 to 10,510 feet)

The highest occurrence of the dinoflagellate Dapcodinium priscum (= Mendicodinium reticulatum) at 10,060 feet indicates the top of the Bajocian. Gonyaulacysta filapicata also continues in abundance. The presence of foraminiferal linings and dinoflagellates indicates a marine environment to 10,510 feet. Litholiogies are similar to those of the previous interval; however, sandstone is absent. The depositional environment is interpreted as low and higher energy inner to middle shelf.

Barren Interval (10,510 to 11,590 feet)

This interval may include the Lower Jurassic Aalenian and Toarcian stages; however, there is no fossil evidence to support this. Cuttings fragments are mostly micritic limestone, together with oolitic limestone and shale. Inner shelf, low and higher energy environments of deposition are indicated.

Early Jurassic

Pliensbachian (11,590 to 11,680 feet)

Single specimens and tetrads of the spore Kaeuselisporites reissingeri have their uppermost occurrence at 11,590 feet, along with the spore Porcellispora longdonensis. On the Scotian Shelf, neither species ranges above the Pliensbachian. The environment of deposition is interpreted as low energy, inner shelf, based on the micritic limestone dominant lithology and on the environments inferred for the overlying and underlying stages.

Hettangian - Sinemurian (11,680 to 12,450 feet)

Peak occurrence of Corollina (Gliscopollis) meyeriana and Cycadopites spp. at 11,680 feet, including C. subgranulatus at 11,770 feet, indicate Hettangian to Early Sinemurian age. Although no marine fossils were recognized, micritic limestone is the dominant lithology, with thin intervals of oolitic limestone, shale, and sandstone. Traces of lignite also occur. A shallow, inner shelf environment of deposition is inferred.

TRIASSIC

Late Triassic

Rhaetian-Norian (12,450 to 14,570 feet)

The highest occurrence of the Late Triassic dinoflagellates Hebecysta brevicornuta, Heibergella asymmetirca, H. salebrosus, and Noricysta spp. at 12,450 feet and the spores Triancoraesporites sp. and Cycadopites spp.

indicate a Rhaetian-Norian age. Corollina meyeriana also indicates the Rhaetian. However, unlike the Scotian Shelf, this interval is marine, based on foraminifera and dinocysts present. The dominantly micritic limestone cuttings contain minor dolomite and anhydrite, as well as shale, sandstone and lignite fragments. Altogether, these characteristics suggest an inner shelf depositional environment.

Barren Interval (14,570 to 16,690 feet)

Kerogen slides indicate that this is a carbonized, barren interval. Cuttings are composed of micritic limestone with increasing amounts of dolomite and anhydrite and minor shaly intervals. An inner shelf to marginal marine environment is indicated.

Carnian (16,690 to 16,780 feet)

Several specimens of Camerosporites secatus and Aratrisporites sp. indicate a Carnian age for this interval. Lithologies are as above, and the same depositional environment is inferred.

Barren Interval (16,780 to 18,127 feet)

This interval is barren to total depth. Cuttings lithologies remain the same, except that dolomite and anhydrite are even more abundant. The lowermost 500 feet are dominated by dolomite. The environment of deposition is interpreted as inner shelf to marginal marine.

FORMATION EVALUATION

Taken and adapted from R. R. Nichols, MMS internal report

Schlumberger Ltd. ran the following geophysical "electric" logs in the Tenneco LC Block 187 No. 1 well to provide information for stratigraphic correlation and for evaluation of formation fluids, porosity, and lithology:

Table 4. Well logs

Log Type	Depth Interval (ft.) Below KB
DISFL/Sonic (dual induction spherically focused log/sonic)	578-14,462
DIL (dual induction laterolog)	8,647-18,135*
CNL/FDC (compensated neutron log/compensated formation density)	1,276-18,135*
HDT (high resolution dipmeter)	4,984-18,135*
CYBERLook	4,979-14,458
RFT (repeat formation tester)	14,550-18,087

* Deepest logging depth listed is greater than the operator's total measured depth of 18,127 feet.

Exploration Logging, Inc. provided a formation evaluation "mud" log, which included a rate of penetration curve, sample description, and graphic presentation of any hydrocarbon shows encountered (1,340 to 18,127 feet). In addition, for the same interval, a pressure evaluation log and a drilling data pressure log were provided.

The electric logs, together with the mud log and other available data, were analyzed in detail to determine the thickness of potential reservoirs, average porosities, and feet of hydrocarbon present. Reservoir rocks with porosities less than 5 percent were disregarded. A combination of logs was used in the analysis, but a detailed lithologic and reservoir property determination from samples and sidewall cores, in addition to full consideration of any test results, is necessary to substantiate the following estimates as shown in table 5.

Table 5. Well log interpretation summary

Epoch	Depth Interval (feet)	Potential Reservoir (feet)[1]	Ave ϕ	SW%	Feet of Hydrocarbon
L K	3,316-3,642	10	32	NC*	NC*
	3,698-3,732	20	33		
	4,176-4,206	25	33		
	4,380-4,495	87	30		
	4,580-4,590	7	31		
	4,640-4,666	23	33		
	4,696-4,747	43	33		
	4,788-4,797	7	31		
	4,803-4,822	17	32		

Continued

Table 5. Well log interpretation summary--*continued*

Epoch	Depth Interval (feet)	Potential Reservoir (feet)[1]	Ave ϕ	SW%	Feet of Hydrocarbon
LK	4,870-4,902	23	32		
	5,200-5,243	18	29		
U J	5,492-5,504	12	11		
M J	6,600-6,609	9			
	6,810-6,832	10	26		
	6,974-7,040	48	24		
	7,151-7,166	15	22		
	7,253-7,266	12	22		
	7,320-7,351	31	23		
	7,398-7,442	27	22		
	7,892-7,902	7	18		
	8,198-8,232	24	19		
	8,278-8,310	9	18		
	8,683-8,703	9	16		
	9,286-9,299	5	5	10	5
	9,414-9,430	16	18	52	16?
U Tr	12,917-12,936	11	8		
	13,649-13,697	27	12	30	-[2]
	14,303-14,350	12	12	14	-[2]
	16,886-16,899	13	9	10	-[3]

* Not calculated for most intervals
[1] Generally in beds > 10 feet thick and > 5%
[2] Test results indicate zone is impermeable
[3] Calculated water saturation is 10%, but total gas is 3 units and permeability from sidewall cores is less than 0.1 md.

The electric logs were of acceptable quality. However, the interval 4,926 to 4,979 feet on the dual induction spherically focused log was not recorded and the dual induction laterolog shows poor repeatability from 14,300 to 14,440 feet.

Fifty-three successful sidewall cores were taken in the well, and table 6 summarizes lithology, porosity, and permeability, as well as bulk gas and oil, for the limestone and sandstone cores. Sidewall core porosities generally compare favorably with CNL/FDC log porosities. However, below 14,200 feet, the log porosities are substantially lower than the sidewall core porosities. The sidewall core bullets may have induced fractures in the harder limestone and dolomite, giving higher apparent porosities in the lower section penetrated by the well.

Table 6. Selected sidewall core data

Depth (feet)	Lithology	Porosity (%)	Permeability (md)	Bulk Gas (%)	Bulk Oil (%)
9,271-9,288	Limestone	13.4-15.7	0.1-0.2	2.0-3.0	0.0
9,416-9,476	Sandstone	17.3-22.3	1.0-35	7.2-8.8	0.0
9,522	Sandstone	14.0	0.7	5.8	0.0
12,357-12,363	Limestone	13.7-14.6	0.1-0.2	3.2-6.5	0.0
12,923	Sandstone	18.4	1.9	3.1	0.0
13,650-13,710	Limestone	7.3-17.0	0.3-4.2	1.6-6.3	0.0-0.2
14,018	Sandstone	17.9	2.1	5.8	0.0
14,064-14,069	Limestone	10.8-17.9	0.3-0.9	1.9-4.6	0.0
14,208-14,210	Limestone	11.6-12.0	< 0.1	3.8-6.0	0.0
14,342-14,600	Limestone	8.0-15.7	< 0.1-0.3	1.8-8.1	0.0-1.8
15,175-15,984	Limestone	5.1-13.1	< 0.1-0.2	1.9-4.8	0.0-0.1
16,445-18,020	Limestone	8.9-16.3	< 0.1-0.4	2.3-3.9	0.0-0.2

CONVENTIONAL CORES

No conventional cores were taken in this well.

DIPMETER

No arrow plots were available from this well.

SIGNIFICANT SHOWS

Table 7 lists shows of hydrocarbon encountered in this well. Of particular significance are the shows encountered from 9,274 to 9,288 feet, 13,630 to 13,670 feet, and 14,310 to 14,360 feet, within the intervals listed in the table.

A flame ionization total hydrocarbon detector performed continuous ditch gas analysis. Output from this detector is recorded in units, where 50 units equal 1 percent methane-in-air. Gas chromatography of the paraffin series from methane (C_1) to normal butane (nC_4) was carried out on a continuous automatic cycling flame ionization detector. The use of a 4-minute cycle may result in formation gas peaks of short duration being missed. Cuttings gas was routinely measured on each unwashed sample, using 100 ml of cuttings in 500 ml of water, blended for 30 seconds, with a waiting period of 30 seconds, before the air-gas mixture was drawn through the catalytic micro-gas analyzer. Results are in units where 50 units are equal to 1 percent methane-in-air. Readings above the 9,274 foot depth are not reported because they are only methane and of probable biogenic origin.

PORE PRESSURE

A normal pressure gradient (approx. 9.0 ppg EQMW) was noted to a depth of 11,505 feet, where trip gas of 383 units was encountered. Pore pressure at this point was estimated at 9.6 ppg. The section from 12,450 to 13,950 feet was drilled with a 10.0-ppg EQMW. At 13,650 feet, the pore pressure was estimated at 10.3 ppg EQMW. From 14,330 to 14,445 feet, the pore pressure increased from 10.6 to 11.7 ppg. The pore pressure was estimated to be 10.2 ppg at 16,600 feet; however, at 16,882 feet, the well kicked (25 bbl.) and pore

Table 7. Hydrocarbon shows and related well information

Depth (feet)	Drilling Break (ft/hr)	Sample Description (Mud Log)	Total Gas b.g.		Cutt. Gas	Chromatography	Sidewall Cores Depth	Sidewall Cores ϕ (%)	Sidewall Cores K (md)	Gas b (%)	Oil b (%)	Well Log Interpretation Depth	Well Log Interpretation ϕ (%)	Well Log Interpretation SW (%)	Tests
9,274 - 9,288	10 - 14	LS, ool, dull org-yel flu, no cut	5	118	—	$C_{1-2-3-4}$	9,286 9,288	13.4 14.1	0.2 0.1	— —	— —	9,286 - 9,299	5	10	—
9,410 - 9,420	10 - 37	SS, hd, no flu, no cut	3	30	—	C_{1-2}	9,416 9,428	17.3 22.3	1.0 35.0	8.8 7.6	— —	9,414 - 9,430	18	52	—
12,330 - 12,345	9 - 25	LS, ool, g ϕ, dull yel flu, no cut	2	40	—	C_{1-2}	—	—	—	—	—	12,337 -12,345	< 5	< 100	—
12,550 - 12,620	—	LS, dull yel flu, occ wht cut/with crshd cuttgs	15	18	—	C_{1}	—	—	—	—	—	—	—	—	—
12,904 - 12,918	5 - 12 (new bit)	SS, hd, no flu, no cut	15	23	—	C_{1-2-3}	12,923	18.4	1.9	—	—	12,917 - 12,936	8	62	—
13,630 - 13,670	8 - 60	DOL & LS, occ g ϕ, yel flu, no cut	15	650	—	C_{1-2-3}	13,650 - 13,670	9.9 - 16.3	1.3 - 2.6	—	—	13,649 - 13,671	12	30	13,615 - 14,325 (?) rec. 73 b/mud 10 b/spacer wtr 29 b/acid (500 units off btm)
13,690 - 13,708	10 - 15	LS & DOL AA, no flu, no cut	23	55	—	C_{1-2-3}	13,690 - 13,710	7.3 - 17.0	0.3 - 0.5	5.2	—	13,695 - 13,697	4	21	
13,750 - 13,760	—	DOL, g ϕ, no flu, no cut	15	80	—	C_{1-2-3}	13,756	(gypsum)		—	—	—	—	—	
14,065 - 14,075	—	Sltstn, hd, no flu, no cut	15	25	—	C_{1-2-3}	14,064 - 14,069	10.8 - 17.9	0.3 - 0.9	—	—	14,062 - 14,070	< 4	100	—
14,160 - 14,170	—	Sltstn, mod ϕ, no flu, no cut	15	35	—	C_{1-2-3}	—	—	—	—	—	—	—	—	—
14,200 - 14,210	7 - 8	LS, ool, g ϕ, dull org flu, no cut	20	45	—	C_{1-2-3}	14,208 - 14,210	11.8	< 0.1	6.0	—	—	—	—	—
14,310 - 14,326	7 - 35	LS, g ϕ, yel-org flu, yel flash cut, brt yel crsh cut, yel-wht pinheads in unwshd sample, tr free oil in mud	10	950	93	$C_{1-2-3-4}$	—	—	—	—	—	14,303 - 14,328	≥ 5	8	14,093 - 14,375 fm. not taking acid 14,157 -14,325 acidize with 800 psi no success
14,340 - 14,360	6 - 8	LS, AA	83	950	22	C_{1-2-3}	14,342 - 14,351	11.5 - 15.7 (blue-wht flu--45 API)	< 0.1 - 0.3	2.5 - 8.1	0.1- 1.8	14,337 - 14,350	15	19	
14,440 - 14,455	5 - 20	LS, hd, no flu, no cut	20	32	—	C_{1-2-3}	—	—	—	—	—	—	—	—	—
15,624 - 15,630	8 - 10	LS, hd, no flu, no cut	2	4	—	C_{1-2}	15,628	8.1	< 0.1	—	—	15,614 - 15,626	< 4	—	—
16,855 - 16,865	9 - 30	DOL, hd, yel flu, no cut	2	2	—	C_{1} (1 unit CO_2)	16,894	13.6	< 0.1	—	—	16,886 - 16,889	9	10	—
16,870 - 16,890	9 - 30	AA (well flowing @ 16,874')	2	3	—	C_{1} (30 unit CO_2)	—	—	—	—	—	—	—	—	—
17,585 - 17,595	8 - 23	DOL, hd, yel-org flu, no cut	1	1	—	C_{1}	—	—	—	—	—	17,593 - 17,604	3	77	—
17,760 - 17,770	8 - 13	DOL, hd, yel flu, no cut	1	1	—	C_{1-2}	—	—	—	—	—	—	—	—	—

pressure was calculated at 12.7-ppg EQMW. Drilling continued with 13.2 ppg mud. The mud weight was then raised to 13.8 ppg after another small invasion of CO_2 at 17,150 feet. Drilling then continued normally until the well was completed.

WELL TESTS

Drillstem tests on selected intervals are summarized in table 8.

Although as much as 950 units of gas were detected while drilling the well, tested intervals had low porosity and very poor permeability.

Table 8. Well tests

Intervals	Recoveries
14,093-14,375	None - formation not taking acid
14,157-14,825	None - acidize with 8,000 psi, no success
13,615-14,325?	Acidize - formation broke at 8,450 psi; left 86 bbl acid in formation; recovered 73 bbl mud, 10 bbl spacer water, 29 bbl acid; reverse circulated 500 units of gas off bottom; pressure decreased to zero in 52 minutes

Note: Perforated intervals and tested intervals reported by the operator are difficult to reconcile.

GEOTHERMAL GRADIENT

Figure 8 shows bottomhole temperatures for seven logging runs in the Tenneco LC Block 187 No. 1 well plotted against depth. A temperature of 60 ^{0}F is assumed at the seafloor at an indicated depth of 383 feet (300-foot water depth plus 83-foot kelly bushing elevation). Shown also is a straight-line graph between the seafloor and total-depth temperatures in order to represent an overall geothermal gradient for the well, which is 1.35 ^{O}F/100 ft. Calculated geothermal gradients for all Georges Bank wells range from 1.06 to 1.40 ^{0}F/100 ft.

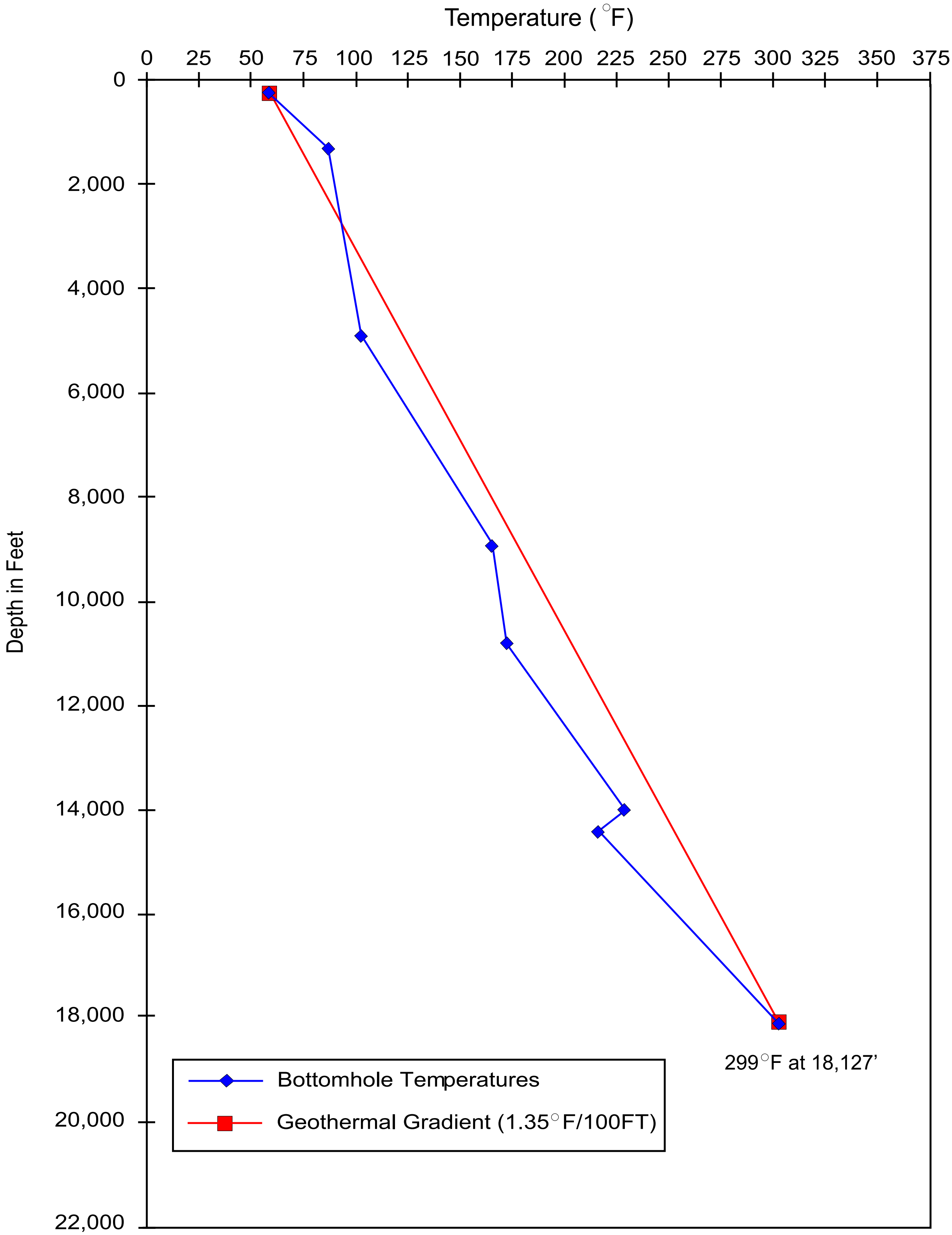

Figure 8. Well temperatures and geothermal gradient for the Tenneco Lydonia Canyon Block 187 No. 1 well. Well temperatures from bottomhole temperatures of logging runs. Geothermal gradient based on bottomhole temperature of deepest logging run.

KEROGEN ANALYSIS

Taken and adapted from C. E. Fry, MMS internal report

Kerogen types and thermal rank were determined by microscopic examination of kerogen slides and palynology slides made from drill cutting samples from the Tenneco LC Block 187 No. 1 well.

For this analysis, organic material dispersed in sedimentary rock is classified as four major types: algal-amorphous, organic material mostly of marine origin, either recognizable algae or its unstructured remains; herbaceous, leafy portions of terrestrial plants including spores and pollen; woody, plant detritus with a lignified fibrous texture; coaly, black opaque material thought to be chemically inert (Hunt, 1979). Visual estimates are made for the percentage of each type, relative to the total abundance of kerogen, contained in each of the slides. Algal and marine-derived kerogen have a high potential for oil generation; more structured terrestrial kerogen has less oil generation potential, but can generate gas at higher temperatures (Tissolt and Welte, 1978).

Thermal maturity of the organic material is estimated by comparing the color of palynomorphs, on both the kerogen and palynology slides, to the thermal alteration index (TAI) scale (figure 9) taken from Jones and Edison (1978). The colors displayed by the organic matter are an indication of the degree to which the kerogen has been thermally altered (Staplin, 1969). Judging thermal maturity using samples from well cuttings must be done with great care to ensure that the material being analyzed is indigenous to the level sampled. Caved or reworked material will each give false indications of maturity. Oxidation caused by a high-energy environment of deposition also can alter the appearance of kerogen. Kerogen type and thermal alteration rank can be used with total organic carbon abundance and molecular geochemical analysis to evaluate the petroleum source rock potential of sedimentary rocks encountered in a well (see **Petroleum Geochemistry** chapter).

KEROGEN TYPE

The Upper Cretaceous rocks of Tenneco LC Block 187 No. 1 well (1,340 feet to 2,600 feet) contain mostly terrestrially derived kerogen. Algal kerogen is 5 to 10 percent of the observed population, herbaceous material is 15 to 35 percent, woody material is 10 to 20 percent, and coaly kerogen ranges from 40 to 70 percent (figure 10). The distribution of kerogen types is more marine within the Lower Cretaceous Series (2,600 to 5,480 feet). Algal kerogen ranges from 10 to 30 percent, and herbaceous, woody and coaly types are generally 30, 30, and 20 percent, respectively, through most of the interval.

Within Upper and Middle Jurassic rocks, kerogen distributions are fairly constant down to 8,000 feet with algal material ranging from zero to 10 percent, herbaceous, about 15 to 40 percent,

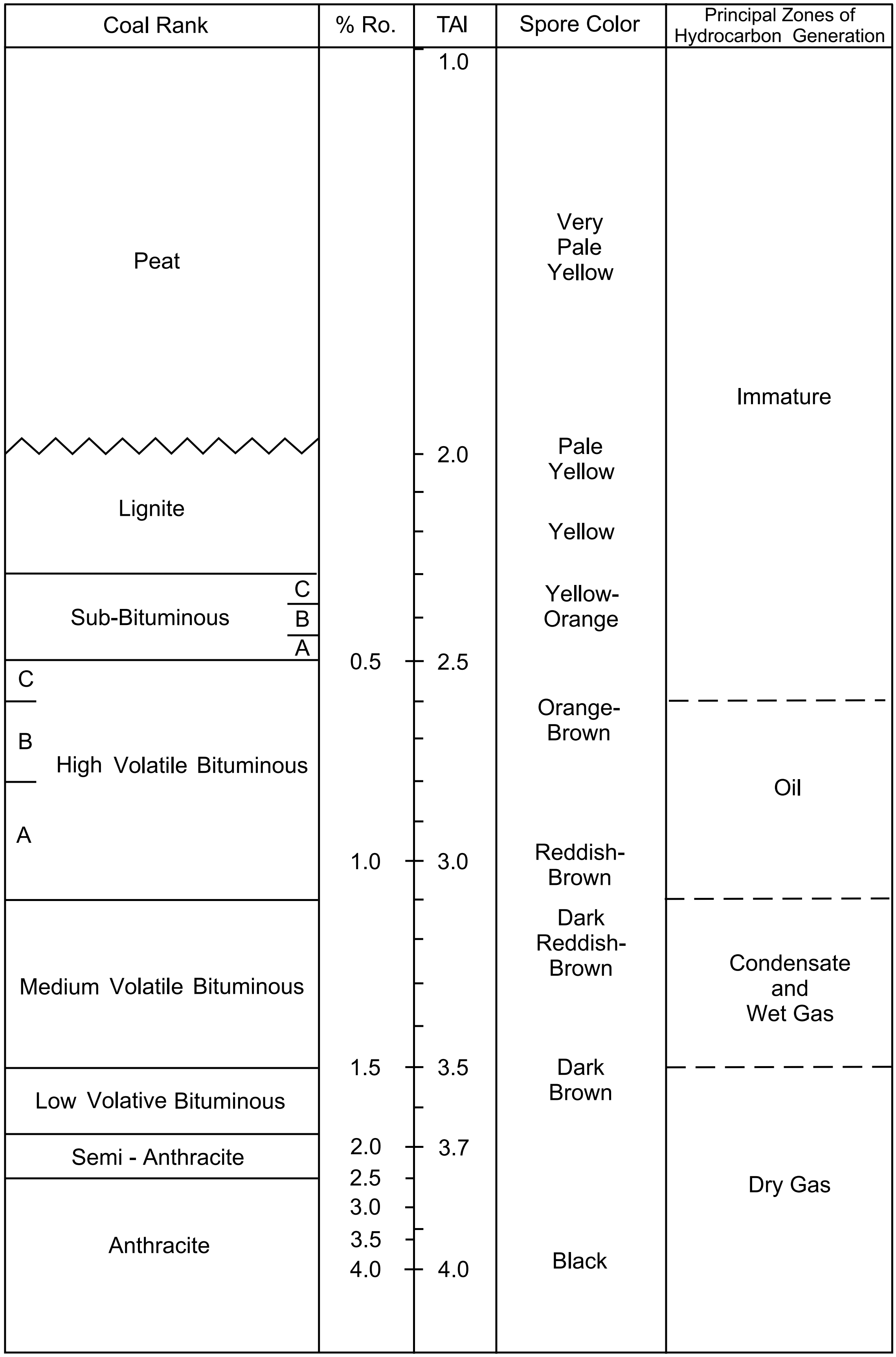

Figure 9. Relationships among coal rank, percent R_o, TAI, spore color, and thermal zones of hydrocarbon generation (after Jones and Edison, 1978).

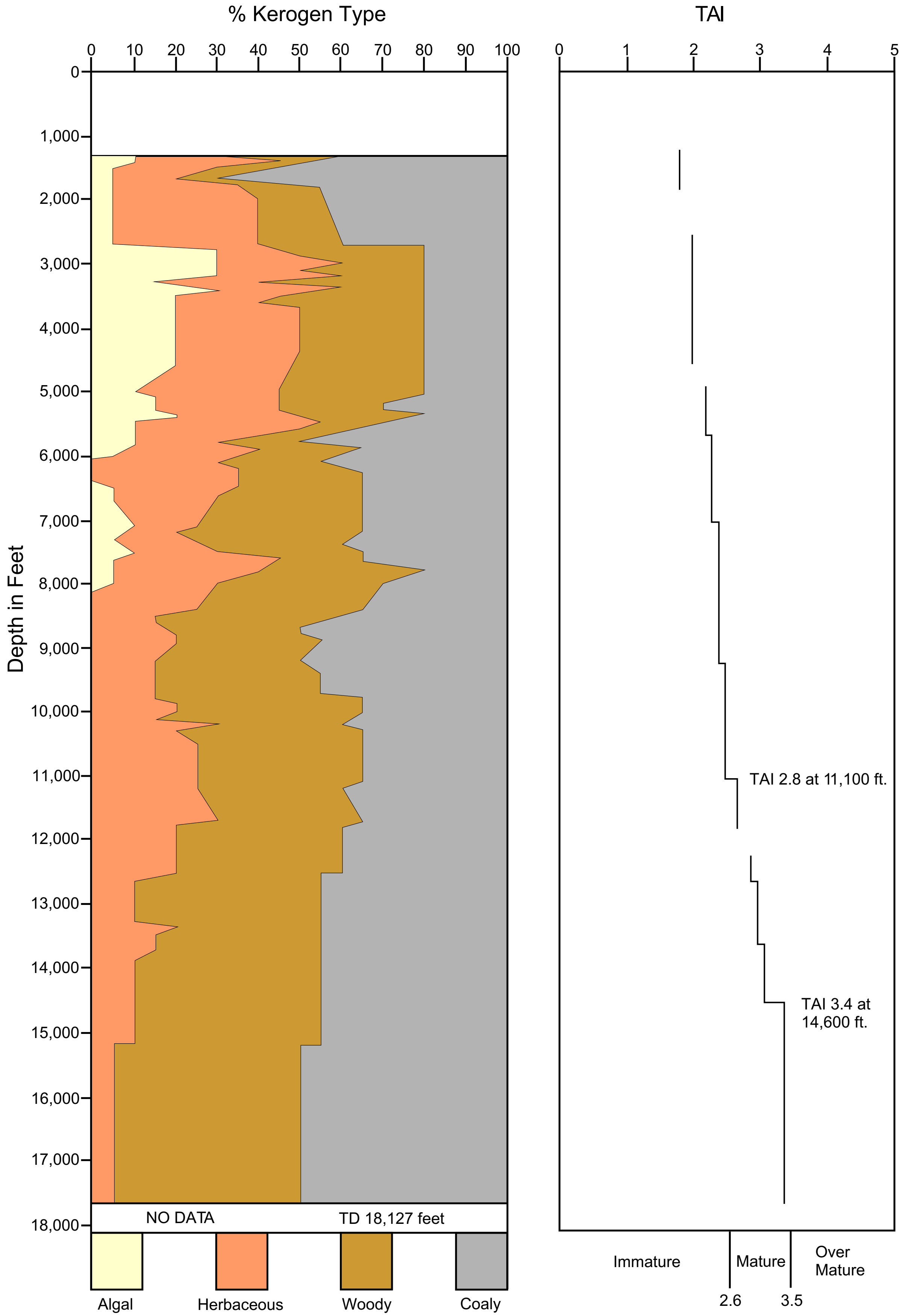

Figure 10. Graph of kerogen types and organic thermal maturity for the Tenneco Lydonia Canyon Block 187 No. 1 well.

woody, about 20 to 40 percent, and coaly, about 20 to 50 percent.

Below 8,000 feet, algal material, if present at all, is only observed in trace amounts. For the remaining Middle Jurassic section, down to 11,590 feet, herbaceous, woody, and coaly kerogens are about 15 to 25, 35 to 40, and 35 to 50 percent, respectively. From the top of the Lower Jurassic (11,590 feet) to T. D. (18,127 feet), herbaceous abundance decreases from as much as 30 percent to 5 percent, and woody and coaly kerogens increase a like amount, together amounting to 95 percent of total kerogens below 15,200 feet.

MATURITY

Organic thermal maturity contained in the Tenneco LC Block 187 No. 1 well was estimated by the visual observation of palynomorph color (figure 10). The first evidence of mature colors occurs in lower Middle Jurassic rocks at 11,140 feet. The orange/brown color of the dinoflagellates found at this depth corresponds to the TAI value of 2.7 representing a thermal maturation level just beyond borderline maturity. Colors indicating peak maturity occur below 12,450 feet, within the Upper Triassic. Palynomorphs exhibiting the highest maturity colors (3.4 TAI) occur at 14,630 feet and below.

CONCLUSION

Lower Cretaceous sedimentary rocks of the Tenneco LC Block 187 No. 1 well contained the greatest and perhaps significant amounts of marine oil-prone source material. However, thermal maturity through this interval was too low (2.0 to 2.2 TAI) to expect the generation of hydrocarbons.

Organic material with mature colors (>2.6 TAI) first occurred at 11,140 feet. Colors representing peak maturity (3.0 TAI) were observed below the Triassic boundary at 12,450 feet. Within the thermally mature section there is virtually no algal-amorphous organic matter, and with greater depth, woody and coaly kerogens increasingly predominate. With sufficient organic richness, Lower Jurassic and Triassic rocks would most likely produce natural gas. Very mature kerogen (>3.4 TAI) observed at 14,720 feet further suggests gas. As temperature rises, any oil and gas condensates are converted to gas.

PETROLEUM GEOCHEMISTRY

Taken and adapted from R. E. Miller, D. M. Schultz, H. Cousminer, D. T. Ligon, Jr., and H. E. Lerch, MMS internal report

Note: The Petroleum Geochemistry Group, which operated a laboratory in Reston, Virginia, is no longer in existence. Most of the analytical data that this report is based on are not available.

The objectives of this study are to assess source-rock potential, thermal maturity, and types of organic matter within stratigraphic intervals of the Tenneco LC Block 187 No. 1 well and to evaluate the thermal history and any resulting hydrocarbon generation in the vicinity of the well.

ANALYTICAL METHODS AND PROCEDURES

The Petroleum Geochemistry Group analyzed 18 well cutting samples for their C_{15+} characteristics and 69 gas samples from canned cuttings from well depths of 1,490 to 18,127 feet. The headspace gas in one-quart cans of unwashed cuttings samples was first analyzed to determine the concentration of the C_1 to C_4 light hydrocarbons.

After the head-space light gas 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. The samples were then examined with a binocular microscope, described, and divided into aliquots for total organic carbon analyses, gasoline-range hydrocarbon analysis, Soxhlet solvent extraction, liquid-column chromatography, and high-resolution glass capillary gas chromatography of the saturated paraffin-naphthine hydrocarbon fractions. Details of these methods and procedures are described in Miller and others (1979, 1980, 1982).

RESULTS AND DISCUSSION

<u>SOURCE-ROCK RICHNESS</u>

The Cretaceous stratigraphic interval (1,340 to 5,480 feet) consists of interbedded silty shales and sands with a few limestone units in the Berriasian (5,120 to 5,480 feet). Total organic carbon (TOC) values for this stratigraphic interval range from 0.22 to 7.65 weight percent (compare with table 9 and figure 11, which show Tenneco TOC data that range from 0.10 to 2.00 percent for this interval). The higher values are believed to be associated with coaly and lignitic organic matter in the bulk samples. The total extractable hydrocarbons reach a maximum of 671 ppm at 4,580 in the Hauterivian. This same sample contains nitrogen, sulfur, and oxygen (NSO) compounds totaling 1,274 ppm, further suggesting the influence of coaly and lignitic organic matter.

Table 9. Total organic carbon
Data submitted by Tenneco

Epoch	Stage	Depth (feet)	TOC(%)
UK	Campanian	1,340	0.25
	Santonian	1,520	0.20
		1,710	0.20
	Turonian Cenomanian	1,940	0.60
		2,120	0.75
		2,300	0.10
		2,420	0.10
LK	Aptian	2,780	0.70
		3,020	0.70
		3,200	1.00
		3,380	0.60
		3,620	0.50
	Barremian	3,800	0.25
		3,980	0.30
	Neocomian	4,220	0.45
		4,400	0.60
		4,580	2.00
		4,820	0.20
		5,000	0.80
		5,220	0.15
		5,400	0.25
UJ	Tithonian Kimmeridgian	5,600	0.25
		5,800	0.20
	Oxfordian	6,010	0.35
		6,200	0.40
MJ	Callovian	6,400	0.30
		6,620	0.35
		6,820	0.50
		7,020	0.50
	Bathonian	7,200	0.50
		7,410	0.60
		7,590	0.55
		7,800	0.55
		8,000	0.60
		8,200	0.45
		8,400	0.40
		8,600	0.60
		8,800	0.45
		9,000	0.35
		9,200	0.30
		9,400	0.30
		9,600	0.65
		9,800	0.50
		10,000	0.35
	Bajocian	10,200	0.25

continued

Table 9. Total organic carbon--*continued*

Epoch	Stage	Depth (feet)	TOC(%)
MJ	Bajocian	10,400	0.30
		10,600	0.30
		10,800	0.25
		11,000	0.25
		11,200	0.20
		11,400	0.30
LJ	Pliensbachian	11,600	0.20
	Hettangian-Sinemurian	11,800	0.30
		12,000	0.30
		12,200	0.20
		12,400	0.20
UTr	Rhaetian-Norian	12,600	0.40
		12,800	0.40
		13,000	0.45
		13,200	0.30
		13,400	0.40
		13,600	0.50
		13,800	0.25
		14,000	0.40
		14,200	1.00
		14,400	1.65
		14,600	0.25
		14,800	0.20
		15,000	0.80
		15,200	0.35
		15,400	0.10
		15,600	0.10
		15,800	0.30
		16,000	0.10
		16,200	0.15
		16,400	0.25
		16,600	0.20
	Carnian	16,800	0.15
		17,000	0.35
		17,200	0.25
		17,400	0.70
		17,600	0.80
		17,800	0.30
		18,000	0.45
		18,127	0.30

Middle and Upper Jurassic rocks from the Tithonian to the Bajocian Stage (5,480 to 10,060 feet) consist of interbedded calcareous shales, sands, and carbonates. TOC values for this stratigraphic interval range from 0.67 to 0.72 percent (0.20 to 0.60 percent, Tenneco data). Total extractable hydrocarbons vary from 15 to 146 ppm with NSO's ranging from 35 to 74 ppm. This range of organic content places Middle to Upper Jurassic

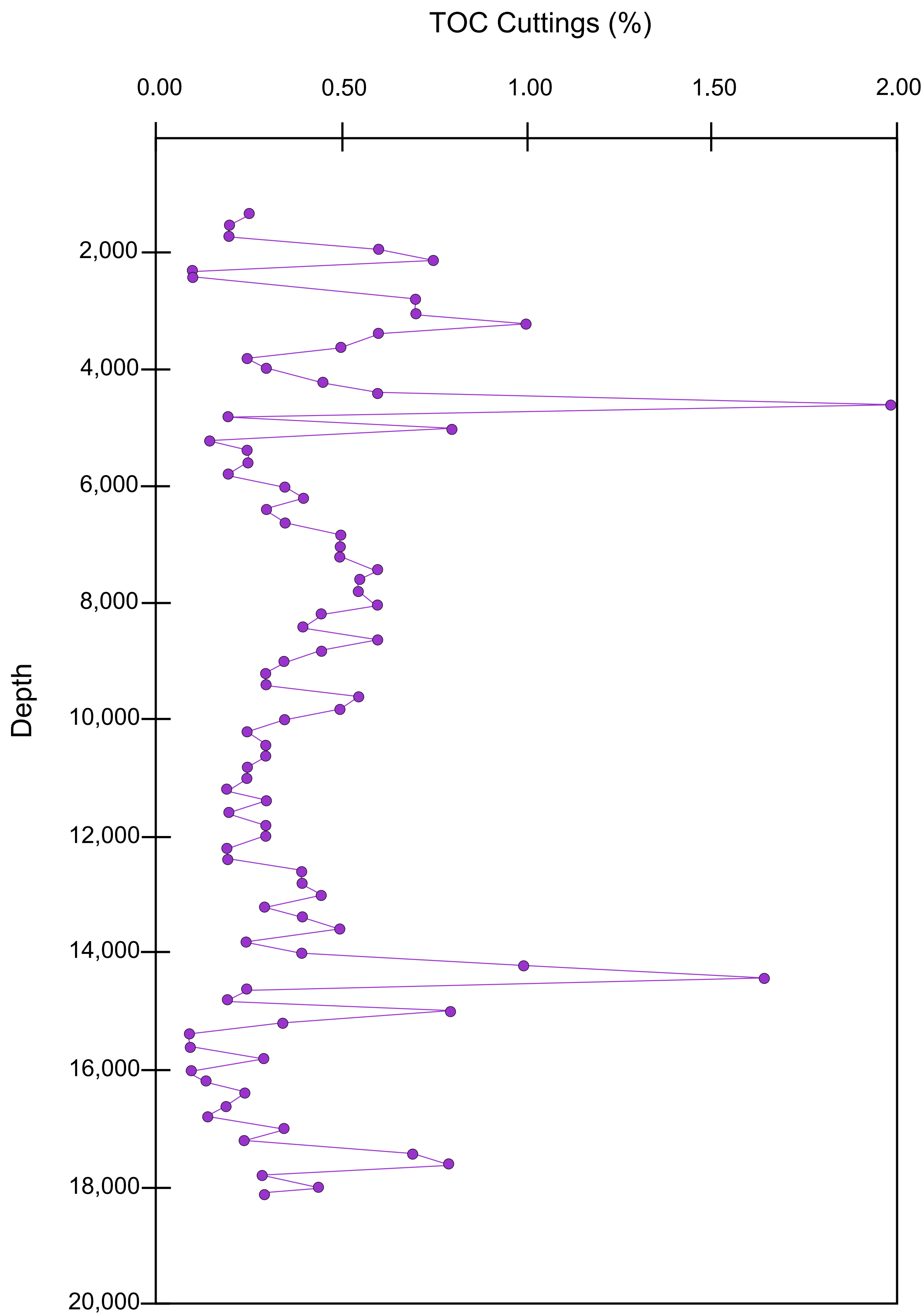

Figure 11. Graph of total organic carbon plotted against well depth for the Tenneco Lydonia Canyon 187 No. 1 well. Data are from Tenneco.

shales and carbonates in the poor to fair source-rock category.

The Middle (?) and Lower Jurassic interval of 10,510 to 12,450 feet is characterized by increased amounts of carbonate rocks. The higher proportion of carbonates correlates with a decrease in TOC (0.18 to 0.36 percent, MMS data; 0.20 to 0.30 percent, Tenneco data). Total extractable hydrocarbons and extractable NSO compounds are also low, ranging from 20 to 54 ppm and 20 to 38 ppm, respectively. These values indicate poor quality for Lower Jurassic potential source rocks.

Late Triassic dinoflagellates were identified at 12,450 feet (Rhaetian) and 16,690 feet (Carnian) (see **Biostratigraphy** chapter). The predominant lithologies are limestone and dolomite with interbedded silty, calcareous shales. TOC values range from 0.11 to 0.31 percent (0.10 to 1.65 percent, Tenneco data) from 12,450 feet to total depth, 18,127 feet. Such values are in the poor to fair category for carbonates. However, the weight percent of TOC required to make an excellent, good, or poor source rock is less well defined for fine-grained, medium- to dark-gray limestones and dolomites than for shales and mudstones. Hunt (1979) points out that because of the amorphous nature of Type-I kerogen derived from hydrogen-rich marine algae, these carbonates may have the potential to generate more hydrocarbons than shales with the equivalent amounts of total organic matter. Therefore, medium- to fine-grained, dark-gray to dull-brown limestones and dolomites with a TOC content as low as 0.3 weight percent may have sufficient richness to be classified as source rocks (Hunt, 1967; Miller and others, 1982). In the Tenneco LC Block 187 No. 1 well, the possible source rocks - those which are thermally mature - have organic richness qualities that are in the poor to fair category. Such source-rock categories are similar to those that occur in the COST G-2 and the Shell LC Block 410 No. 1 wells and lower than those of the Exxon LC Block 133 No. 1 well.

KEROGEN ELEMENTAL ANALYSIS

Hydrogen-to-carbon ratios vary from 0.11 to 0.76 in the Tenneco LC Block 187 No. 1 well. These low values are consistent with hydrogen-poor Type III, woody and coaly, gas-prone kerogen types reported in the **Kerogen analysis** chapter of this report. The highest hydrogen-to-carbon ratio (0.76) occurs at a well depth that coincides with the zone of peak hydrocarbon evolution (figure 12). This ratio suggests that any thermal generation products of this Type-III kerogen will be gas and possibly some gas/condensate.

THERMAL MATURITY

The hydrocarbon evolution window for the Tenneco LC Block 187 No. 1 well is shown in figure 12. The evidence provided by the temperature-sensitive geochemical ratio of the C_{15+} saturated hydrocarbon-to-TOC, plotted as a function of well depth, shows that the threshold of intense oil generation (TIOG) occurs at a well depth of about 11,000 feet. Peak hydrocarbon generation occurs between 12,500 and 14,000 feet. There is consistent agreement between these high-molecular-weight geochemical maturation depths and thermal alteration index (TAI) determinations made by viewing kerogen slides in transmitted light (figure 10).

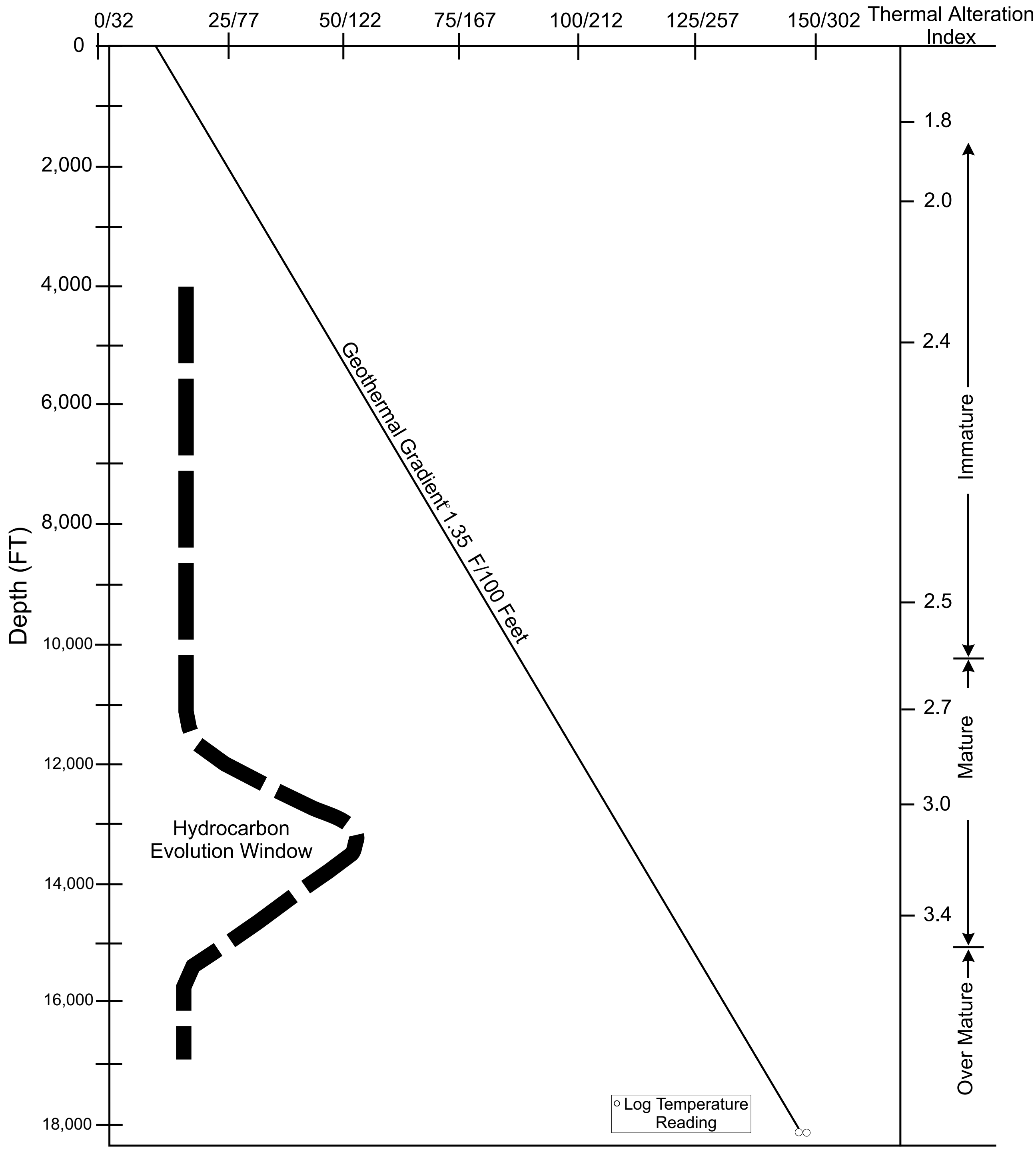

Figure 12. Hydrocarbon evolution window, geothermal gradient, and thermal maturity (TAI) plotted against well depth for the Tenneco Lydonia Canyon Block 187 No. 1 well.

Colors that indicate marginal thermal maturity were observed in the Middle Jurassic at 11,140 feet with a TAI value of 2.7. Peak generation TAI colors (reddish brown = 3.0) were observed in Upper Triassic rocks at 12,700 feet. More mature darker brown colors were detected at 14,630 feet with a TAI value of 3.4. A geothermal gradient of 1.35 ^{O}F/100 feet, based on bottomhole temperatures, indicates a temperature of 100 ^{O}C at about 12,000 feet, consistent with peak generation at about the same depths indicated by geochemical and optical maturation studies.

Three temperature-sensitive light-hydrocarbon molecular geochemical ratios (n-C_4/iso-C_4), (n-C_4/methylcyclopentane), and (cyclohexane/methalcyclohexane) were also plotted as a function of well depth. These ratios are consistent with the C_{15+} saturated hydrocarbon-to-TOC ratio and TAI assessment of the depth of the hydrocarbon-evolution window in this well. Biostratigraphic age determinations indicate that peak hydrocarbon generation occurs within the Late Triassic Rhaetian-Norian.

The light gases C_1-C_4 (methane through butane) were analyzed as headspace components. Total C_1-C_4 concentrations range from 105 ppm in the Barremian to 4,409 ppm in the Late Triassic. The maximum gas wetness (74%) is reached at a depth of 13,000 to 13,500 feet. This also coincides with the zone of peak hydrocarbon generation. Hydrocarbon generation processes are in place; however, low total gas concentrations raise questions about the richness of the potential source rocks within the generation window.

BURIAL MODEL

The burial model for the stratigraphic section penetrated in the Tenneco LC Block 187 No. 1 well (figure 13) is based on the biostratigraphic determinations of the Minerals Management Service paleontological staff (figure 7) and the Cretaceous and Jurassic time scale of Van Hinte (1976a and 1976b). The burial model for the Tenneco LC Block 187 No. 1 well is similar to those of the COST G-1, G-2, and the other industry wildcat wells on Georges Bank. The Upper Triassic-Lower Jurassic boundary occurs at a well depth in the Tenneco LC Block 187 No. 1 well of 12,450 feet. This coincides with the zone of peak oil generation within the context of the hydrocarbon-evolution window.

The basin model time-temperature history curve for the Tenneco LC Block 187 No. 1 well shows three major subsidence and sediment loading events. The initial phase of Triassic-Early Jurassic rifting from 212 to 180 MYBP was followed by rapid Jurassic subsidence and deposition until 156 MYBP (Bathonian) when basin subsidence and loading were reduced. This period of basin activity continued to 97 MYBP (Cenomanian), after which a Late Cretaceous-Cenozoic quiet period of even less subsidence was established that has continued to the present. On the basis of the present-day geothermal gradient, Upper Triassic and perhaps lower Lower Jurassic sediments became thermally mature for petroleum generation 60 to 70 million years ago. The generation potential is believed to favor wet gas/gas condensate for the Type-III source shales within the hydrocarbon evolution window.

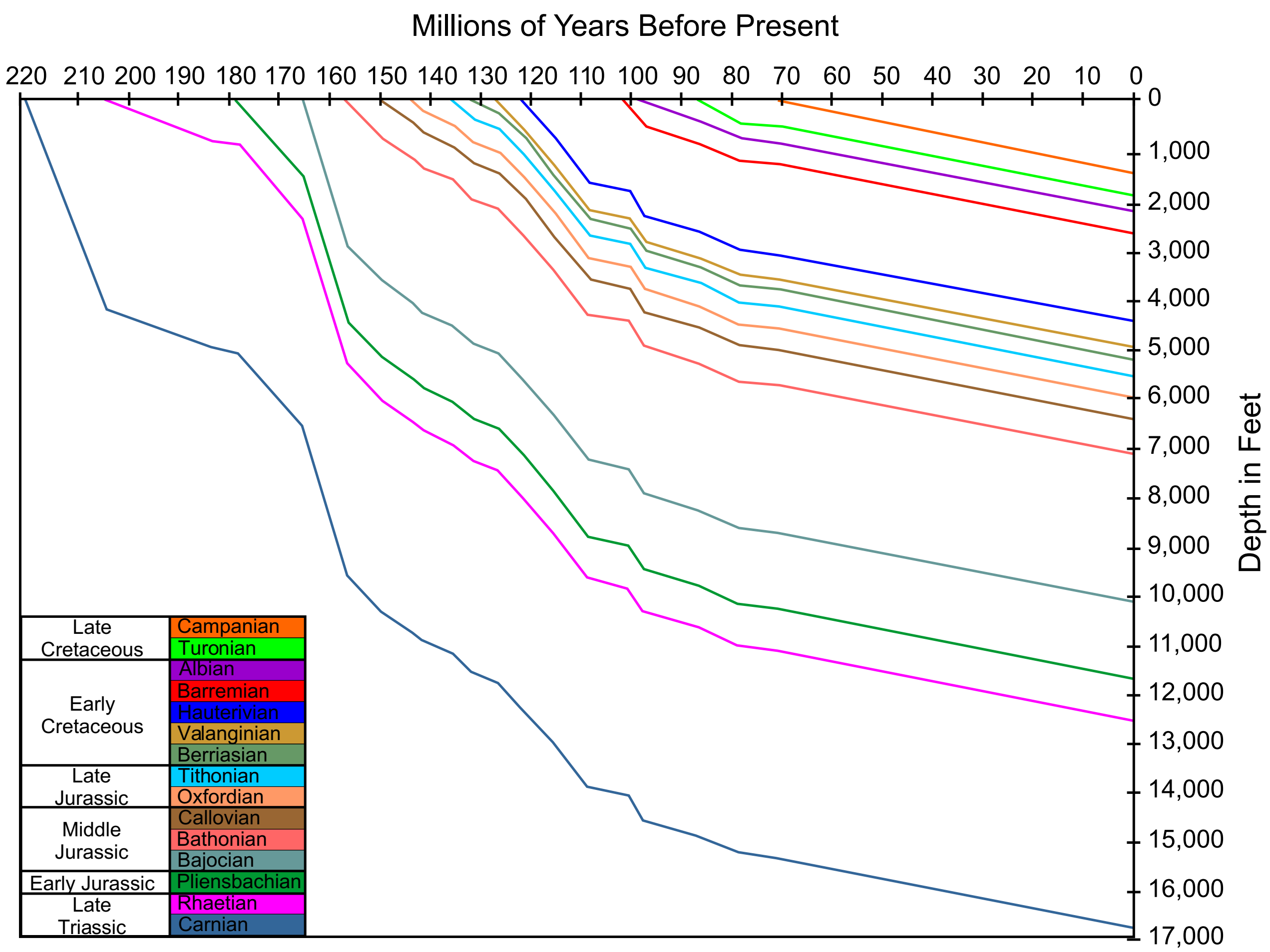

Figure 13. Burial diagram for the Tenneco Lydonia Canyon Block 187 No. 1 well.

COMPANY-SUBMITTED DATA

Data and reports were submitted by Tenneco Oil Exploration and Production Company to MMS when the Tenneco LC Block 187 No. 1 well was drilled, as required by Federal regulations and lease stipulations. Items of general geological, geophysical, and engineering usefulness are listed below. Items not listed include routine submittals required by regulation and detailed operations information, such as the Exploration Plan, Application for Permit to Drill, daily drilling reports, monthly reports, well location survey, and drilling pressure and temperature data logs. Well "electric" logs are listed in the **Formation Evaluation** chapter. Listed and unlisted company reports and data are available through the Public Information Unit, Minerals Management Service, Gulf of Mexico OCS Region, 1201 Elmwood Park Boulevard, New Orleans, Louisiana 70123-2394; telephone (504)736-2519 or 1-800-200-GULF, FAX (504)736-2620. Well logs are available on microfilm from the National Geophysical Data Center, 325 Broadway Street, Boulder CO 80303-3337, attn. Ms Robin Warnken; telephone (303)497-6338, FAX (303)497-6513; e-mail rwarnken@NGDC.NOAA.GOV.

At a later date, additional original technical data, including well logs, will be added to the compact disk (CD) version of the Georges Bank well reports. The CD will be available from Gulf of Mexico OCS Region Public Information Unit.

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