UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGICAL AND OPERATIONAL SUMMARY, COST NO. B-2 WELL, BALTIMORE CANYON TROUGH AREA, MID-ATLANTIC OCS

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Open-File Report 76-774

1976

This report has not been edited for conformity with Geological Survey editorial standards or stratigraphic nomenclature

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INTRODUCTION

Sale No. 40, the first oil and gas lease sale by the U.S. Government for the Atlantic Outer Continental Shelf, was held on August 17, 1976. The 154 tracts that were offered included 876,750 acres on the Baltimore Canyon Trough area of the Mid-Atlantic shelf off the coasts of New Jersey and Delaware. About one year before the proposed date of the sale, Ocean Production Company, the operator for a group of petroleum companies forming the Continental Offshore Stratigraphic Test (COST) Group, applied for a permit to drill a deep stratigraphic test well to a total depth of 16,000 feet at a site adjacent to the sale area. COST wells had been drilled in the Gulf of Mexico and others were planned for the Southern California and Gulf of Alaska Outer Continental Shelf areas before lease sales that were held for these areas earlier in 1976. Like other COST wells, the Mid-Atlantic well was drilled "off structure" away from any potential petroleum-bearing feature so that there would be a minimal chance of encountering oil and gas while obtaining information on the regional stratigraphy, reservoir beds, and hydrocarbon potential. The geologic data obtained from this first well in the Mid-Atlantic shelf area were extremely useful in evaluating structural interpretations derived from geophysical survey data, for determining the ages of the sediments drilled, and for estimating the potential of the penetrated rocks to generate and accumulate hydrocarbons.

Approval for the test well included a list of requirements for the operator that specified procedures for the drilling program, COST group participation, and disclosure of information obtained. This open-file report has been written in compliance with Stipulation No. 4, that all information from the approved program be made available for public disclosure by the U.S. Geological Survey 60 days after the first Federal lease was issued within 50 miles of the drill site. Of the 101 tracts receiving bids in Sale No. 40, 82 were less than 50 miles from the well and the closest block was less than 2 miles away. The summary of information presented here is based mainly on electric logs, drill cuttings, and cores which may be inspected at the Eastern Region Office of the Conservation Division, U.S. Geological Survey, 1725 K Street, N. W., Washington, D. C.

The COST No. B-2 well was drilled in 298 feet of water at the primary site 2,000 feet east of the center of unleased Block 594 on the Official OCS Protraction Diagram NJ-18-3 of the Bureau of Land Management. Its location, the Sale No. 40 area, and the adjacent coastline 78 miles to the west-northwest are shown in Figure 1. (An alternate site for a COST No. B-1 well at a water depth of about 190 feet was selected 43 miles to the southwest in the northern part of Block 934 on the same diagram in case the B-2 location could not be approved and successfully drilled.) Once the semi-submersible drill barge had been anchored in its drilling position and a location survey had been completed, drilling commenced on December 14, 1975, and was completed at a measured depth of 16,043 feet on March 18, 1976. After wireline logging, collecting sidewall cores, formation testing, and running velocity and temperature surveys, the well was plugged and abandoned in accordance with Geological Survey OCS orders and the rig was released on March 28, 1976.

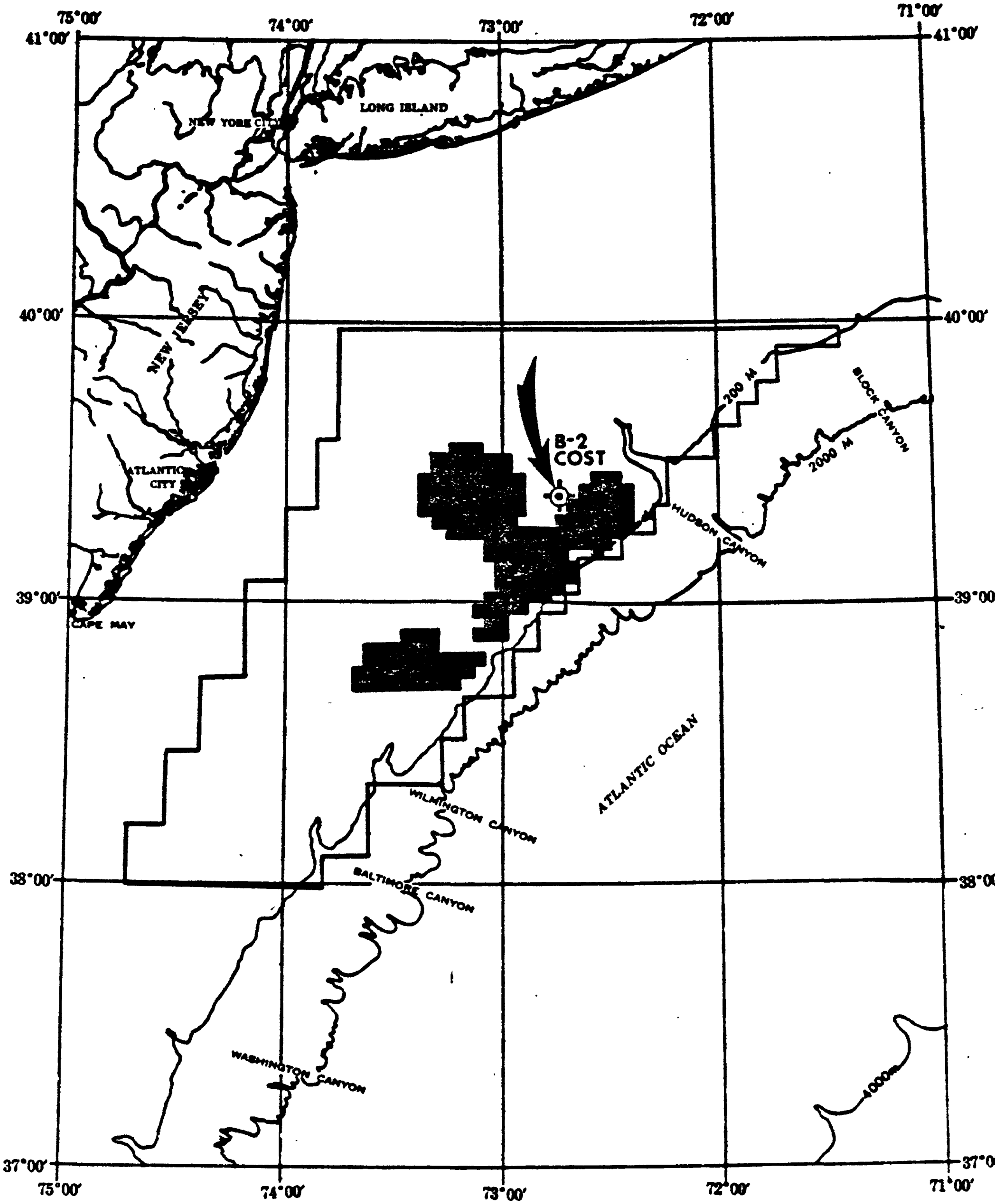

Figure 1 Map showing location of the COST No. B-2 well in the Baltimore Canyon Trough area. Heavy black line shows outline of the area in which tracts were nominated and shaded area indicates tracts included in OCS Sale No. 40. Labeled lines indicate water depths in meters.

OPERATIONAL DATA

General Information

The COST No. B-2 well was drilled by Ocean Production Company, acting as the operator for the group of 31 petroleum companies listed below.

Amerada Hess Corporation

Amoco Production Company

Ashland Oil, Inc.

Atlantic Richfield Company

BP Alaska

Champlin Petroleum Company

Chevron Oil Company

Cities Service Company

Columbia Gas Development Corporation

Continental Oil Company

Diamond Shamrock Corporation

ERA North America, Inc.

Exxon Company, U.S.A.

Getty Oil Company

Gulf Energy and Minerals Company

Kerr-McGee Corporation

Marathon Oil Company

Mobil Oil Corporation

Ocean Production Company

Pennzoil Company

Phillips Petroleum Company

Placid Oil Company

Shell Oil Company

Skelly Oil Company

Sun Oil Company

Superior Oil Company

Tenneco Oil Company

Texaco, Inc.

Texas Eastern Transmission Corporation

Transco Exploration Company

Union Oil Company of California

Expenses were paid on a cost-sharing basis and all logs, washed and unwashed sample core slabs, sample analyses, and other results were sent to the U.S. Geological Survey as required by the drilling stipulations. The Maryland Geological Survey ac ed as the data distributor for the Geological Surveys of some of the other Atlantic coastal states. In this capacity, they received copies of the electric logs and other proprietary information.

The final location of the test well was at latitude 39°22'31.972" North and lon itude 72°44'03.871" West or, using U.T.M. coordinates for zone 18, X = 695,155.32 meters and Y = 4,360,692.62 meters. This site was 7,521.70 feet from the south lin and 5,395.92 feet from east line of Block 594 on OCS Protraction Diagram NJ-18-3 (see Figure 2). The well was drilled in 298 feet of water by an approved semi-submersible drilling unit, the SEDCO J, to a measured depth of 16,043 feet. The rotary kelly bushing (R.K.B.) elevation was 90 feet above mean sea level. The drilling rig arrived on location on December 12, 1975, and drilling and logging operations were conducted for a period of 106 days from December 14 to March 28,

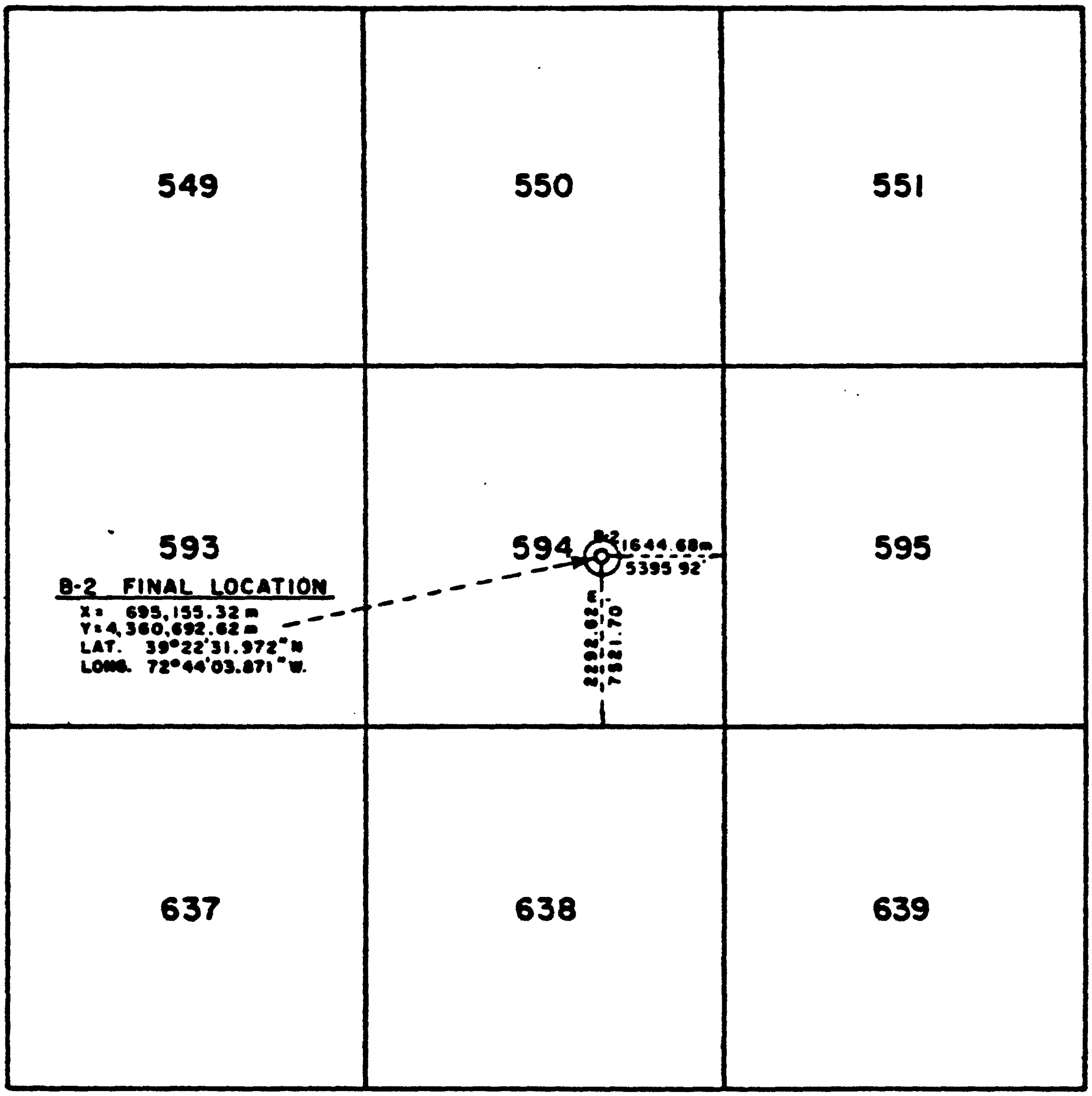

Figure 2 Location plat showing exact location of the COST No. B-2 well. (Survey
J. E. Chance and Associates, Inc., Lafayette, Louisiana)

1976, when the well was plugged back to a depth of 488 feet R.K.B. and abandoned.

Drilling Programs

Forty-three drill bits were needed to drill the deep stratigraphic test hole and four strings of casing were cemented in the upper part of the well. A 36-inch bit was used to drill to a depth of 608 feet R.K.B. A 26-inch hole was then drilled to 1,152 feet, a 17-1/2 inch hole to 4,055 feet, a 12-1/2 inch hole to 10,098 feet, and an 8-1/2 inch hole to 16,043 feet. Drilling rates varied from 3 to 84 feet/hour and averaged 55 feet/hour to 608 feet, 52 feet/hour in the interval to 1,152 feet, 80 feet/hour in the interval to 4,055 feet, 22 feet/hour in the interval to 10,098 feet and 8 feet/hour for the remainder of the well. The casing program included 30-inch casing set at 553 feet R.K.B. with 475 sacks of Class B cement, 20-inch casing set at 1,093 feet with 900 sacks of Class B cement, 13-3/8-inch casing set at 4,011 feet with 1,700 sacks of Class B cement, and 9-5/8-inch casing set at 10,077 feet with 1,310 sacks of Class H cement. Figure 3 is a schematic diagram of the plugged well showing the casing points as well as the position of the cement plugs. A seawater-gel slurry was used as the drilling fluid for the first 220 feet below the mudline until circulation had been established and a normal drilling mud could be used. The mud weight for the well was increased from 8.8 to more than 11.3 pounds per gallon at total depth. A pH between 11 and 11.8 was maintained during most of the drilling operation. Chloride was added to the drilling fluid in concentration as high as 16,100 ppm at shallow depths but was held to a level between 2,000 and 2,800 ppm below 10,100 feet. Calcium in concentrations up to 240 ppm was added to the mud for the upper part of the hole but was limited to trace amounts when the drilling went below 8,100 feet.

The final estimated well cost was $8.4 million. A summary of time spent on

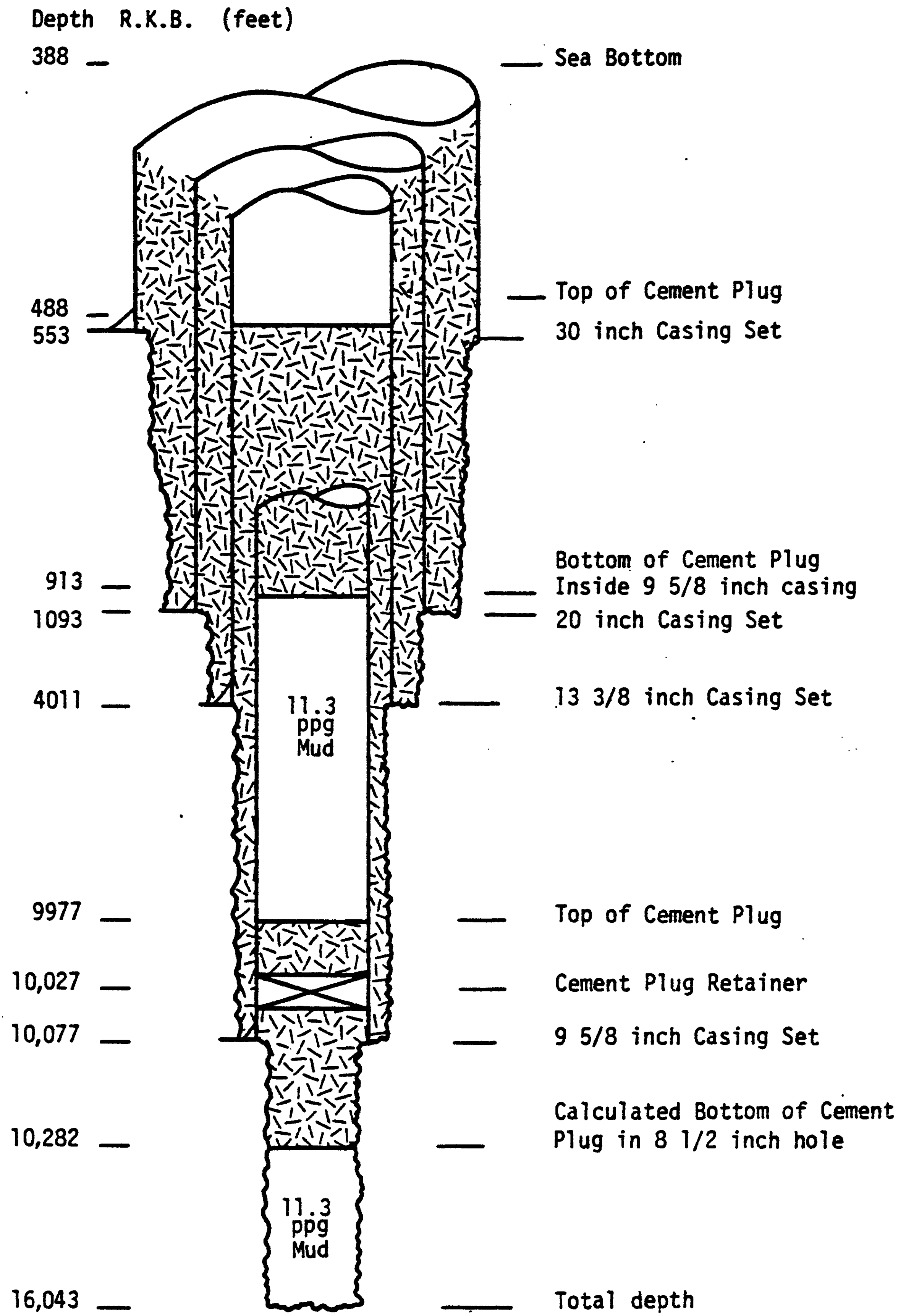

Figure 3 Schematic diagram showing casing and cement programs, COST No. B-2 w

various activities in the drilling operation is given below.

	Hours	Percent of Total
Drilling	1,120.0	44.10
Tripping	613.5	24.16
Wire Line Logging	175.0	6.89
Circulating & Conditioning Mud	140.0	5.51
Reaming	90.0	3.54
Testing BOP Stack	85.0	3.35
Rigging Up, Running, & Testing Casing	80.0	3.15
Running & Pulling BOP Stack & Riser	68.0	2.68
Cutting Off Drill Line	35.0	1.38
Waiting on Weather	32.5	1.28
Deviation Survey	29.0	1.14
Conventional Coring	27.5	1.08
Cementing	14.5	0.57
Rig Repair	6.5	0.26
Other	23.0	0.91
Total	2,539.5	100.00

Sampling, Tests, and Surveys

Four conventional cores were taken in the COST No. B-2 well. Core No. 1 was attempted from 5,030 to 5,090 feet, but only 1.5 feet of core at the top of this interval was recovered. Core No. 2 had 28.4 feet of core recovered between 8,238 and 8,268 feet; all of Core No. 3 between 9,280 and 9,330 feet was recovered; and 34.5 feet of sample was recovered in Core No. 4 from the interval from 13,420 to 13,471 feet. The porosity, permeability and grain density were measured for every foot of sandstone recovered. In an 8-foot interval of the deepest core with pinpoint fluorescence under ultraviolet light, residual oil and water saturations were also determined and a detailed geochemical analysis was run. Petrographic descriptions were made of thin sections, generally two at right angles to each other, for 81 samples and the mineral contents of 30 samples were determined by x-ray diffraction. Scanning electron micrographs were taken of Core No. 4. Microfossils from 8 samples were examined and thermal conductivity measurements were made on samples from all cores.

Three series of sidewall core sampling were run and 822 cores were collected from the well bore. In the first series, to a depth of 4,050 feet, 99 cores were recovered out of 131 attempts. Between 4,050 and 10,098 feet, 286 cores were taken in 383 attempts. Between 10,098 feet and the bottom of the hole at 16,043 feet, 437 cores were recovered in 594 attempts. Representative samples from the available sidewall cores were analyzed for several studies. Porosities, permeabilities, fluid saturations, and grain densities were measured for 174 samples. Thin sections were described from 128 samples. The mineral content of 100 finely ground samples was determined by x-ray diffraction and microfossils from 205 samples were studied. Organic geochemical analysis was made of 11 sidewall core samples, but the quantity of material available was too small to yield definitive results. Well cuttings collected at frequent intervals were also analyzed in the biostratigraphic and geochemical programs and for shale density determinations.

Five formation tests were attempted when the hole reached a measured depth of 10,098 feet and nine deeper repeat formation tests were attempted after all drilling was completed. Tests at depths of 8,240, 9,568, 11,070, 13,390, and 14,559 feet were successful and water analyses were made of the fluid samples. Additional pressure data were obtained at eight other test depths. Conventional drill stem tests were not attempted in this well.

Logging runs were made when the hole reached measured depths of 4,050, 10,098, 13,510, and 16,043 feet. The upper limit for most logs was 1,091 feet. Composite logs for the entire interval at scales of 2 and 5 inches to 100 feet were run for the Dual Induction-Laterolog and Sonic Logs with 5 to 7 foot spacing and 7 to 9 foot spacing. The 2-inch logs were also run for the upper interval of the Microlaterolog-Microlog and for the Temperature Log over the entire interval to the mudline. The Computed Dipmeter was printed at a scale of 1 and 5 inches to 100 feet for the entire well. Detailed (5-inch) logs were made on all runs with the Compensated Formation Density Log, the Simultaneous Compensated Neutron-Formation Density Log, the Microlaterolog-Microlog, the Four Arm, High-Resolution, Continuous Dipmeter, and the Synergetic Log using the SARABAND program for sandstone with silt. A 5-inch Proximity Log-Microlog was run only below 10,066 feet. A 1-inch Continuous Velocity Log was computed from data off the Long-Spaced Sonic Log and the Well Seismic Tool, and a second velocity survey produced a 1-inch Interval Velocity Log.

The COST No. B-2 well was drilled as a straight (vertical) hole with less than 3 degrees inclination. A directional survey, required by OCS orders for all wells, determined the true vertical depth to be 16,038.84 feet and the bottom hole location to be 98.44 feet north and 109.06 feet west of the surface location.

Drilling System Logs

Several logs were run simultaneously with the drilling operation of the COST No. B-2 well by the Analysts, Inc. These logs monitored the mud system and were run primarily to ensure more efficient drilling. They included the Physical Formation Log, the Instantaneous Drilling Evaluation Log, and the Delta Chloride Log. Useful information derived from the drilling system logs is discussed below.

The Physical Formation Log (PFL) displays the rate of drill bit penetration, rock type, mud temperature, shale density, gas detection and chromatographic analysis, as well as mud weight and viscosity. The drilling fluid gas analysis indicated an anomalous interval between 7,770 and 7,870 feet where 40 units total gas mud content, possibly due to a mud additive, were recorded. A surfactant, "Lubrikleen", was incorporated in the mud system in the interval between 7,600 and 7,955 feet. This ester lubricates and reduces surface tension and may have caused locked gas in the system to be released. The trapped gas may have been derived from lignitic sections higher in the well and could have accumulated in the drilling mud before "Lubrikleen" was added. The small amounts (less than 10 units) of methane that were detected on the gas chromatograph at 12,850, 13,150, and 13,190 feet may be related to the increased amount of lignite in this section.

The Instantaneous Drilling Evaluation Log (IDEL) is not intended for final well evaluation but gives an estimate of porosity, permeability, and pore pressure. The IDEL porosity, recorded seconds after rock penetration, agreed particularly well with the SARABAND porosity for marl and limestone intervals.

The Delta Chloride Log (DCL) was placed in service at 8,300 feet to measure changes in mud salinity. This log is a good indicator of salt water inflows from porous formations in the uncased portion of the hole. The display of NaCl ppm differential indicated that the well was drilled with an underbalanced mud system, i.e. the flowline salinity was greater than the suction pit salinity allowing salt water to flow from the formations being drilled. This underbalanced mud system contributed to a faster drilling rate, precluded mud loss and formation damage, and maintained the best pH level for geochemical testing.

Core and Shale Analysis

Detailed analyses for the four conventional cores were made by Core Laboratories, Inc. (1976), on cylindrical samples with 1-inch diameters taken from each foo of sandstone. Examination of x-ray diffraction patterns and thin sections provided information on the mineral content and petrography of different sections of the cor

Only 1.5 feet at the top of Core No. 1 from a depth of 5,030 feet was recovered. The rock is light brown, fine- to medium-grained, well-sorted sandstone with microgranular calcite cement. This sandstone shows moderate induration and contains abundant glauconite pellets with small patches and coatings of hematite. Two samples, 1.2 feet apart, were analyzed and show the effect of additional interstitial calcite cement in filling available pore space. The two measured porosities were 7.7 and 24.7 percent while the corresponding permeabilities were 0.32 and 563 millidarcies.

For Core No. 2, 28.4 feet of the interval from 8,238 to 8,268 feet was recovered. The core contains a gray to light grayish-green, medium- to coarse-grained, poorly to moderately sorted sandstone with calcite cement. It shows a moderate degree of induration, is generally well bedded, and contains abundant shells and microfossils with traces of glauconite and muscovite. Lignite is found in small lenses, laminae, and particles throughout the lower half of the core. The bottom 5 feet of the cored interval contains interbedded dark gray siltstone layers and the sandstone becomes vugular in places at this depth. Porosity measurements for the sandstone ranged from 3.6 to 28.7 percent with an average of 16.9 percent and permeability varied from 0.07 to 1,220 millidarcies with an average of 76 millidarcies.

Core No. 3 consists of a complete recovery for the 50-foot interval below 9,280 feet. Most of the sandstone, which makes up about 58 percent of the core, is gray to green and moderately to well indurated with calcite and, less commonly, silica cement. The upper half of the core is generally poorly sorted with variable grain size whereas the lower half is moderately to well sorted and fine to medium grained. The top half is also fossiliferous, much of the rock throughout the core is laminated, and lignite lenses are common. Glauconite, muscovite, and pyrite are generally present in trace amounts. Eight siltstone layers, 0.4 to 7.2 feet thick, and numerous smaller lenses and laminae occur in the core. Sandstone porosities range from 5.3 to 28.1 percent, averaging 15.5 percent, and permeabilities from 0.08 to 983 millidarcies, averaging 41 millidarcies.

Core No. 4 was cut between 13,420 and 13,471 feet, and 34.5 feet at the top of the interval was recovered. Numerous sandstone beds and two siltstone zones forr the upper 21.8 and the lower 2.4 feet of this core. The sandstone is generally light gray, medium to very fine grained, moderately to well sorted, and well indurated with a highly siliceous cement which contains a trace of $CaCO_3$ in parts of the core. Laminae of mica and lignite, faint cross-bedding, and hematite microconcretions are common while glauconite, mica, lignite, hematite, and pyrite also occur as trace constituents. Alternating layers of shale and coal occur over a 10.5-foot interval below 13,442 feet. Burrows and mud balls are found in the shale layers and in about 9 feet of sandstone overlying this interval while shales in thi section also contain abundant microfossils. Pyrite and mica occur in these rocks i trace amounts. The average measured porosity and permeability for the sandstone wa 8.8 percent and 1.98 millidarcies with a range from 3.2 to 16.4 percent and 0.04 to 12 millidarcies. The interval of Core No. 4 between 13,425 and 13,433 feet showed pinpoint fluorescence under ultraviolet light. Saturation analysis was done on eight samples from this section and a residual oil saturation of 4.6 percent was measured for a 1-foot interval at 13,427 feet. However, detailed organic geochemical analyses by Geochem Laboratories, Inc. (1976), and by Amoco Production Company indicated no petroleum-related liquid hydrocarbons at this level.

Analyses by Core Laboratories, Inc. (1976), of samples from sidewall cores collected throughout the well provided a complete series of porosity and permeability values for sandstones. Permeability determinations were made by comparing each sample with sandstone from the Gulf Coast area with the same grain size and shaliness values and assuming that the permeability would also be similar. These data, as well as the calculated grain densities, are listed in Table 1 and plotted against depth in Figures 4 and 5. A general decrease in both porosity and permeability with depth was expected because of increasing compaction and can be seen within the wide limits set in Figures 4 and 5. The large range of values and occasional low readings can be explained by increases in shaliness or in the amount of silt and, in some cases, by the presence of abundant calcite cement or mica. The high permeability reading at a depth of 8,870 feet was recorded for a sandstone that was exceptionally clean and coarser grained than other potential reservoir rocks this deep in the well. The close correlation between the porosity and permeability measurements is depicted in Figure 6. The porosity readings were determined directly and are more reliable than the empirically determined permeability values, especially for samples with different mineral contents, extensive calcite cement, or abundant inclusions.

Table 1. Porosity, permeability, and grain density data from sidewall core analyses of sandstones. (Determinations by Core Laboratories, Inc.)

Depth (feet)	Porosity (percent)	Permeability* (millidarcies)	Calculated Grain Density (g/cc)
1,275.0	28.4	162	2.58
2,009.0	26.5	264	2.55
2,089.0	29.0	1,250	2.68
2,311.0	34.2	3,604	2.64
2,334.0	34.0	3,605	2.61
2,448.0	29.6	515	2.54
2,509.0	33.9	1,951	2.60
3,056.0	31.5	495	2.42
3,161.5	24.9	214	2.63
3,165.0	26.6	754	2.64
3,230.5	26.7	135	2.59
3,262.0	32.2	1,952	2.63
5,031.0	30.9	1,650	2.66
5,072.0	24.4	254	2.59
5,096.0	32.6	1,650	2.69
5,140.0	30.6	86	2.61
5,964.0	26.1	0.2	2.80
5,991.0	32.4	322	2.64
6,015.0	33.2	2,740	2.69
6,079.0	31.2	1,950	2.65
6,102.0	28.6	187	2.64
6,107.0	28.9	1,950	2.62
6,125.0	33.1	321	2.69
6,136.0	29.0	1,950	2.56
6,157.0	32.8	3,600	2.65
6,186.0	31.4	1,950	2.68
6,204.0	25.4	5.2	2.85
6,235.0	25.8	66	2.65
6,264.0	30.0	1,100	2.62
6,301.0	31.6	1,400	2.66
6,329.0	31.0	162	2.68
6,351.0	31.2	31	2.61
6,372.0	19.1	6.5	2.45
6,421.0	26.2	301	2.66
6,489.0	28.7	28	2.68
6,507.0	31.8	107	2.63
6,563.0	24.5	2.3	2.64
6,572.0	23.3	0.4	2.68

Depth (feet)	Porosity (percent)	Permeability* (millidarcies)	Calculated Grain Density (g/cc)
6,669.0	32.0	221	2.67
6,693.0	26.6	5.3	2.61
6,785.0	32.0	662	2.58
6,808.0	22.7	1.4	2.58
6,819.0	22.2	2.5	2.58
6,953.0	28.5	27	2.63
6,991.0	21.4	0.2	2.65
7,565.0	25.1	2.3	2.66
7,574.0	23.7	0.8	2.64
7,659.0	25.4	1.8	2.63
7,975.0	25.0	3.2	2.62
8,230.0	24.4	7.6	2.68
8,244.0	23.3	2.8	2.75
8,253.0	23.2	2.4	2.69
8,289.0	29.3	27	2.73
8,321.0	30.7	18	2.89
8,375.0	24.8	1.6	2.80
8,399.0	28.3	3.6	2.85
8,411.0	30.2	314	2.68
8,479.0	26.0	13	2.64
8,533.0	27.0	45	2.67
8,559.0	30.6	404	2.76
8,580.0	27.5	3.1	2.71
8,587.0	29.6	221	2.78
8,606.0	28.2	28	2.68
8,659.0	27.2	45	2.69
8,849.0	29.4	155	2.68
8,870.0	29.4	754	2.66
8,917.0	28.1	44	2.74
8,956.0	24.2	9.8	2.51
9,056.0	25.6	2.8	2.79
9,147.0	25.8	3.1	2.65
9,173.0	20.8	3.5	2.73
9,187.0	27.2	15	2.64
9,207.0	25.2	4.7	2.78
9,236.0	30.5	134	2.68
9,293.0	27.8	18	2.64
9,357.0	27.0	20	2.64
9,467.0	9.8	222	2.74
9,534.0	26.8	16	2.70
9,539.0	23.7	43	2.60
9,545.0	27.3	6.6	2.46

Depth (feet)	Porosity (percent)	Permeability* (millidarcies)	Calculated Grain Density (g/cc)
9,569.0	28.5	21	2.72
9,597.0	9.9	22	2.79
9,623.5	19.3	4.5	2.46
9,635.0	27.5	191	2.64
9,659.0	28.2	77	2.67
9,728.5	29.9	42	2.73
9,748.0	27.8	26	2.64
9,773.0	20.4	0.7	2.74
9,778.0	22.5	4.7	2.65
9,825.0	27.8	9.5	2.71
9,918 0	30.1	60	2.65
9,953.0	22.8	9.2	2.72
10,007.0	27.0	73	2.68
10,051.0	24.4	45	2.61
10,256.0	22.4	1.4	2.63
10,346.0	21.7	0.3	2.65
10,409.0	20.8	3.8	2.63
10,429.0	21.8	5.3	2.65
10,499.0	20.9	0.1	2.67
10,555.0	17.2	0.4	2.52
10,791.0	26.5	2.4	2.68
10,817.0	23.8	0.8	2.63
10,899.0	24.7	0.3	2.75
10,967.0	21.5	2.3	2.60
11,037.0	22.7	0.3	2.67
11,064.0	24.0	0.8	2.66
11,102.0	22.0	3.2	2.68
11,141.0	20.3	<0.1	2.72
11,173.0	18.5	<0.1	2.71
11,216.0	25.0	2.6	2.75
11,257.0	24.4	2.0	2.65
11,384.0	20.7	0.8	2.56
11,435.0	18.8	0.1	2.63
11,483.0	22.8	0.6	2.62
11,537.0	20.2	0.3	2.61
11,559.0	22.3	5.9	2.58
11,607.0	18.3	0.3	2.57
11,873.0	20.7	0.7	2.63
11,981.0	18.9	<0.1	2.66
11,999.0	16.5	<0.1	2.72
12,021.0	12.6	<0.1	2.64
12,107.0	19.1	<0.1	2.71

Depth (feet)	Porosity (percent)	Permeability* (millidarcies)	Calculated Grain Density (g/cc)
12,139.0	17.2	<0.1	2.63
12,157.0	18.0	<0.1	2.62
12,218.0	15.4	<0.1	2.63
12,289.0	11.6	0.4	2.44
12,515.0	20.4	0.1	2.63
12,597.0	12.5	<0.1	2.60
12,627.0	18.1	0.2	2.58
12,711.0	19.7	<0.1	2.70
13,083.0	21.2	<0.1	2.77
13,165.0	21.1	0.3	2.61
13,217.0	23.6	7.2	2.66
13,243.0	18.2	1.5	2.49
13,349.0	22.1	0.1	2.72
13,409.0	21.0	4.5	2.52
13,479.0	22.2	0.3	2.65
13,518.0	17.6	2.9	2.48
13,614.0	18.5	0.3	2.56
13,906.0	12.9	0.6	2.43
13,931.0	15.9	0.1	2.57
13,987.0	17.9	0.4	2.53
14,070.0	20.8	0.8	2.57
14,092.0	21.5	0.3	2.62
14,252.0	16.3	0.2	2.54
14,384.0	9.5	<0.1	2.65
14,562.0	17.5	0.4	2.53
14,619.0	19.9	0.3	2.60
14,654.0	14.7	<0.1	2.57
14,781.0	10.6	<0.1	2.57
14,789.0	7.6	<0.1	2.68
14,950.0	13.7	<0.1	2.58
14,960.0	17.7	0.1	2.59
15,242.0	17.4	0.4	2.56
15,324.0	13.9	0.2	2.52
15,346.0	15.4	<0.1	2.73
15,375.0	14.4	<0.1	2.74
15,417.0	17.9	0.8	2.51
15,447.0	17.4	0.2	2.56
15,506.0	15.0	0.1	2.58
15,883.0	10.8	<0.1	2.66
15,890.0	11.0	<0.1	2.56
15,922.0	10.5	<0.1	2.64
15,954.0	12.3	0.6	2.42

*Permeability values determined empirically from grain size and shaliness.

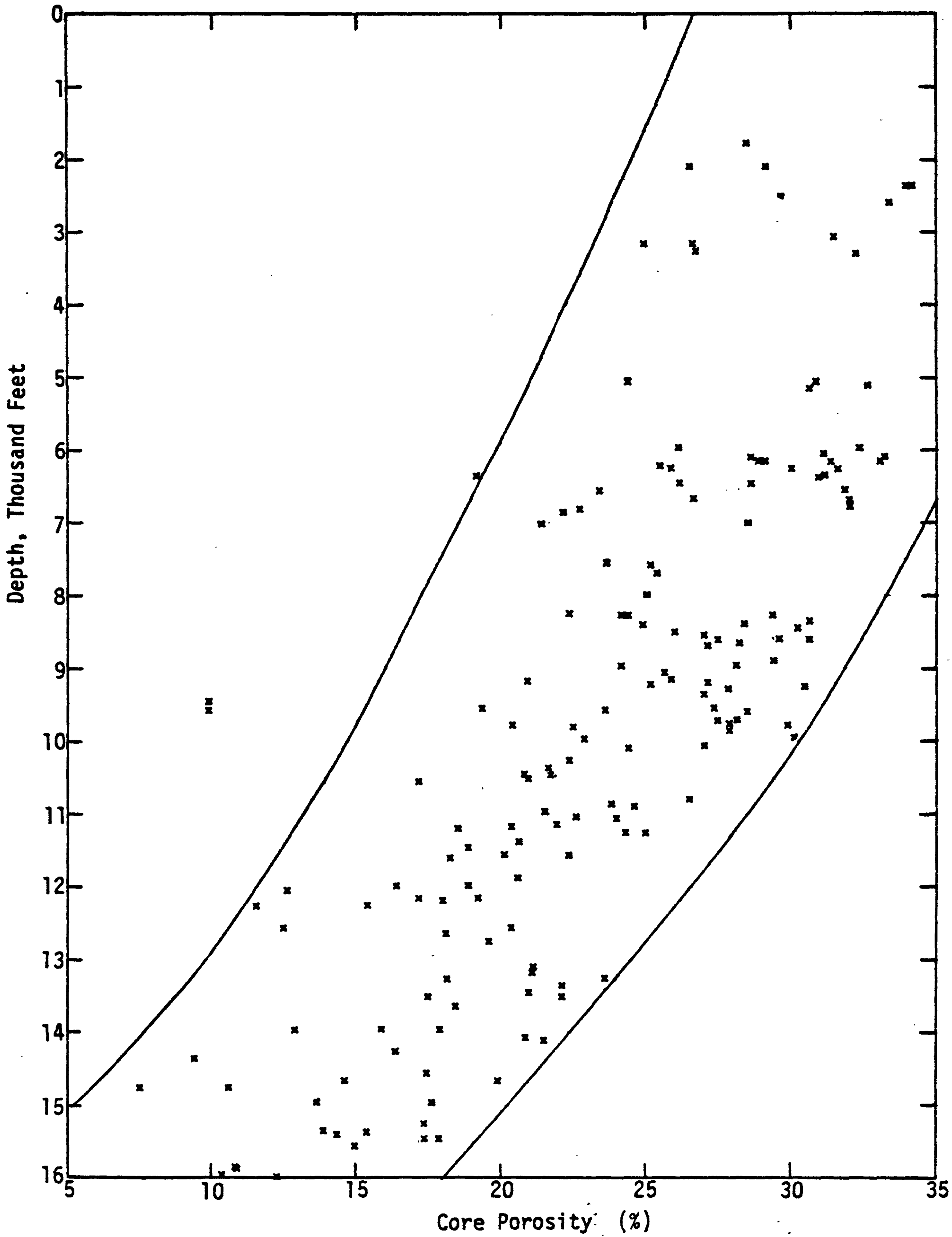

Figure 4 Sidewall core porosities, COST No. B-2 well.

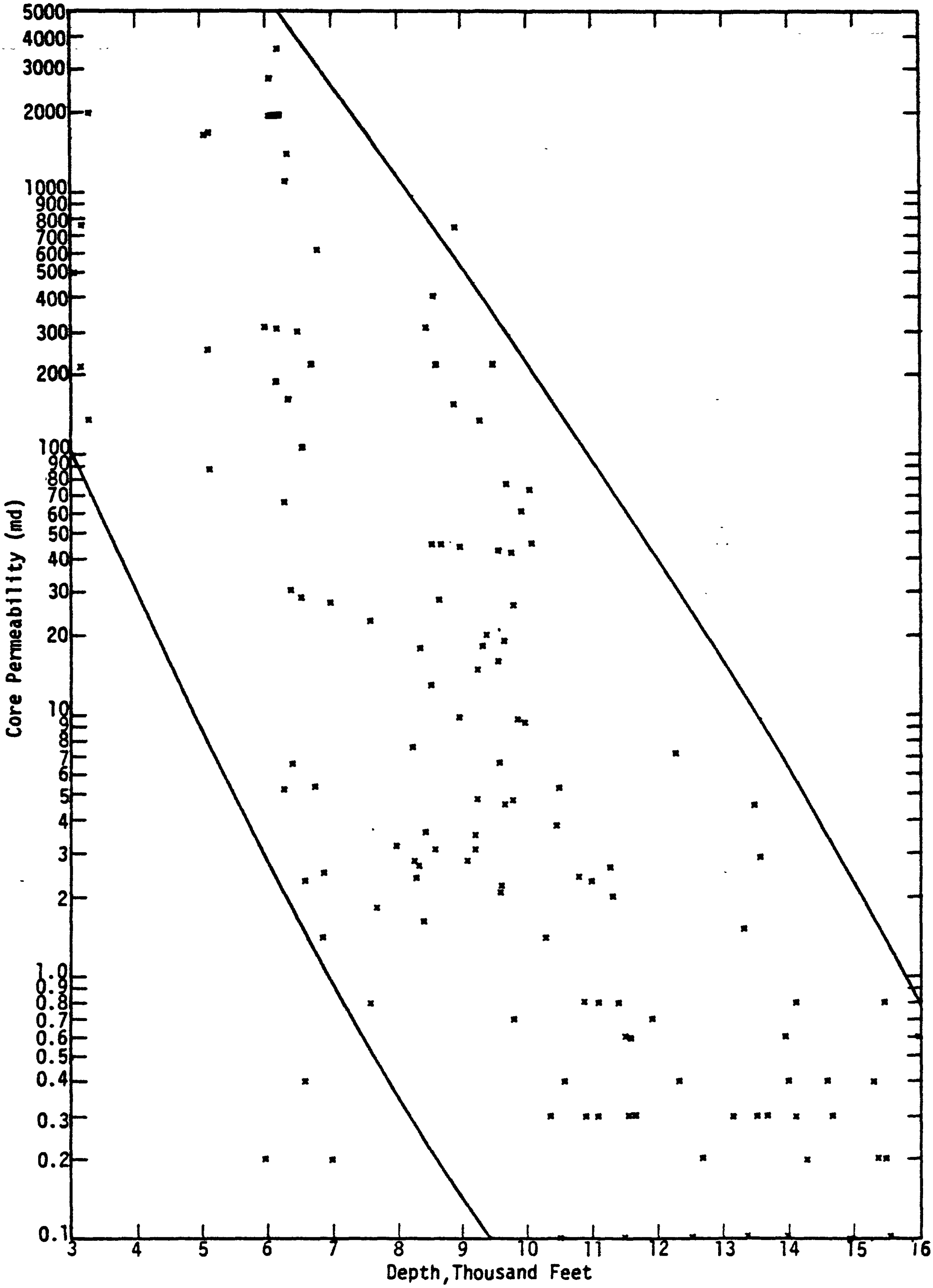

Figure 5 Empirically determined sidewall core permeabilities, COST No. B-2 well.

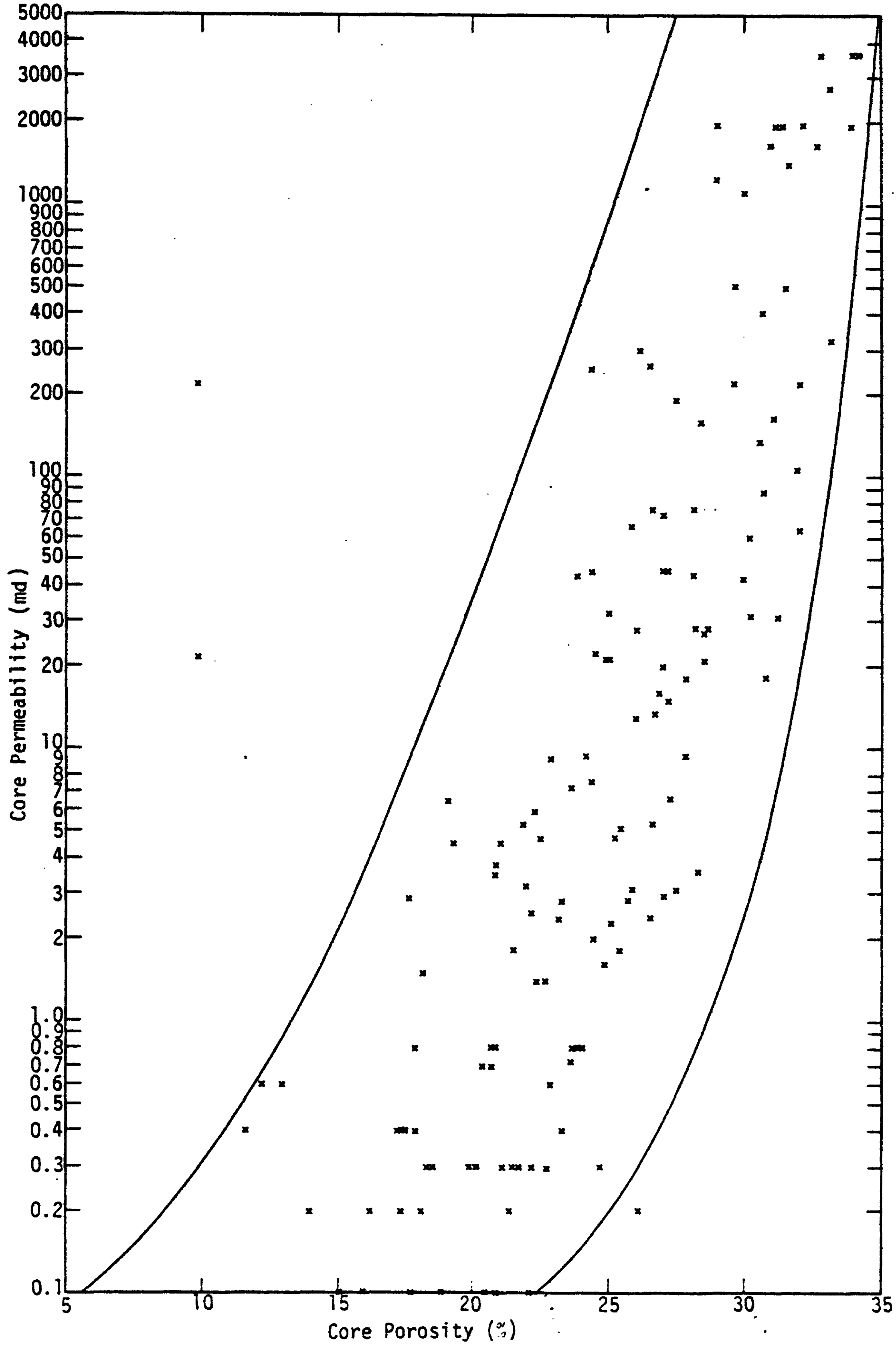

Figure 6 Sidewall core porosities plotted against permeabilities, COST No. B-2 w

Amoco Production Company ran x-ray diffraction analyses and density and porosit determinations on 43 samples of shale drill cuttings collected every few hundred fe in the well. The wet bulk density for fresh water-saturated shale and the measured shale porosity are plotted against depth in Figure 7. Shale density increases mark edly to a depth of about 10,000 feet and then gradually to the bottom of the well. As the density of the shale increases, the porosity shows a related decrease with most compaction occurring within the top 10,000 feet of section.

Temperature Gradient

The approximate temperature gradient of the COST No. B-2 well, as determined from three Temperature Log runs, was 1.5°F/100 feet. The elapsed time from the cessation of mud circulation ranged from 26 to 31 hours. Over the period, the drilling mud should have reached a temperature equilibrium with the adjacent formations. No noteworthy temperature anomalies were encountered in the well.

Fluid Analysis and Pressure Data

Formation tests are wireline, downhole tests that measure flowing and shut-in pressures and recover small amounts of fluid for analysis. However, the formation fluid is often mixed with mud filtrate making an accurate chemical analysis difficult. Five fluid samples, ranging in size from 3,600 to 10,250 c.c., were analyzed by Amoco Production Company. Three samples consisted entirely of mud filtrate and the other two contained about 33 percent and no more than 15 percent formation water. The concentrations of major ions and organic constituents were measured, bu the organic content was entirely derived from the drilling fluid.

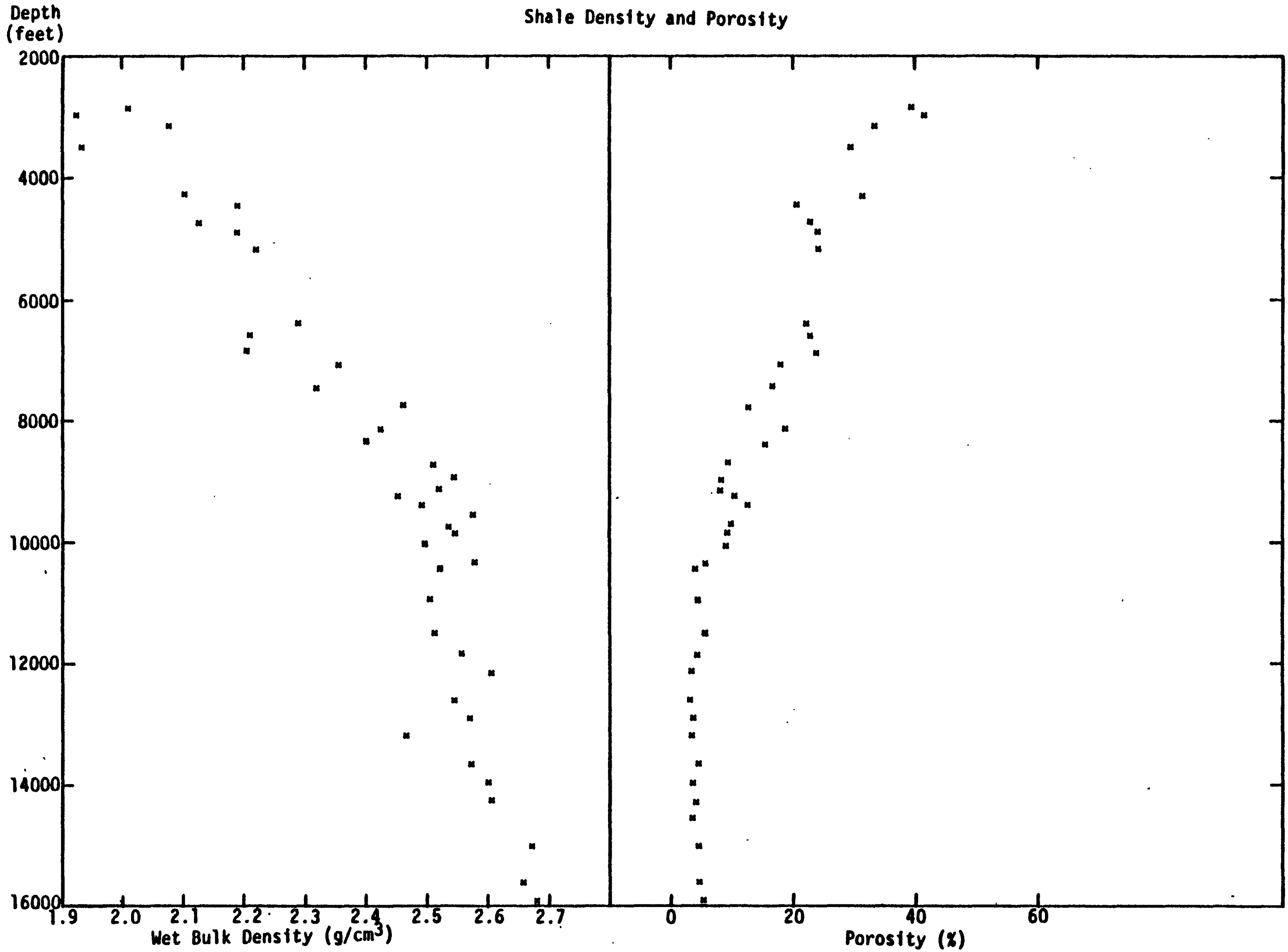

Figure 7   Shale densities and porosities measured on well cuttings, COST No. B-2 well.

The final shut-in pressures from successful tests are plotted against depth in Figure 8. A pressure gradient of about 43.5 p.s.i./100 feet is indicated between 6,000 and 15,000 feet, slightly lower than the average gradient of 46.5 p.s.i./100 feet determined from wells in the Gulf of Mexico.

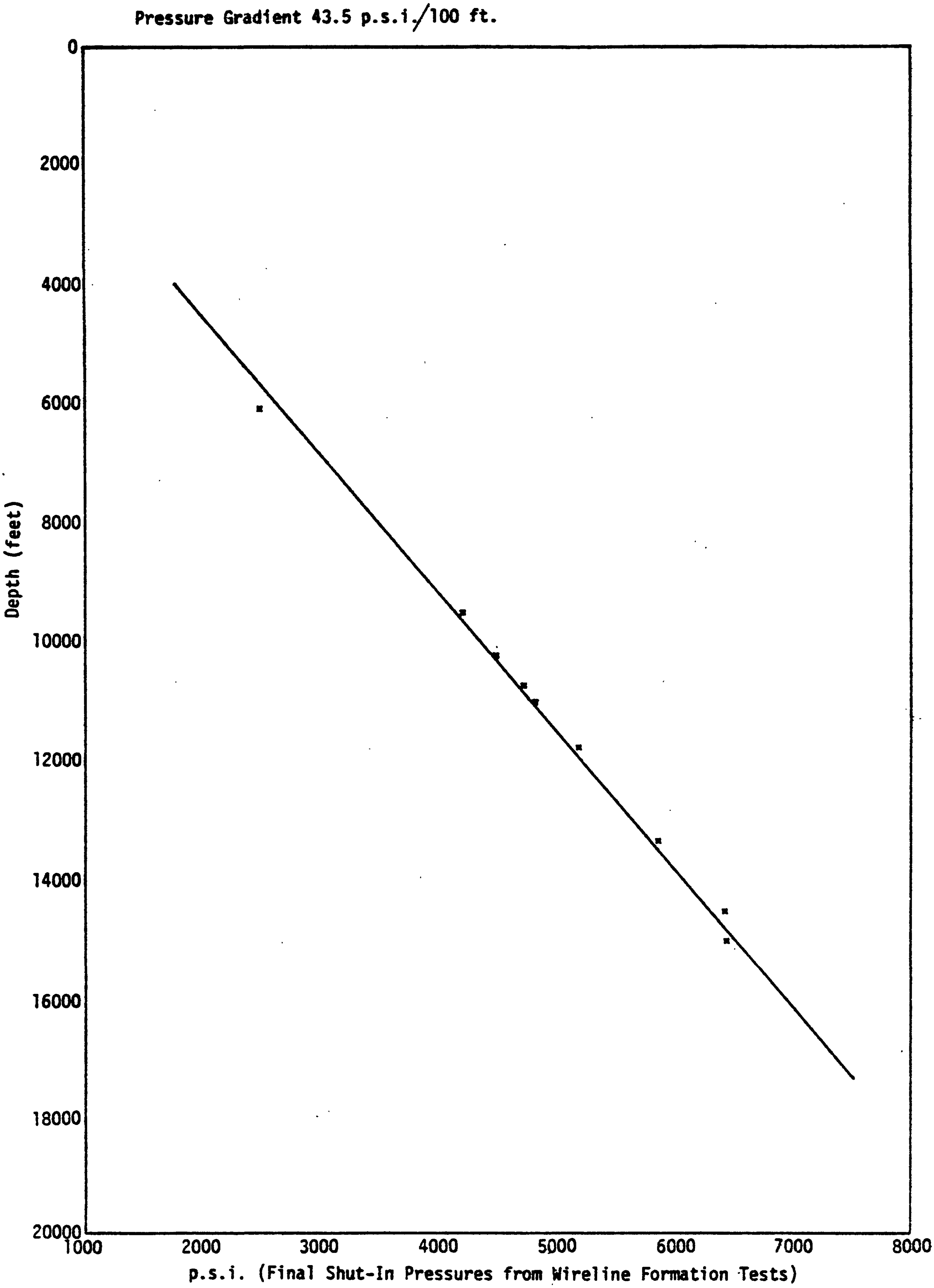

Figure 8 Pressure gradient for COST No. B-2 well determined from formatic test measurements.

ELECTRIC LOG INTERPRETATION

Rock Characteristics

A complete suite of logs for lithology determination and reservoir calculation was run on the well by Schlumberger. Descriptions of the major lithologic units based on electric log analysis are listed below. The intervals given are measured depths in feet below the rotary kelly bushing.

388 to 2,540 :	Predominantly poorly consolidated sand.
2,540 to 3,050 :	Shale.
3,050 to 3,280 :	Loose sand with 40 percent porosity.
3,280 to 3,540 :	Shale.
3,540 to 3,550 :	Impermeable limestone.
3,550 to 3,940 :	Interbedded sand and calcareous shale showing increased consolidation.
3,940 to 4,300 :	Impermeable, clayey, calcareous shale.
4,300 to 4,580 :	Impermeable, marly, chalky limestone.
4,580 to 4,874 :	Predominately shale with numerous interbedded limestone beds.
4,874 to 4,968 :	Shale interbedded with more massive limestone.
4,968 to 5,000 :	Relatively dense limestone.
5,000 to 5,150 :	Well-lithified, massive, porous, permeable, water-saturated sandstone. Average porosity is 21 percent with a range from 17 to 32 percent, and average permeability is 70 millidarcies with a range from 10 to 700 millidarcies. The Sonic Log was erratic

with cycle skipping in the upper 24 feet although the other porosity logs reacted normally and showed the same values as in the sandstone below. This section may have a different lithologic composition or may contain residual hydrocarbon shows. A water saturation of 80 to 100 percent was calculated.

5,150 to 5,200 : Siltstone with a gradational change to finer grain size.

5,200 to 5,680 : Massive, clayey, calcareous shale.

5,680 to 5,976 : Interbedded carbonate-clay-silt sequence to a depth of 5,910 feet, grading to low-permeability sandstone at the base.

5,976 to 6,470 : Numerous porous, reservoir-gravity sandstone beds with interbedded calcareous shale and lignite. Porosities range from 15 to 35 percent, averaging 24 percent, and permeablities from 2 to 1,000 millidarcies, averaging 110 millidarcies.

6,470 to 6,560 : Siltstone and very fine-grained, silty, low-permeability sandstone.

6,560 to 6,850 : Carbonate and low permeablity sandstone beds.

6,850 to 7,500 : Alternating very thin beds of shale and carbonate.

7,500 to 7,578 : Tight, sandy section. Porosity increases in bottom 20 feet.

7,578 to 8,218 : Tight interval consisting mostly of shale with interbedded carbonate and probably some low-permeability sandstone.

8,218 to 8,500 :	Silty sandstone with occasional tight streaks and an average porosity of 20 percent with a range of 14 to 30 percent. The estimated permeability ranges from 2 to 200 millidarcies and averages 40 millidarcies. Radioactive minerals were found in a sandstone bed between 8,392 and 8,404 feet.
8,500 to 9,065 :	Good, clean reservoir sandstone with porosity averaging 23 percent and estimated permeability averaging 70 millidarcies.
9,065 to 9,380 :	Silty, limy sandstone with lower permeability. The porosity ranges from 7 to 25 percent and averages 18 percent. The estimated permeability varies from less than 1 up to 100 millidarcies with an average of 10 millidarcies. There are numerous interbedded limestone beds with 10 to 14 percent porosity.
9,380 to 9,420 :	Reservoir-quality sandstone with a porosity of 22 percent and permeability of 50 millidarcies. A similar sandstone bed is found between 9,550 and 9,580 feet.
9,420 to 10,022 :	Silty, tight, limy sandstone with some thin limestone beds and more extensive shale. A radioactive bed occurs in sandstone from 9,582 to 9,590 feet.
10,022 to 10,220 :	Shale with some sandy and silty sections. Coal beds are found below 10,090 feet.

10,220 to 11,140 :	Sandstone in this interval is essentially clean and massive with decreasing porosity. In Cretaceous rock, this can still be considered a potentially productive reservoir. The porosity ranges from 13 to 25 percent. The permeability is consistent and fairly high for this level of porosity, with values up to 100 millidarcies. Thin coal beds are extensive.
11,140 to 11,650 :	Sandstone, gradually becoming more silty with the porosity and permeability decreasing to 12 percent and 5 millidarcies. Two beds between 11,140 and 11,234 feet become siltier and less permeable toward their bases. A tight limestone occurs beneath the second sandstone from 11,234 to 11,245 feet.
11,650 to 11,766 :	Shale.
11,766 to 12,416 :	Sandstone with porosity ranging from 10 to 23 percent, permeability from less than 1 up to 100 millidarcies, and with variable amounts of silt.
12,416 to 13,200 :	Shaly, limy sequence with some coal beds. A few sandstone beds are present.
13,200 to 16,043 :	Abundant sandstone with porosities ranging from 4 to 17 percent and estimated permeabilities up to 10 millidarcies. Although these beds are relatively free of silt, good rates of production would not be expected even if hydrocarbons were present. No coal was seen

on the electric logs below 13,580 feet although deeper coal and lignite were found in the well cuttings and noted on the lithologic log. Repeat formation tests in the lower rocks indicated good shut-in pressures with normal salt water gradients.

The electric log analysis for the entire stratigraphic test well indicates excellent reservoir conditions that have good potential for hydrocarbon accumulation where traps are provided by geologic structures. Sandstone considered to be effective as a potential reservoir rock forms 23 percent of the interval between 5,000 feet and total depth.

The section encountered by this well consists of shales with interbedded sandstones that vary in thickness from less than 2 to more than 100 feet and minor amounts of carbonate and coal. Tertiary sediment extends to 5,000 feet and is poorly consolidated. The Upper Cretaceous section contains alternating porous sandstone and shale with interbedded carbonate and a few lignite beds. The shaly interval from 6,850 to 8,218 feet does not contain good reservoir sandstone, but may be a facies change section that grades laterally into better reservoir rocks. A section with abundant, mostly clean, massive, permeable sandstone with interbedded shale and limestone is found in the Lower Cretaceous and possible Upper Jurassic interval between 8,218 feet and total depth of 16,043 feet. Below 10,000 feet, shale beds become more extensive and the sandstone becomes progressively less porous in a linear, gradational manner. Compaction must have been quite intensive, as the sandstone at 9,380 feet has 22 percent porosity and values decrease consistently to 9 percent at 15,800 feet.

Dipmeter Interpretation

Analysis of the High-Resolution, Four-Arm Continuous Dipmeter survey confirmed that the well was not located on any individual structure within the Baltimore Canyon Trough. Shale sections near the bottom of the hole showed an easterly to southeasterly regional dip of about 1 to 3 degrees. This dip pattern continued upward through Mesozic and Cenozoic rocks to a depth of about 1,400 feet, the shallowest level where regional dip could be interpreted. The attitude of the strata varied from being essentially flat or having only a fraction of a degree easterly or southeasterly dip to having a maximum dip of about 3 degrees in these directions. The only exception was Lower and Middle Eocene limestones which appear to have a regional dip of 1/4 to 1/2 degree to the southwest.

Practically all unconsolidated sand and sandstone in the well showed random dip clusters which indicate a high energy, shallow water environment. Shale sections, deposited in deeper water, had a multitude of bedding planes with clusters about the overall regional dip. The different orientations of clusters in sandstones suggested small sedimentary structures, compactional phenomena, slumping, reworking of compacted or partially compacted sediments, and foreset or cross-bedding. A detailed evaluation of these orientations could be a significant help in interpreting the history of sedimentation in the Baltimore Canyon Trough area from earliest Cretaceous through Pleistocene time.

A fault, striking north-northeast, was indicated at approximately 7,060 feet an was probably a down-to-the-basin type. A lithologic change was noted in well cuttings at this depth supporting this interpretation.

LITHOLOGIC DESCRIPTION

A detailed lithologic log was prepared for the COST No. B-2 well by Ocean Production Company and is available for inspection along with other logs and samples at the Eastern Region Office. Studies of well cuttings were also made by U.S. Geological Survey geologists and substantiated the accuracy of the lithologic log. Well cuttings samples were obtained at 30-foot intervals from 610 to 4,620 feet and at 10-foot intervals from 4,620 to 16,043 feet. It should be noted that cuttings analysis is an interpretive art and that lithologic descriptions from well cuttings do not always correspond closely to the lithologic character inferred from electric logs of the same interval. Discrepancies may be caused by poor mud conditions whereby cuttings circulations is not complete, by large washouts or lost circulation zones, by extensive caving of the hole, or by lithologies which disintegrate in the mud before samples are obtained. Therefore, some differences may occur between the electric log analysis and the descriptions in the summary of the lithologic log which follows. The COST No. B-2 well lithologies are shown on Plate 1.

The interval from 610 to 2,550 feet consisted of coarse- to very coarse-grained unconsolidated quartz sand with abundant shell fragments, glauconite, and pyrite. Pebble zones with subangular to subrounded quartz clasts as large as 4mm in diameter occurred at 1,150, 1,350, and 1,450 feet. Gray shale and soft gumbo-like clay were found between 2,550 and 3,050 feet and coarse-grained, loosely consolidated quartz sand with 2 to 4 mm pebbles occurred from 3,050 to 3,520 feet. The interval from 3,520 to 4,320 feet was predominantly gray and brown shale with light gray, fossiliferous claystone, glauconite and pyrite grains, and small amounts of very fine-grained, light gray sand.

Carbonate first appeared in the well at about 4,300 feet and continued to 5,000 feet. This carbonate was a tan to buff, dense, argillaceous limestone with lesser amounts of calcareous shale and claystone. Tan, medium-grained, angular to sub-rounded, calcareous, and poorly consolidated sandstone with abundant dark minerals giving a "salt and pepper" appearance occurred from 5,000 to 5,200 feet.

The interval from 5,200 to 5,900 feet contained dark gray, calcareous, micaceous sticky clay with small amounts of light gray, dense limestone, tan, calcareous, medium-grained sandstone, and glauconite. Massive sandstones occurred between 5,900 and 6,850 feet. These were white and tan, medium- to coarse-grained, calcareous, well-consolidated sandstones with minor amounts of gray and tan, fossiliferous, dense limestone, lignite, and dark gray shale. The section between 6,850 and 8,220 feet consisted of a mixture of several lithic types of which tan and gray shale predominated. Other lithologies included fine-grained, generally non-porous, argillaceous sandstone, tan, silty dolomite, and white, microgranular to chalky limestone.

Massive, white, calcareous, medium- to coarse-grained, pyritic sandstone occurred from 8,220 to 10,050 feet along with interbeds of gray, brown, and red shale and coal. Dark gray, silty shale occurred between 10,050 and 10,200 feet with interbeds of coal and lignite. The interval from 10,200 to 11,200 consisted predominantly of gray, black, brown, and tan shale with a few sandstones and thin beds of lignite and coal. One thick, coarse-grained, porous sandstone was noted between 10,350 and 10,450 feet and small percentages of sandstone were found in other parts of the 1,000-foot interval. However, the electric logs indicated a predominance of sandstone with thinner interbeds of shale.

A mixture of several alternating lithic types occurred from 11,200 to 13,000 feet. This mixture included thin beds (generally less than 50 feet thick) of fine- to coarse-grained calcareous sandstone along with dark gray and brown shale, coal and lignite (which are abundant in parts of this interval), and thin beds of limestone and dolomite. The section from 13,000 to 14,200 feet consisted of an alternating sequence of fine- to medium-grained, white and tan sandstone and dark gray shale with thin interbeds of lignite and coal. Some sandstone in this interval was slightly calcareous but most was cemented with clay. The lowest interval, from 14,200 to 16,043 feet, comprised both calcareous and micaceous, fine- to coarse-grained, white sandstone and a mixture of variegated gray, greenish-gray, reddish-brown, and maroon waxy shales with minor amounts of lignite.

BIOSTRATIGRAPHY

General Statement

Paleontological analysis for age determination and paleobathymetry (water depth of sediments at the time of deposition) was done for the COST No. B-2 well by International Biostratigraphers, Inc. (1976). Microfossils (primarily foraminifers), nannofossils, and palynomorphs (spores and pollen) were analyzed. American/Canadia Stratigraphic Service Ltd. (1976) also provided palynological age determinations for the well cuttings. In addition, L. A. Latta of the U.S. Geological Survey in Metairie, Louisana, analyzed the samples for microfossils and made a paleoenvironmental summary. Samples studied included well cuttings, plugs from three conventional cores, and 205 sidewall cores. Samples were continuously collected and analyzed at 30- or 10-foot intervals from 610 feet to the total depth of the well.

The COST No. B-2 well was determined to have penetrated about 4,100 feet of moderate- to deep-water marine Tertiary strata (Pliocene and Pleistocene strata wer not identified), about 3,130 feet of moderate- to deep-water marine Upper Cretaceou rocks, and about 7,910 feet of shallow-water marine and terrestrial Lower Cretaceou (and possibly some Jurassic) sediments. The stratigraphic section and lithologies encountered by the well are shown in Plate 1. The following is a combined summary of the paleontological data showing depths to the tops of geologic series with approximate Gulf Coast equivalents in parentheses:

Depth (feet)	Geologic Series or Stage
610	Shallowest sample examined - no age determined
910	late Miocene
1,172	middle Miocene

Depth (feet)	Geologic Series or Stage
3,557	early Miocene
3,596	late Oligocene (Anahuac-Frio)
4,011	early Oligocene (Vicksburg)
4,082	late Eocene (Jackson)
4,204	middle Eocene (Claiborne)
4,629	early Eocene (Wilcox)
4,964	Paleocene (Midway)
5,000	Maastrichtian (Navarro) - Upper Cretaceous
5,100	Campanian (Taylor) - Upper Cretaceous
5,736	Santonian (upper Austin) - Upper Cretaceous
6,063	Santonian-Coniacian (lower Austin) - Upper Cretaceous
7,057	Turonian (Eagle Ford) - Upper Cretaceous
7,610	Cenomanian (Woodbine-Tuscaloosa) - Upper Cretaceou
8,130	Albian (Washita-Fredericksburg) - Lower Cretaceou
8,900	Aptian (Trinity) - Lower Cretaceous
10,000	Barremian (upper Hosston) - Lower Cretaceous
11,000	Hauterivian-Valanginian (middle Hosston) - Lower Cretaceous
12,000	Berriasian (lower Hosston) - Lower Cretaceous
16,043 (T.D.)	lowermost Cretaceous*

*American/Canadian Stratigraphic Service Ltd. (1976) interpreted the interval from 14,650 to 16,043 (T.D.) as Jurassic (Tithonian and possibly Kimmeridgian).

Age Determinations

The first tentative age determination was made from cuttings collected at 910 feet where an age of late Miocene was assigned based on the occurrence of *Bulimina elongata*. The 300 feet of cuttings above 910 feet were barren of diagnostic microfossils and it was assumed that this interval plus the 222 feet of section between the first collected cuttings (610 feet) and the sea floor (388 feet R.K.B. or 290 feet below sea level) was a combination of latest Miocene, Pliocene, and Pleistocene sediments.

Age determinations in the Tertiary and Upper Cretaceous section relied heavily on foraminifers. Zonation of this interval, based largely on these microfossils, had been worked out over a period of many years and where present in sufficient numbers and diversity forminifers provide the most reliable stratigraphic determinations. Age determinations in this interval were supplemented and confirmed by calcareous nannofossils, palynomorphs, and the dinoflagellates which are useful for dating and correlating shallow marine sediments which commonly lack other diagnostic fossils.

Age determinations in the Lower Cretaceous section were based primarily on dinoflagellates and (in the basal portion of the well) spores and pollen. These interpretations were necessarily less precise than those of the younger interval because zonations based on these fossils have not been refined to the degree of precision obtainable with planktonic foraminifers in the late Mesozoic and Cenozoic.

TERTIARY (910-5,000 feet)

MIOCENE (910-3,596 feet)

The Miocene section in the test well was quite sandy, and foraminiferal faunas were not well developed. Bulimina elongata occurred with the most consistency, while Robulus americanus, Globigerinoides triloba, Cassidulina crassa, Bulimina inflata, Globigerina bulloides, Quinqueloculina seminulina, Cibicides americanus, Cassidulina subglobosa, Cibicides concentricus, Sphaeroidinellopsis subdehiscens, and Eponides umbonatus occurred more sporadically.

The relatively poor assemblage from the shallowest sidewall core at 1,172 feet was interpreted as possible middle Miocene, based on its similarity to assemblages of that age from Maryland and Virginia. Confirmation of a middle Miocene age was provided by the occurrence at 2,796 feet of the planktonic species Globorotalia peripheroacuta. No foraminifers indicative of an age older than middle Miocene were noted in the sidewall cores between 2,822 and 3,596 feet.

Sidewall cores from the Miocene interval also yielded assemblages in which bisaccate pollen (Pinus, Abies, and Picea) was generally dominant. Other forms occurring more or less consistently were Caryapollenites simplex, Tiliapollenites, Ilexpollenites, and Tsugaepollenites. Rare specimens of spinose Compositae pollen (Compositioipollenites sp. B) were noted at 2,711 and 3,198 feet, but aside from this form none of the species could be considered age-diagnostic.

Cenozoic placoliths were noted in the samples from 2,711 and 2,822 feet, and silicoflagellates were noted at 2,711 and 3,482 feet. Diatoms were present at 2,711; 2,796; 3,009; 3,366; and 3,482 feet. Samples from 3,557 and 3,596 feet belong within the Triquetrorhabdulus carinatus Zone. This zone spans the uppermost Oligocene-basal Miocene interval and can be considered either latest Oligocene or earliest Miocene.

OLIGOCENE (3,596-4,082 feet)

Radiolarians, shell fragments, and a few foraminifers occurred in the sidewall cores between 3,638 and 4,000 feet, but no diagnostic species were noted. The interpretation of this interval as upper Oligocene was based on calcareous nannofossil evidence which indicated that sidewall cores from 3,695, 3,809, and 3,873 feet belong in the Sphenolithus ciperoensis Zone of late Oligocene age and dinoflagellates which dated the core from 3,596 feet as Oligocene. The Sphenolithus predistentus Zone was recognized at 3,891 feet, and the Sphenolithus distentus (S. tribulosus) Zone was present between 3,999 and 4,011 feet. The distinctive lower Oligocene species Cyclococcolithina formosa occurred at 4,011 feet, and several other diagnostic forms such as Chiasmolithus oamaruensis and Isthmolithus recurvus also occurred in the lower Oligocene interval.

Although foraminiferal and calcareous nannofossil data suggested that the sidewall core at 3,596 feet may be either earliest Miocene or latest Oligocene, the core was interpreted palynologically as Oligocene based on the presence of Chiropteridium aspinatum and Chiropteridium dispersum, neither of which have been previously recorded from younger sediments. Other distinctive forms having their shallowest occurrence in this sample were Pentadinium laticinctum and "Cordosphaeridium" floripes.

Further subdivision of the Oligocene may be practicable within the Baltimore Canyon Trough area based on the tops and abundances within this interval of distinctive dinoflagellates such as Deflandrea phosphoritica, Dinopterygium cladoides (sensu Morgenroth), Wetzeliella symmetrica, Thalassiphora pelagica, Cordosphaeridium cantharellum, Areosphaeridium arcuatum, Cordosphaeridium funiculatum, Deflandrea heterophlycta, and Areosphaeridium diktyoplokus.

EOCENE (4,082-4,964 feet)

Foraminiferal assemblages of late, middle, and early Eocene age were well represented in the samples. The faunas represent deposition in a lower bathyal environment and were exceedingly abundant and diverse. The sidewall core from 4,126 feet fell within the upper Eocene Globorotalia cerroazulensis Zone based on the occurrence of Globorotalia cerroazulensis, Globigerina tripartita, Globigerina angiporoides, and Globigerinita dissimilis. Benthonic species such as Uvigerina cookei, Karreriella chilostoma, Bulimina jacksonensis, and Bolivinopsis trinitatensis were also common. Samples from 4,147 and 4,171 feet fell within the Globigerinatheka semiinvoluta Zone of early late Eocene age. Chiloguembelina species were very abundant in these samples.

The Truncorotaloides rohri Zone of late middle Eocene age was recognized in the sidewall core from 4,204 feet. Globorotalia spinulosa, Globorotalia bullbrooki, and Truncorotaloides species characterized this fauna. The sidewall cor from 4,570 feet fell within the lower middle Eocene as indicated by the presence of Globigerina frontosa, Globorotalia pentacamerata, Globorotalia broedermanni, and *Globorotalia renzi*.

The Oligocene-Eocene boundary was placed at 4,082 feet based on the first occurrence of the calcareous nannofossil *Discoaster saipanensis* in that core. This sample was interpreted as early Oligocene on forminiferal evidence, mainly because of the absence of Eocene planktonic species in the very poor assemblage, and might equally well be placed in the late Eocene. The poor assemblage from the core at 4,964 feet might be considered as latest Paleocene, and evidence from dinoflagellates suggested that it is not younger than earliest Eocene. Although a precise and detailed zonation of the Eocene based on nannofossils exists, a further breakdown in the well was not practicable because of the poor preservation and limited sample coverage. Except for fine pollen, which was abundant in a few of the Eocene sidewall core assemblages, spores and pollen were a minor component of the floras.

PALEOCENE (4,964-5,000 feet)

The sidewall core from 4,964 feet yielded only a few radiolarians, but calcareous nannofossil and dinoflagellate assemblages from this core indicated a latest Paleocene to earliest Eocene age. The nannofossil *Discoaster multiradiatus* was suggestive of a late Paleocene age.

UPPER CRETACEOUS (5,000-8,130 feet)

MAASTRICHTIAN (5,000-5,100 feet)

Cuttings samples between 5,000 and 5,100 feet contained fair Cretaceous assemblages incuding Globotruncana arca, Globotruncana fornicata, Globotruncana gagnebini, and Globotruncana lapparenti, indicating an early Maastrichtian age (Globotruncana stuartiformis Zone).

CAMPANIAN (5,100-5,736 feet)

Rich foraminiferal assemblages occurred in the Campanian interval, and Globotruncana stuartiformis, Globotruncana duwi, Globotruncana marginata, Whiteinella aprica, Bolivinoides decorata, and Kyphopyxa christneri were common. Ventilabrella grabens was present in sidewall cores from the lower part of this interval.

The sidewall core from 5,173 feet yielded a sparse assemblage containing the dinoflagellates Palaeohystrichophora infusorioides, Australiella victoriensis, and Diconodinium sp. and the pollen Rugubivesiculites rugosus, all of which are indicative of a Late Cretaceous age (late Campanian). The interval between 5,537 and 5,941 feet, dated as Campanian and Santonian by foraminifers, was characterized palynologically by the presence of the dinoflagellates Odontochitina costata, Oligosphaeridium complex, Surculospaeridium longifurcatum, Tanyosphaeridium variecalamum, and several other less frequently occurring species, none of which range higher in the sidewall cores. Spores and pollen were more common in the lower part of this interval, where Appendicisporites tricornitatus, Araucariacites australis, and Taurocusporites segmentatus had their first occurrences. No diagnostic nannofossils were identified in the

Maastrichtian or Campanian intervals.

SANTONIAN (5,736-6,063 feet)

The top of the Santonian Stage was placed at the 5,736 feet, where *Globotruncana coronata* and *Globotruncana carinata* occurred together in a moderately rich benthonic and planktonic fauna. The joint occurrence of these species placed the core within the *Globotruncana carinata* Zone of late Santonian age. The sidewall core from 5,824 feet was somewhat older as indicated by the presence of *Globotruncana concavata*, a form which is restricted to the lower Santonian.

SANTONIAN to CONIACIAN (6,063-7,057 feet)

Twelve sidewall cores in this interval yielded poor, non-diagnostic foraminiferal faunas and no calcareous nannofossils. Except for a few specimens of *Cyclonephelium distinctum*, sidewall cores between 6,063 and 6,857 feet also lacked dinoflagellates. Spores and pollen were common and well preserved in most samples from this interval, and a number of forms which gave the assemblages an aspect more typical of the Lower Cretaceous had their first occurrences at 6,737 feet. *Deflandrea pirnaensis* occurred in the sidewall cores from 5,991 and 6,375 feet, but was found more consistently in the Aptian section where it occurred together with the somewhat similar species *Deflandrea perlucida*. *Complexiopollis* cf. *funiculatus* and *Complexiopollis* cf. *patulus* were among the few angiosperm species occurring in the lower section and indicated that the age was not younger than Coniacian.

TURONIAN (7,057-7,610 feet)

The top of the Turonian Stage was placed at the first occurrence of Globotruncana helvetica at 7,057 feet. It should be noted that this point marked a return to marine conditions below the non-marine to marginal marine lower Senonian interval. The "top" of Globotruncana helvetica was probably depressed in the well and some of the overlying sediments may actually have been deposited during Turonian time.

Foraminiferal assemblages of the Turonian interval were rich and diverse, and were characterized by the occurrence of Globotruncana helvetica, Globotruncana schneegansi, and Praeglobotruncana turbinata. The marine environment which prevailed during the Turonian was reflected by the return of dinoflagellates to the palynomorph assemblages. Most of the species present also occurred in the Campanian, although Deflandrea perlucida was not noted above 7,057 feet and Oligosphaeridium pulcherri was not present above 6,903 feet.

CENOMANIAN (7,610-8,130 feet)

The top of the Cenomanian was placed at the shallowest occurrence of Rotalipora cushmani in the well cuttings at 7,610 feet. The sidewall core from 7,659 feet was barren, but the sample from 7,683 feet yielded a good Cenomanian assemblage including Rotalipora cushmani, Rotalipora greenhornensis, Hedbergella planispira, Praeglobotruncana stephani, Praeglobotruncana turbinata, Heterohelix moremani, Heterohelix washitensis, and Hedbergella simplex. Aptea eisenacki, a distinctive dinoflagellate species known only from the Albian and Cenomanian, had its first occurrence at 7,735 feet and was consistently present in assemblages as deep as 8,818 feet. The land-derived palynomorphs occurring in the

Cenomanian assemblages were not as diverse as those in the overlying Turonian and Coniacian, but the bisaccate pollen Rugubivesiculites rugosus had its deepest occurrence in the sidewall core at 7,888 feet and might prove to be a useful marker.

LOWER CRETACEOUS (8,130-16,043 feet)

ALBIAN (8,130-8,900 feet)

Sidewall cores below 7,683 feet either were barren of foraminifers or yielded very poor, non-diagnostic assemblages. The top of the Albian was placed at about 8,130 feet, where Planomalina buxtorfi and Hedbergella washitensis had their first occurrences in the cuttings. The highest occurrence of the nannofossil Braarudosphaera africana was at 7,735 feet. However, this species was lacking in the next four lower cores and was not seen again until 8,200 feet. The shallowest unquestionably Lower Cretaceous palynomorph assemblage was also present in the sidewall core from 8,200 feet, where Trilobosporites variverrucatus, T. sp. cf. perverulentus, Klukisporites pseudoreticulatus, Trilobosporites apiverrucatus, Pilosisporites trichopapillosus, Concavissimisporites punctatus, Abietineaepollenites microreticulatus, Appendicisporites degeneratus, and other distinctive species had their first occurrences.

The base of the Albian was somewhat arbitrarily placed at about 8,900 feet, below the deepest occurrence of Aptea eisenacki at 8,893 feet. Foraminifers were lacking in five sidewall cores processed for foraminiferal study between 8,397 and 10,007 feet. A few foraminifers noted during the examination of cuttings included such forms as Lenticulina nodosa (8,620 and, 9,560 feet), Haplophragmium sp. (8,940 feet) and Ticinella roberti (8,840 feet).

APTIAN (8,900-10,000 feet)

Sidewall core coverage in this interval was rather sparse, and the sample from 9,099 feet lacked diagnostic dinoflagellates. Four fragments of conventional Core No. 3 were processed, however, and all yielded sparse to abundant assemblages including both dinoflagellates and land-derived palynomorphs. This core was interpreted as Aptian based on the abundant occurrence of *Cyclonephelium tabulatum*, a dinoflagellate from the Aptian type sections and not known to occur in older or younger strata. The absence of the distinctive species *Ovoidinium scabrosum* in dinoflagellate-rich assemblages suggested that Core No. 3 may be of early Aptian age. The base of the Aptian was arbitrarily placed at 10,000 feet, where *Cyclonephelium tabulatum*, *Astrocysta cretacea*, *Deflandrea pirnaensis*, and *Cribroperidinium edwardsi* had their deepest occurrences.

BARREMIAN (10,000-11,000 feet)

The exact age of this interval was difficult to interpret because of the relative scarcity of diagnostic dinoflagellate species in what appeared to be an oscillating marine and non-marine environment. None of the sidewall cores between 10,000 and 11,128 feet yielded dinoflagellates, yet important forms such as *Pseudoceratium pelliferum* and *Muderongia simplex* were identified in the cuttings from this interval, suggesting an age not younger than Barremian for sediments below 10,100 feet.

HAUTERIVIAN-VALANGINIAN (11,000-12,000 feet)

Microfossils identified from this interval included *Epistomina caracolla* and *Marssonella* sp. between 11,530 and 11,620 feet and *Everticyclammina eccentrica* between 11,680 and 11,800 feet. Dinoflagellates were present in the sidewall cores between 11,100 and 11,600 feet, and Muderongia cf. staurota, Cordosphaeridium eoinodes, Ctenidodinium elegantulum, and Oligosphaeridium anthophorum had "tops" in this interval. Two other forms not noted higher in the well were Hystrichosphaeridium ramuliferum and Gonyaulacysta longicornis. The former species was found in the Hauterivian and Valanginian of the type section at Valangin, and the Gonyaulacysta occurred in the Berriasian-Valanginian of the Amoco-IOE Puffin well on the Grand Banks of Canada. The lower limit of this interval was placed at about 12,000 feet because the calcareous nannofossil Polycostella senaria, a species described from the Barriasian type section, occurred in the sidewall core from 12,120 feet.

BERRIASIAN (12,000-16,043? feet)

Although the occurrence of Polycostella senaria indicated a Berriasian age at 12,120 feet, all samples below 12,868 lacked calcareous nannofossils and the age of the well at total depth could not be positively determined. Microfossils identified in the interval between 12,100 and 13,000 feet included Epistomina caracolla, Epistomina ornata, Epistomina cf. hechti, Lenticulina cf. vacillantes, Lenticulina cf, munsteri, Pseudocyclammina sp., and Protocythere sp. Schuleridea hatterasensis was identified at 12,100 feet in the cuttings. The type locality for this species is the ESSO No. 1 Hatteras well at Cape Hatteras, North Carolina, where it occurred at 6,300 feet and at several lower horizons. Epistomina ornata also occurred in several wells drilled on the Scotian shelf including the Sable Island area.

Dinoflagellates become progressively more rare in the lower portion of the well, but single specimans of Pseudoceratium pelliferum, Muderongia simplex, Hystrichosphaeridium ramuliferum, and Wanaea sp. were noted in the sidewall core from 14,116 feet. Below this point dinoflagellates were lacking and the abundance and quality of preservation of spores and pollen decreased drastically, although species characteristic of the lowermost Cretaceous were still present in many sidewall cores.

Except for the sample from 15,480 feet, samples between 14,900 and 15,900 feet were virtually barren of palynomorphs. The sidewall core from 15,961 feet, however, yielded a good assemblage in which spores and pollen were common and well preserved. The occurrence of such forms as Pilosisporites trichopapillosus, Trilobosporites apiverrucatus, Concavisporites juriensis, Contignisporites dorsostriatus, and Foraminisporis wonthaggiensis indicated that the well bottomed in sediments of earliest Cretaceous (Berriasian) age.

Palynological age determinations by American/Canadian Stratigraphic Service Ltd. (1976), however, indicated that Jurassic sediments may occur in the interval from 14,650 to 16,043 feet (T.D.). They listed palynomorphs such as Gonyaniacysta cf. jurassica, Imbatodinium sp., Pareodinia ceratophora, and Pilosisporites sp. H at 14,650 feet as possibly indicative of an uppermost Jurassic age (Tithonian) and Hexagonifera jurassica at 14,950 feet as definitely Upper Jurassic. Endoscrinium luridium, Leptodinium cf. subtile, Tasmanites sp., Densoisporites veltatus, and Callialasporites dampieri for the interval 15,950 to 16,043 feet are listed as being of possible Kimmeridgian age in the Upper Jurassic.

Paleoenvironmental Analysis

Interpretations of paleoenvironments were based on benthonic foraminifers and the presence or absence of dinoflagellates. A non-marine environment of deposition was inferred when dinoflagellates were absent from a given interval. Paleobathymetry was inferred by comparing benthonic fossil foraminiferal faunas with Recent faunas known to favor certain ecological conditions. These inferences become progressively less accurate with increasing geological age. Dinoflagellates and foraminifers (primarily arenaceous types) occur only sporadically in the Lower Cretaceous section of the well, and it appears that most of this interval was deposited in non-marine to very shallow marginal marine environments.

The depositional environment of the interval from 1,172 to 1,342 feet (middle Miocene) was interpreted as inner neritic. Sidewall cores from 1,785 and 1,931 feet were barren suggesting a shallowing of the environment, perhaps to non-marine conditions. Foraminifers indicative of the inner to middle shelf reappeared between 2,311 and 3,482 feet, and the occurrence in the lowest portion of the Miocene interval of such species as Siphogenerina lamellata, Uvigerina rustica, Uvigernia auberiana, and Uvigerina fusiformis indicated a deeper, outer neritic environment of deposition.

The depositional environment of the upper part of the upper Oligocene interval was interpreted as outer neritic. Sidewall cores from 3,809, 3,873, and 3,891 feet yielded only shell fragments, glauconite, fish teeth, and rare specimens of Robulus americanus and Eponides umbonatus, suggesting a shallowing of the environment to inner shelf depths. The abundance and diversity of the foraminiferal assemblages of the lower Oligocene interval indicated deposition in outer shelf to upper slope environments. Dinoflagellates were dominant in this interval, and land-derived forms were represented by pine pollen and a few specimens of Tilia and Carya which suggested that an open marine environment prevailed during this time.

A rich benthonic foraminiferal assemblage was present in the Eocene interval, indicating depostion in the lower slope environment (greater than 1,500 feet water depth). Radiolarians and benthonic foraminifers were common and also indicated deposition in a slope environment.

Samples between 5,000 and 5,700 feet contained fair to rich foraminiferal assemblages, the benthonic components of which indicated deposition in the outer neritic environment. Samples between 5,736 and 5,865 feet contained abundant planktonic and benthonic species, which also indicated deposition in an outer shelf environment. Below 5,865 feet, however, the abundance and diversity of foraminifers decreased drastically, suggesting a markedly shallower, perhaps even non-marine, environment for the interval down to the top of the Turonian at 7,057 feet. Sidewall cores between 6,063 and 6,973 feet yielded very poor, non-diagnostic foraminiferal faunas indicative a very shallow water or non-marine environment. This environmental interpretation was also confirmed by the absence of dinoflagellates in the palynological preparations.

Rich and diverse foraminiferal assemblages characterized the Turonian interval from 7,057 to 7,610 feet. Although benthonic species were not numerous, genera such as Epistomina, Conorboides, and Lingulogavelinella made their first appearance in this interval and the benthonic assemblage suggested deposition in an outer shelf environment. The Cenomanian interval (7,610 to 8,130 feet) yielded the deepest good foraminiferal assemblage encountered in the well, which indicated deposition in an outer shelf environment.

Sidewall cores and cuttings below 7,683 feet either were barren or yielded very poor, non-diagnostic foraminiferal assemblages, and foraminifers were virtually absent in the cuttings from 9,600 feet to the total depth of 16,043 feet. Dinoflagellates were consistently present in the Albian interval (8,130 to 8,900 feet) indicating deposition within a marine environment, and the few foraminifers noted in this interval suggested that at least marginal open marine conditions existed at various times.

Based on the study of sidewall cores, the interval from 10,100 to 11,100 feet appeared to be predominantly non-marine. Muderongia simplex occurred in cuttings as high as 10,720 feet, however, and the environment must have been at least marginal marine over a portion of the interval. Because dinoflagellates were lacking in the 14 sidewall cores between 10,000 and 11,128 feet, the first appearance of these species probably was the result of a transition from a non-marine to a marine environment and the true Barremian-Aptian boundary may be somewhat lower within the non-marine interval.

Except for a short interval between 12,100 and 12,280 feet, the rest of the well (from 11,500 feet to total depth) was zoned as inner shelf (deposition in water less than 50 feet deep) to terrestrial (non-marine), with the section from 13,500 to 16,043 being interpreted as entirely terrestrial. The interval from 12,100 to 12,280 feet was considered to be a deep-water environment with water depths from 300 to 1,500 feet. The following table summarizes the paleoenvironmental analysis of the COST No. B-2 well:

Depth Interval (feet)	U.S. Geological Survey Ecologic Zone Number	Water Depth Range During Deposition (feet)	Environment of Deposition
610-2,311	I	0-50	inner shelf
2,311-3,482	I-II	0-300	inner to middle shelf
3,482-4,011	III	300-600	outer shelf
4,011-5,865	III-IV	300-1,500	outer shelf to upper slope
5,865-7,057	I	0-50	inner shelf
7,057-8,130	III	300-600	outer shelf
8,130-11,500	I-II	0-300	inner to middle shelf
11,500-12,100	I	0-50	inner shelf
12,100-12,280	III-IV	300-1,500	outer shelf to upper slope
12,280-16,043 (T.D.)	I	0-50	inner shelf to terrestrial

Correlation with Other Atlantic Wells

The lithologies, ages, and thicknesses of correlatable intervals in the stratigraphic test well were compared with several other key wells in the central and northern Atlantic area. Included wells were located on the coastal plain close to the shoreline (ESSO #1 Hatteras, 10,019-foot T.D., Cape Hatteras, North Carolina; ESSO #1 Maryland, 7,697-foot T.D., eastern Maryland; Anchor Gas #1 Dickinson, 6,407-foot T.D., southern New Jersey; USGS #1 Island Beach Park, 3,891-foot T.D., central New Jersey) and offshore on the Scotian shelf of Canada in the Browns Bank area (Shell #B-93 Mohawk, 6,975-foot T.D.) and in the Sable Island area (Mobil-Tetco #C-67, 15,106-foot T.D.).

In general, the COST No. B-2 well is similar to Scotian Shelf wells in lithologies, ages of sediments, and environments of deposition. Comparisons with most coastal wells are difficult due to their extremely abbreviated sections. Table 2 lists the approximate thicknesses by age of the major sediment intervals for the test well and surrounding wells. Figures 9 and 10 are regional cross sections showing the relationship of the major sediment groups. Figure 9 is a strike section from Cape Hatteras, North Carolina, to the Scotian Shelf of Canada, and Figure 10 is a dip section which correlates the COST No. B-2 well with two wells on the New Jersey coastal plain.

Table 2 Summary of approximate thicknesses by geologic age of some key Atlantic Coastal and offshore wells. Depths and thicknesses are in feet.

Well Name	Total Depth	Plio-Pleistocene	Mio-cene	Oligocene	Eocene	Paleocene	Upper Creataceous	Lower Cretaceous (Albian)	Lower Cretaceous (Aptian)	Lower Cretaceous (Neocomian)	Jurassic
B-2 COST	16,043	522	2,686	486	882	36	3,130	770	1,100	4,650 ?	*1,393 ?
ESSO #1 Hatteras	10,019	170	1,230	300	1,055	155	3,000	200 ?	1,640	1,400	728
ESSO #1 Maryland	7,697	180	1,480	Not Present	200	220	660	1,200±	1,160	2,070	* 527
Anchor Gas #1 Dickinson	6,407	100	960	Not Present	570	320	480	1,100±	1,000±	1,350	400+
U.S.G.S. #1 Island Beach	3,891	100	410	Not Present	340	345	1,180	600±	360±	510	Not Present
Shell #B-93 Mohawk	6,975	600 ?	750?	100 ?	200	400	2,400	←	812	→	1,564
Mobil-Tetco #C-67	15,106	950 ?	880	970	500	715	1,975	400 to 1,000	3,300 to 3,900	3,700	*1,116 ?

*Entire Section Not Penetrated

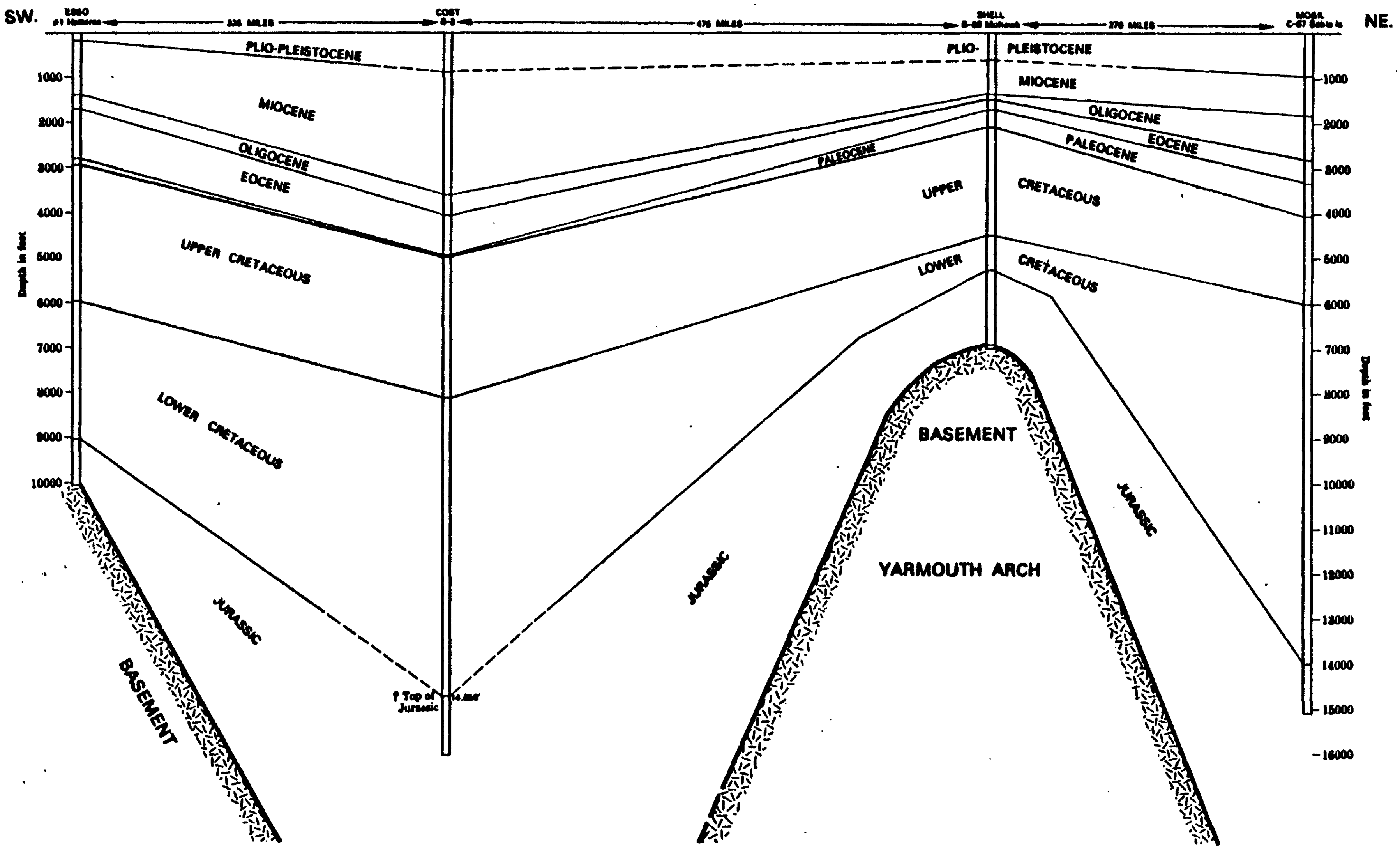

Figure 9 NE-SW cross section in the strike direction of the Atlantic offshore from Cape Hatteras, North Carolina, to Sable Island, Nova Scotia, showing the stratigraphic relationship between the COST No. B-2 well and three other deep wells drilled on the continental margin.

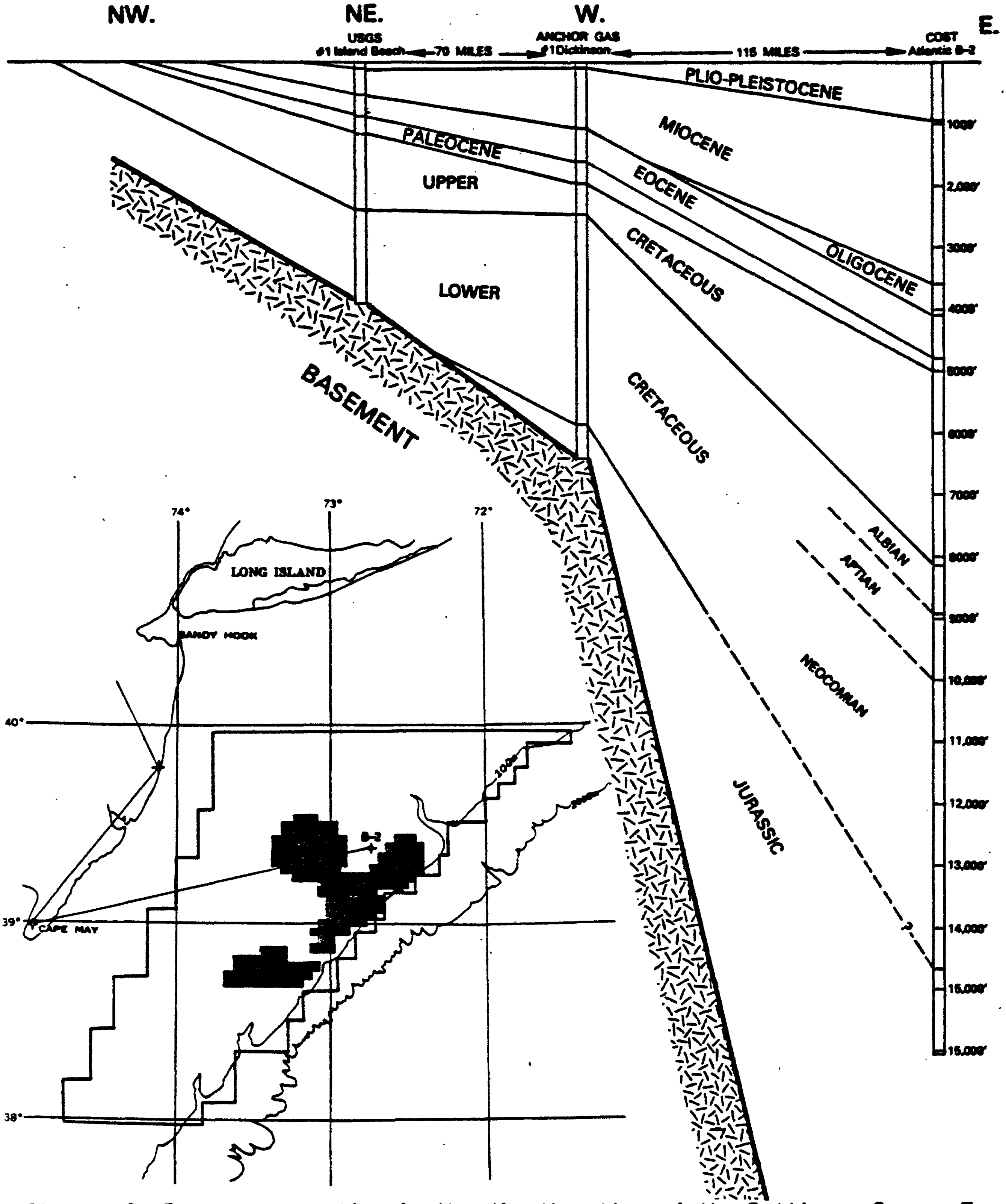

Figure 10 E-NW cross section in the dip direction of the Baltimore Canyon Trough showing the stratigraphic relationship between the COST No. B-2 well ar two shallower wells drilled along the New Jersey coastline.

GEOCHEMICAL ANALYSIS

Hydrocarbon source rock analysis, provided for the COST No. B-2 well by Geochem Laboratories, Inc. (1976), is a means of evaluating the potential for petroleum generation of organic-rich shales encountered in a well. The organic geochemistry of potential source rocks was analyzed in detailed studies to determine the quantity, composition, thermal maturity, amount of secondary alteration, and age of any hydrocarbons. Table 3 presents the values of important geochemical parameters throughout the well. Their significance and trends seen in the stratigraphic section are discussed below.

The total organic carbon content indicates whether a potential source rock is sufficiently rich in organic material to have generated commercial amounts of petroleum. The organic carbon percentage shows an overall increase with depth down to the bottom 2,000 feet of the hole. Between 7,000 and 14,700 feet it consistently exceeds 0.5 percent, the minimum quantity required for significant petroleum generation in shales.

The C_1 through C_7 hydrocarbon content of the well cuttings and the air space in their storage cans was measured before the samples were washed for further analysis. Hydrocarbon concentrations increase significantly below 9,400 feet with C_1 through C_4 generally exceeding 1,000 ppm to total depth and C_5 through C_7 exceeding 100 ppm for most of the interval above 13,900 feet. Soluble organic matter was extracted from the samples, separated by absorption chromatography, and analyzed. The highest concentration of heavier hydrocarbons (C_{15} and greater) occurred in the same interval as for the C_5 through C_7 hydrocarbons.

Table 3. Hydrocarbon concentrations and geochemical parameters obtained from detailed analysis of well cuttings.

Depth* (feet)	Total Organic Carbon (percent)	C_1-C_4 (ppm)	C_5-C_7 (ppm)	C_{15+} (ppm)	Gas Wetness (percent)	Carbon Preference Index	Vitrinite Reflectance
610	0.20	666.1	19.2	37	8.0	1.16	**
910	0.08	646.1	16.9	28	2.1	1.29	**
1,270	0.16	461.7	13.6	75	6.0	1.29	0.24
1,630	0.05	697.7	42.2	16	7.4	1.43	0.24
1,990	0.10	380.7	10.2	-	9.8	1.37	0.28
2,350	0.07	580.2	16.1	-	4.6	1.40	**
2,710	0.54	2,985.1	16.4	271	1.7	1.10	0.29
3,070	0.61	1,255.6	11.0	97	1.0	1.53	0.35
3,430	0.26	1,671.5	15.2	27	1.6	1.54	0.37
3,790	2.70	1,417.7	56.5	208	23.7	1.40	0.37
4,140	0.35	632.2	56.1	68	13.1	1.46	0.34
4,500	0.93	528.8	27.9	-	6.8	1.21	0.41
4,860	0.61	512.1	26.3	59	18.0	1.23	0.40
5,230	0.78	406.3	54.0	184	52.0	1.13	**
5,590	2.15	358.1	45.3	74	21.3	1.24	**
5,950	0.47	164.2	9.2	78	9.7	1.08	**
6,310	0.81	612.4	2.3	761	4.9	1.08	**
6,670	0.29	731.4	17.0	43	9.9	1.21	0.41
7,030	0.84	669.3	53.2	843	21.4	0.87	0.40
7,390	0.86	668.3	66.6	62	42.0	1.05	0.46
7,750	1.20	382.6	112.8	111	47.3	1.11	0.47
8,110	0.83	947.3	157.1	77	36.7	1.13	0.50
8,470	0.66	345.1	138.7	229	36.5	1.34	**
8,830	0.67	184.2	33.2	-	29.2	1.44	**
9,190	0.32	403.0	35.3	-	17.3	1.40	0.53
9,550	5.45	6,273.8	180.9	1,123	16.3	0.93	0.46
9,910	0.49	590.1	71.5	103	39.8	1.11	0.57
10,330	2.16	2,560.8	73.0	783	25.9	1.23	0.55
10,660	4.40	4,937.9	104.2	2,159	27.0	1.47	0.62
11,020	5.09	6,726.0	254.4	1,144	33.5	1.40	0.57
11,380	1.12	2,354.7	378.0	1,080	50.3	1.00	0.58
11,740	0.67	1,531.3	329.3	123	67.6	1.18	0.54
12,100	1.70	6,346.0	604.9	316	68.3	1.29	0.60
12,490	1.52	11,233.6	351.7	231	40.5	1.18	0.64
12,850	4.91	58,292.7	400.4	736	20.2	1.18	0.68
13,090	2.60	27,015.7	470.5	489	24.6	1.19	0.60

Depth* (feet)	Total Organic Carbon (percent)	C_1-C_4 (ppm)	C_5-C_7 (ppm)	C_{15+} (ppm)	Gas Wetness (percent)	Carbon Preference Index	Vitrinite Reflectance
13,450	6.53	116,007.0	417.3	632	13.9	1.10	0.76
13,810	2.52	28,880.2	233.4	301	17.1	1.23	0.65
14,170	0.65	3,120.4	22.4	38	12.2	1.15	**
14,470	1.06	10,897.5	56.0	101	14.8	1.15	0.63
14,830	0.23	932.2	12.0	-	13.8	1.17	**
15,190	0.34	1,142.5	38.1	-	11.1	1.11	**
15,550	0.40	3,314.9	93.7	-	23.6	1.15	**
15,910	0.30	1,824.3	20.8	-	2.8	1.12	**

* Depths given are tops of 30-foot intervals sampled by well cuttings.

** Insufficient sample of primary vitrinite for analysis.

The organic material deposited with unconsolidated sediments is converted to kerogen, the insoluble organic material in sedimentary rocks, during diagenesis and the type of hydrocarbon produced is a function of temperature and kerogen type. Both structured (woody) and unstructured (amorphous and herbaceous) kerogens are present throughout the stratigraphic section indicating the potential for both gas and oil production. However, the hydrogen content and hydrogen/carbon ratios of separated kerogens, measured by Amoco Production Company, indicate that rocks with oil generating potential may be found only above 4,890 feet where sufficient temperatures for hydrocarbon production have not been reached. These preliminary elemental analyses suggest that source rocks below this depth have the potential for gas and limited liquid generation.

The carbon preference index (CPI), the ratio of odd to even numbered straight-chain paraffins, indicates the degree of thermal maturity of the sedimentary organic material. Immature organic matter yields a high CPI value whereas crude oil provides a value close to 1. Two carbon preference indices were calculated, one listed in Table 3 for C_{21} through C_{27} values and the other for C_{25} through C_{31} values. The highest values for the second index, some of which are greater than 2, fall above 5,700 feet while the lower values and closer readings for the two indices in older rocks show greater maturity.

A more exact determination of the degree of thermal alteration can be made by measuring the reflectance capability (R_0) of polished vitrinite particles from the residual material of cuttings samples. Vitrinite reflectance analysis was done by Superior Oil Company and the R_0 values for primary vitrinite show a steady increase with depth. Thermal alteration of organic material to petroleum begins at temperatures of about 150 F°and R_0 values of 0.45 to 0.5, found at depths of 6,800 to 8,400 feet in the well. The peak value for oil generation, 0.6, is reached at 11,300 feet; the value at T.D. is approximately 0.82; and the peak value for wet gas generation, 1.0, is projected to occur at about 19,000 feet.

The amount of methane in hydrocarbon gas is another indication of thermal maturity because the ethane, propane, butane, and minor amounts of higher hydrocarbons found in wet gas form at the higher temperatures needed for petroleum generation. Beds above 7,100 feet contain primarily dry gas (predominantly methane) and organic-lean rocks in the bottom 2,000 feet of the well also have a low wetness percentage.

Straight-chain compounds replace their branched isomers at increased temperatures, and the isobutane/normal butane ratio drops below 1 at a depth of 11,300 feet. Molecular ratios among the heavier paraffin-naphthene hydrocarbons also show a decrease in hydrocarbons with less stable structures below 10,000 feet because of greater thermal maturation at the higher temperatures deeper in the well.

Abundant organic material and high concentrations of hydrocarbons were found in the interval between 9,400 and 13,900 feet. If these organic-rich shales have been exposed to more extensive temperature alteration in the Baltimore Canyon Trough area, they should form excellent petroleum source beds.

CORRELATION WITH SEISMIC VELOCITY DATA AND SEISMIC REFLECTIONS

Detailed seismic velocity data for the COST No B-2 well were obtained by correcting the integrated Sonic Log with the uphole velocity survey. Corrected velocities were compared with geologic data from the well and with the U.S. Geological Survey seismic reflection line 2. Line 2, shot and processed by Digicon, Inc., in 1973, is a 12-fold common-depth-point (CDP) stacked data. The reflection profile extends from the New Jersey shoreline southeastward to the continental slope. The stratigraphic test well was drilled 7 miles north of shot point 1300. Velocity analyses from shot points 1274, 1306, and 1338 were averaged to give the seismic reflection velocities. On the average, 8 events were picked between 0 and 3.0 seconds on the velocity displays.

Time-depth curves constructed from both the corrected Sonic Log and line 2 were plotted on the same coordinates and show excellent agreement (see Figure 11). The only significant discrepancy occurs at depths above 2,800 feet (0.93 seconds) where the reflection velocities are consistently slower than the sonic velocities. A maximum difference of 15 percent between the two travel times occurs at 1,200 feet (0.45 seconds). This difference probably reflects the unreliability of the shallow events on the velocity displays. The shallow sediment is unconsolidated sand which produces only weak reflections, making it extremely difficult to find reliable velocity picks. The discrepancy on Figure 11 below 12,000 feet (2.7 seconds) is only 2 percent which is within the accuracy of the geophysical measurements, although it appears greater than the shallower difference because of the linear depth scale.

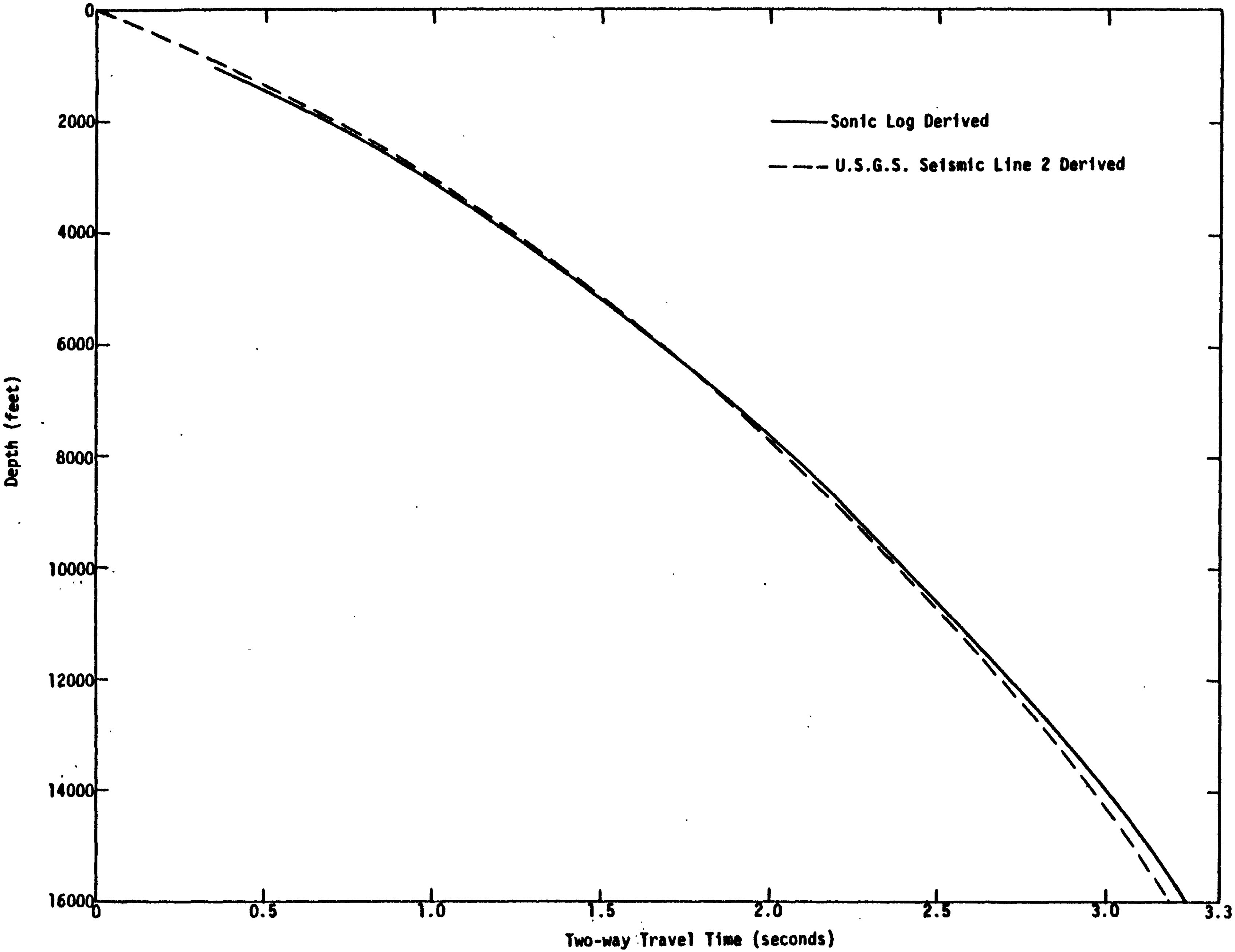

Figure 11 Continueous velocity curve for COST No. B-2 well from Sonic Log and U.S.G.S. Line 2 seismic reflection data.

Interval velocities derived from the Sonic Log and from line 2 were also plotted. The overall agreement is again quite good (see Figure 12). There are, however, significant differences over some 0.1 second intervals, such as between 1.5 and 1.6 seconds. In these cases, the sparsity of recognizable events on the velocity displays caused the reflection data to be averaged over wide intervals.

Sonic-derived velocities were correlated with line 2 and other seismic reflection profiles. Figure 13 shows a portion of line 2 with generalized lithologies and the geologic correlations of the section. The Upper Tertiary section consists predominantly of unconsolidated sand. Line 2 shows seaward dipping foreset bedding which is common throughout the Baltimore Canyon Trough area. Sonic velocities are consistent in this interval, explaining the low amplitude nature of the seismic events. The Lower Tertiary section contains relatively abrupt changes from shale to limestone with a few interbedded sandstones. Reflection coefficients of ± 0.3 occur producing several good seismic reflectors.

The base of the Tertiary section at 5,000 feet (1.47 seconds) is a 20-foot thick dense limestone with a velocity of 14,000 feet/second. This unit is underlain by 150 feet of porous Cretaceous sandstone with an average velocity of 9,100 feet/second. However, the velocities are lower in the upper part of this sandstone, with the upper 10 feet having an average velocity of only 5,300 feet/second. These anomalously low velocities could be caused by residual gas in the formation or by "cycle skipping" on the Sonic Log. Since the low velocities coincide with the high amplitude reflector that marks the top of the Cretaceous, it seems likely that they are real. The section between 5,300 feet (1.5 seconds) and 8,600 feet (2.1 seconds) consists of limy shale with a few sandstones. The velocity changes are so gradual that no distinct boundaries occur, resulting in a zone of poor seismic response. A

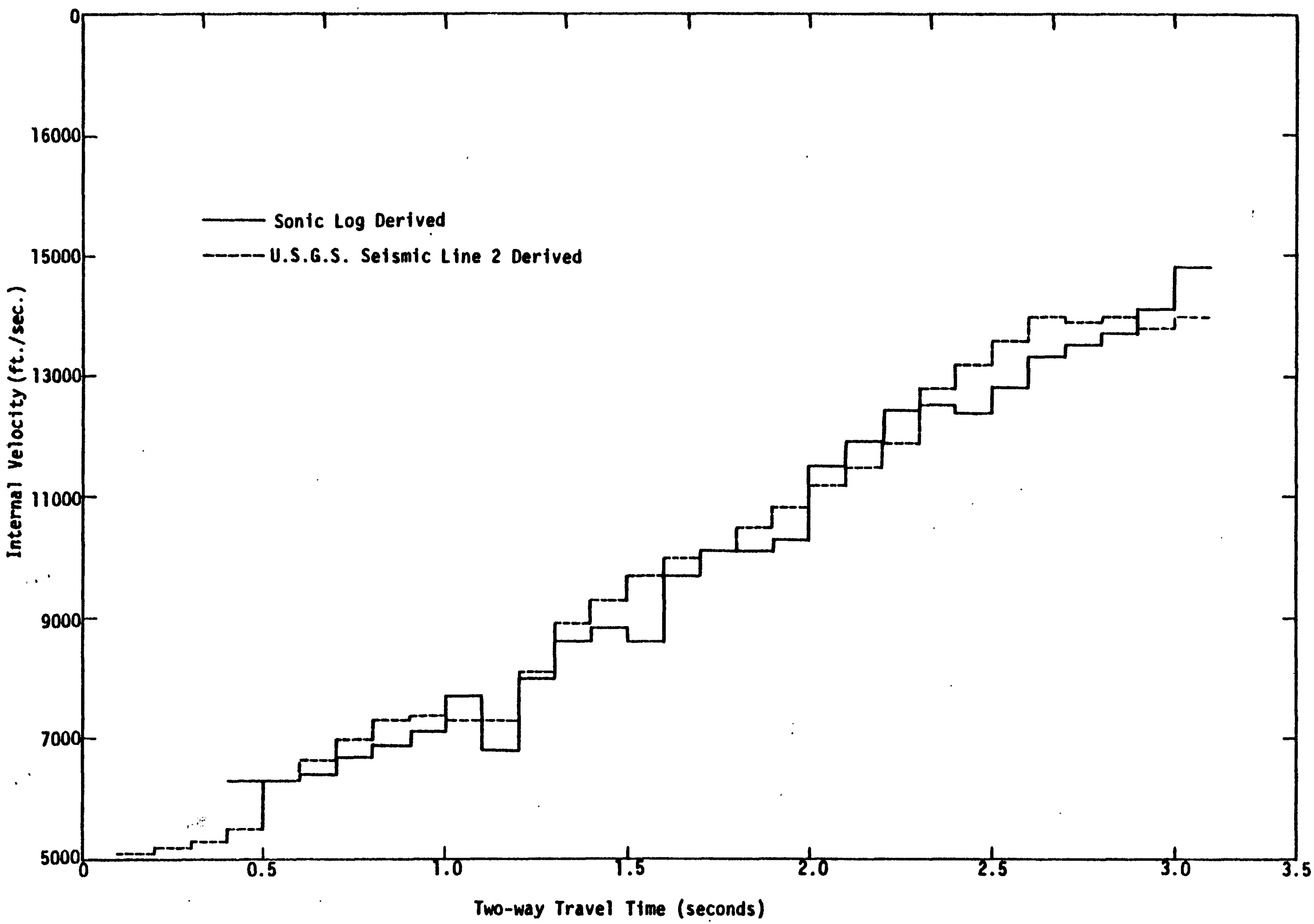

Figure 12 Interval velocity curve for COST No. B-2 well from Sonic Log and U.S.G.S. Line 2 seismic reflection data.

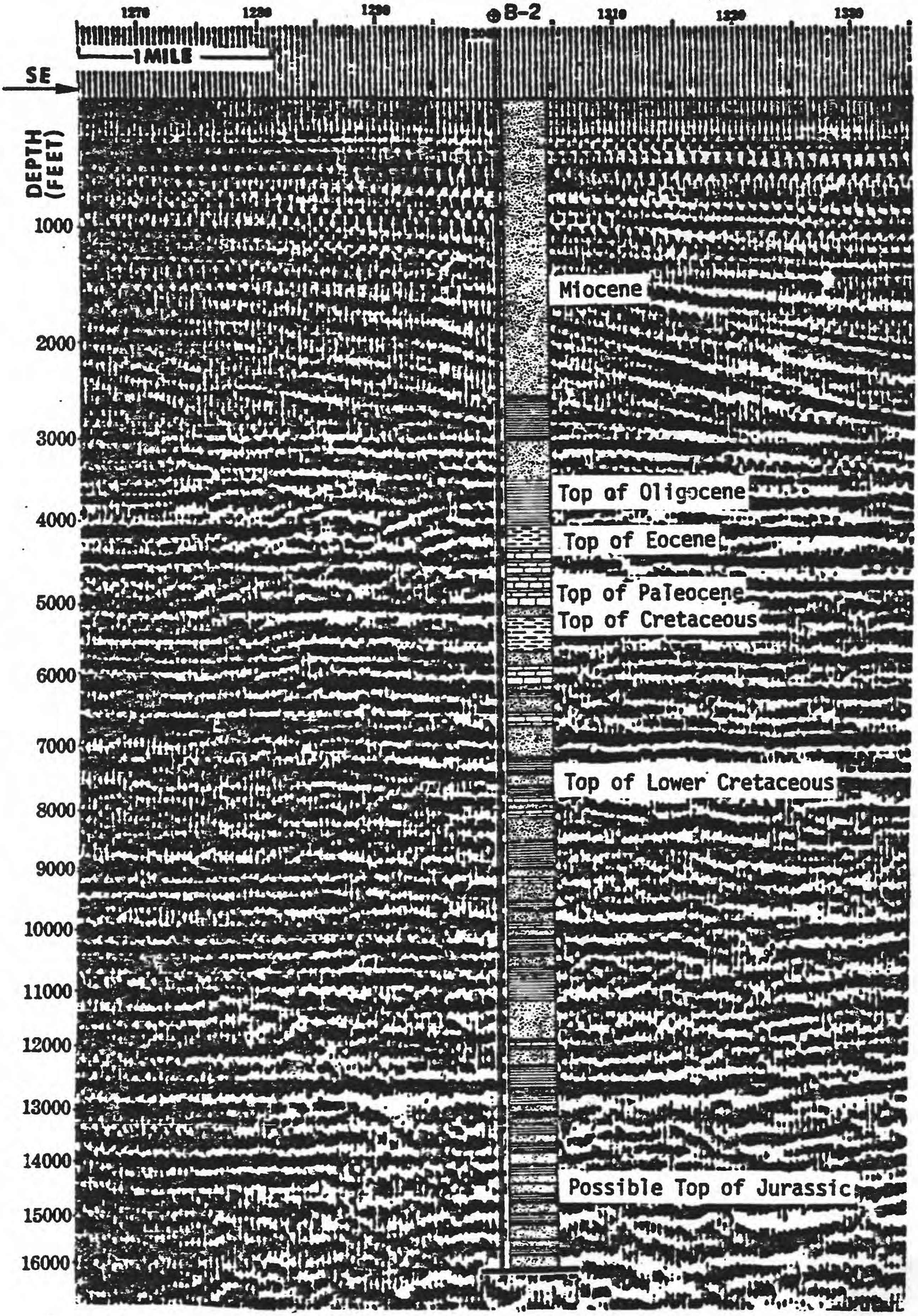

Figure 13 Approximate location, lithology, and geologic horizons of COST No. B-2 well on U.S.G.S. Line 2.

few limy intervals produce reflection coefficients near ± 0.3, but they are only 10 to 20 feet thick and are not evident on the seismic record. From 8,600 feet (2.1 seconds) to 13,500 feet (2.9 seconds), the sonic velocities fluctuate rapidly due to distinct and abrupt lithologic changes in the well. The section consists of thick sandstones and shales with occasional lignite beds and contains many good continuous reflectors. The bottom 2,500 feet of the well consists of alternating sandstone and shale with wildly fluctuating velocities. No consistent velocity extends for more than 30 feet and no continuous seismic event is evident on the record.

ENVIRONMENTAL CONSIDERATIONS

A draft Environmental Analysis of the proposed deep stratigraphic test program for the Baltimore Canyon Trough area was written during the summer of 1975 and comments and suggestions were solicited from other concerned federal agencies, governors and state geologists of the northeastern coastal states, and various fishery and environmental organizations. The final Environmental Analysis was prepared in October 1975 after a review of all responses and further discussion with the parties involved. As with earlier stratigraphic test wells in the COST program, a determination was reached that the proposed drilling did not constitute a major Federal action significantly affecting the quality of the human environment in the sense of N.E.P.A., Section 102(2)(c), and therefore did not require an Environmental Impact Statement.

The COST No B-2 well was drilled 78 miles east-southeast of the New Jersey coastline at the closest point to shore and 91 miles east of Atlantic City. A study of common-depth-point seismic data for the area was used to select a location that was away from any potential petroleum-entrapping structure, therefore minimizing the likelihood of penetrating hydrocarbon-bearing sediments while providing valuable information on the stratigraphic section and possible source and reservoir rocks near the sale area. Archeological, biological, and engineering surveys were also made of the drilling site before approval was granted for the operation.

Geological and other natural hazards as well as man-made hazards that might endanger the drilling operation were taken into consideration in the Environmental Analysis. High-resolution seismic lines across the proposed location that were required of the operator indicated no shallow geologic hazards. The compact sandy surface sediment in the area provided good anchoring characteristics for drilling structures. Evidence of sediment scour was seen in some nearby tracts, but creep was apparent only in deeper water at the shelf edge. No near surface faulting or shallow gas pockets were found in the vicinity and hydrogen sulfide and geopressures were not expected nor encountered by the well. The earthquake risk is also low in the Mid-Atlantic region. Although several underwater cables run through the area and there are numerous chemical and explosive dump sites on this section of the continental shelf, the closest man-made hazard to the COST No. B-2 well was an area of undetonated explosives 12 miles to the south. The outbound shipping lane from New York City runs southeastward 9 miles northeast of the well and a normal risk was present for collisions and other accidents associated with continental shelf drilling programs.

The intensity of storms is somewhat above the average for other shelf areas in the world, but drilling operations were suspended for only 32.5 hours because of inclement weather. Winds averaging 30 knots with waves of 15 feet and swells of 9 feet occurred 10 percent of the total time the rig was on location. Gale force winds up to 56 knots with 50-foot waves and swells up to 20 feet also occurred during the drilling program.

The most detrimental effect on the environment, particularly for the fish and wildlife populations and the coastal tidelands, from this operation would have resulted from a major oil spill. However, the stratigraphic test well was drilled "off structure" on an unleased block to avoid penetrating a hydrocarbon zone. Devanney and Stewart (1974) in a study for the Council on Environmental Quality concluded that a hypothetical offshore spill during the winter at the approximate drilling location would have less than a 5 percent chance of ever reaching the coast. The spill would also take 18 days, on the average, to reach the coast (Smith and others, 1976). U.S. Geolgoical Survey regulations, permit stipulations, and OCS orders prescribe stringent control over the drilling operations and blowout prevention equipment, and the entire operation was continuously monitored by U.S.G.S. inspectors. An oil spill contingency plan directed that a fast-response skimmer system with additional backup spill containment and clean-up equipment be constantly available to the operator.

Normal drilling procedures would not seriously disturb the marine population, fishing industry activity, or recreational users in this area. Most of the domestic fish catch comes from nearer shore, within the 12-mile limit, whereas foreign fishing operations are more prevalent in the vicinity of the well. During the first day of drilling, before the initial string of conductor pipe could be cemented in the hole at a depth of 220 feet below the sea floor and the marine riser installed to allow circulation to the drill ship, salt water was used as a drilling fluid and some sediment was dislodged at the ocean floor. During the remainder of the drilling, only washed cuttings were disposed of in the ocean and about 700 cubic yards of small rock chips were scattered along the sea floor near the well site after settling through the 300-foot water column. The drilling mud was normally recirculated with the mud weight adjusted for pressure control and to prevent fluids from flowing between formations and zones or leaking out at the surface. Small quantities of excess mud were allowed to be dumped at sea only when they contained no oil and the level of toxic additives posed no threat to marine life. A small amount of cement may also have been displaced around the shallow casing strings. The well was plugged and abandoned in accordance with the OCS orders to prevent any future pollution at its location.

In summary, no serious hazards were encountered and all short-term effects that occurred during the drilling procedure were minor and ended when the well site was abandoned. After completion of the operation, cement plugs were set to prevent the migration of fluids and surface leakage. The sea floor was cleared of all obstructions and checked by an observation dive. No long-term effects resulted from drilling the stratigraphic test hole, but essential information and valuable experience were gained for conducting future drilling operations on the Mid-Atlantic Outer Continental Shelf.

SUMMARY AND CONCLUSIONS

The COST No. B-2 well was drilled in the Baltimore Canyon Trough 91 miles east of Atlantic City, New Jersey, to gain geological, geophysical, and engineering data prior to OCS Sale No. 40. The well bottomed at a total depth of 16,043 feet in either lowermost Cretaceous or uppermost Jurassic rocks and was plugged and abandoned. This was the first deep stratigraphic test drilled on the U.S. Atlantic OCS and as such provided unique and valuable data.

Because the well was drilled only to acquire subsurface and drilling information, it was intentionally located away from any subsurface structure or stratigraphic feature that might contain hydrocarbons. The hole was sucessfully drilled to its intended total depth in 106 days, with only 1.28 percent of the total drilling time lost because of bad weather. Well cuttings were continuously sampled and examined from 610 feet to total depth and four conventional cores were obtained and analyzed along with 822 sidewall cores. Various drilling and mud logs were made to constantly monitor the drilling of the well and a complete suite of electric and geophysical logs were run in the hole prior to abandonment. No liquid oil shows were reported in the cores or cuttings and only insignificant amounts of methane gas were noted on the mud log. A few asphaltic stains were revealed during examination of the cuttings; however, there was no indication that the well encountered any zone containing hydrocarbons.

The shallowest strata penetrated by the well were a 222-foot section below the sea bottom where no cuttings were obtained because mud circulation had not been established and an underlying 300-foot interval of coarse sand, shell fragments, and glauconite which was barren of fossils and could not be dated. This section was probably a combination of non-marine or very shallow marine Pleistocene, Pliocene, and uppermost Miocene sediments. The next interval between 910 and 3,596 feet R.K.B. was dated as Miocene, and a middle to outer shelf environment was indicated. Coarse sand continued to 2,600 feet, underlain by gray shale and soft mudstone to 3,050 feet, coarse sand to 3,500 feet, and shale to 3,600 feet. Oligocene rocks were encountered between 3,596 and 4,082 feet and included gray and brown shale and claystone deposited in a deep-water environment. Eocene sediment occurred from 4,082 to 4,964 feet and was predominantly tan and buff, dense, argillaceous limestone with lesser amounts of light gray claystone. A thin sequence of Paleocene rocks occurred between 4,964 and 5,000 feet consisting of tan argillaceous limestone and claystone. Eocene and Paleocene sediments were also deposited in deep (up to 1,500 feet) water.

Cretaceous strata were first encountered at 5,000 feet and the well probably penetrated Cretaceous rocks to total depth, although a questionable Jurassic top was noted at 14,650 feet. Upper Cretaceous strata occurred between 5,000 and 8,130 feet. They included a porous sandstone between 5,000 and 5,200 feet (Core No. 1 was taken in this interval) and shale, dark gray clay, and minor amounts of chalky limestone from 5,200 to 5,800 feet that were deposited in deep water. Coarse- to medium-grained sandstone with lesser amounts of shale, thin limestone, and lignite deposited in shallow to moderately deep water was encountered from 5,800 to 6,850 feet. A mixed sequence of gray and tan shale with thin beds of dolomite, limestone, and fine-grained sandstone deposited in middle shelf or upper slope environments (water depth from 50 to 1,500 feet) was found between 6,850 and 8,130 feet.

Lower Cretaceous rocks extended to at least 14,650 feet and included a thick series of coarse- to medium-grained calcareous sandstone with thin interbeds of gray shale, coal, limestone, and dolomite in the interval between 8,130 and 10,500 feet. This section contained abundant reservoir-quality sandstone deposited in shallow marine water and was sampled by conventional cores at 8,238 feet (Core No 2) and at 9,280 feet (Core No. 3). The interval between 10,500 feet and 11,500 feet consisted of fine-grained sandstone with generally low porosity and brown and gray shale with interbedded coal and lignite. Paleoenvironments alternated in this section from non-marine to shallow marine. The remaining Lower Cretaceous interval to 14,650 feet included a predominantly non-marine sequence of fine- and medium- grained sandstone; gray, tan, and brown shale with abundant coal in places; and thin beds of limestone and dolomite. Core No. 4, taken at 13,420 feet, sidewall cores, and electric logs indicated the existence of some porous sandstone in this section with porosity and permeability values diminishing sharply with depth. The questionable Jurassic (or Lower Cretaceous) section from 14,650 feet to total depth (16,043 feet) was a predominantly non-marine sequence of moderately porous to non-porous, fine- to coarse-grained sandstone and red, brown, maroon, and gray variegated shale with minor amounts of coal and lignite.

Log and sample analyses provided petrophysical data on rock characteristics and lithologic descriptions of the stratigraphic units. Sandstone porosity and permeability values and shale density and porosity values were shown to be a function of depth. Determinations from electric logs of porosity, permeability, water saturation, grain cementation, shaliness of sandstones, and effective sand thicknesses demonstrated that excellent reservoir-quality rocks are present in the Cretaceous section to a depth of 12,100 feet and form about 23 percent of the section below 5,000 feet in this well.

Organic-rich, fine-grained potential source rocks were found between 9,400 and 13,900 feet by detailed geochemical analysis. Studies of thermal maturity indicated that if these rocks were exposed to greater temperature alteration they could generate large quantities of gas and related liquids.

Geophysical data from the uphole velocity survey were combined with the corrected Sonic Log readings to obtain continuous and interval time-depth curves. Reflectors from nearby seismic profiles could then be tentatively correlated with lithologic units encountered in the well.

In addition to the geological information on the Baltimore Canyon Trough obtained from the COST No. B-2 well, invaluable technical experience was gained for future drilling operations on the Mid-Atlantic OCS. Information was provided for this area on drilling costs and rates as well as on casing, mud, logging, and cementing programs. There were no indications of any serious problems for deep drilling and no unexpected hazards were encountered. Valuable weather and oceanographic data were also obtained and indicated that normal winter conditions should not cause extensive drilling delays.

Good bottom conditions with no shallow geologic hazards were present at the well site. Secure anchoring for drilling structures should be no problem except for moderate sediment scour and some creep at the shelf edge. Shallow gas pockets are unlikely and can be identified along with shallow active faulting by preliminary high-resolution studies. Normal pressure and temperature gradients were found throughout the well.

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