UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGICAL AND OPERATIONAL SUMMARY, COST NO. GE-1 WELL, SOUTHEAST GEORGIA EMBAYMENT AREA, SOUTH ATLANTIC OCS

R. V. Amato and J. W. Bebout, Editors

Open-File Report 78-668

1978

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

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U. S. Customary to SI Metric Units:

1 inch = 2.54 centimeters
1 foot = 0.30 meter
1 statute mile = 1.61 kilometers
1 nautical mile = 1.85 kilometers
1 pound = 0.45 kilogram
1 pound/gallon = 119.83 kilograms/cubic meter
1 pound/square inch = 0.07 kilograms/square centimeter
1 gallon = 3.78 liters (cubic decimeters)
1 barrel (42 US gals.) = 0.16 cubic meters

Temperature in degrees Fahrenheit = °F less 32, divided by 1.8 for degrees Celsius.

Other Conversions: 1 knot = 1 nautical mile/hour
1 nautical mile = 1.15 statute miles or 6,080 feet

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INTRODUCTION

The Continental Offshore Stratigraphic Test COST No. GE-1 well was drilled by Ocean Production Company between February 22 and May 31, 1977. Geological and engineering data obtained from this first deep well in the Southeast Georgia Embayment were used by participating companies and the U.S. Geological Survey (USGS) for evaluating the petroleum potential, as well as possible drilling problems, in the U.S. South Atlantic Outer Continental Shelf (OCS) area in preparation for Lease Sale No. 43 held on March 28, 1978. Information obtained on the operations lithology, potential source rocks, temperature and pressure gradients, biostratigraphy, etc., is summarized in this report. As with previous COST wells, the COST No. GE-1 well was drilled away from any potential petroleum-bearing feature, but near several tracts that were included in the sale area.

The COST No. GE-1 well (fig. 1) was drilled to a depth of 13,254 feet at a location approximately 74 nautical miles east of Jacksonville, Florida, in 136 feet of water by ODECO's jack-up drill barge, the <u>Ocean Star</u>.

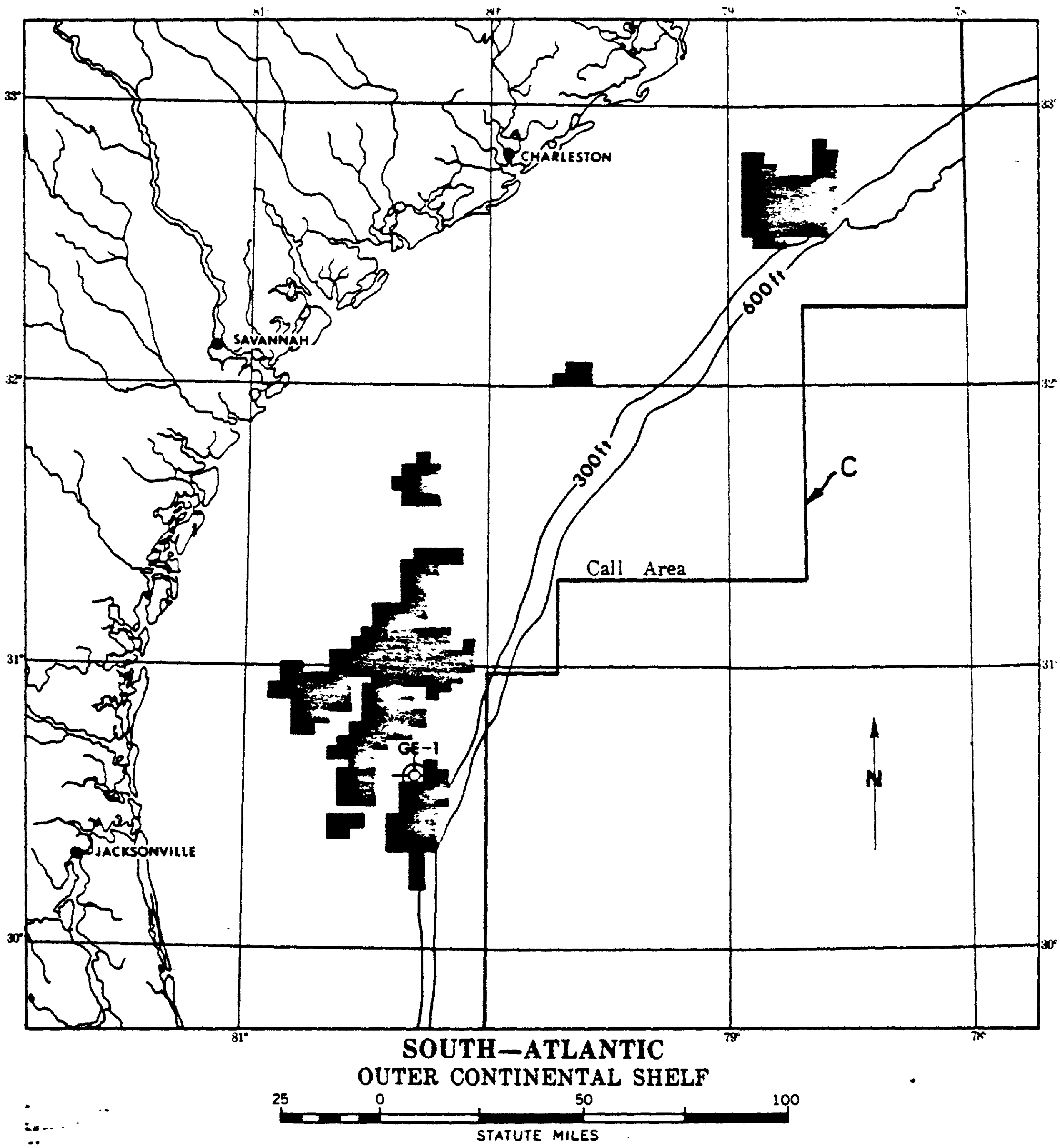

Figure 1. Map of the South Atlantic O.C.S. showing the location of the COST No. GE-1 well, the tracts offered for lease in Sale No. 43 (in black) and the eastern limits of the call area for tract nominations (C).

The public disclosure provision of the regulations on geological and geophysical explorations of the OCS (30 CFR 251.14) specifies that geological data from deep stratigraphic tests, including analyzed and interpreted information, shall be released 60 days after the issuance of the first Federal lease within 50 nautical miles of the test site, or 5 years after the well completion if no lease is issued. Block 433, 5.5 nautical miles southeast of the GE-1 well, was leased on May 1, 1978, by Mobil and Amerada-Hess Oil Corporations following OCS Lease Sale No. 43, held on March 28, 1978.

Part of the information included in this summary is based on contract reports by service companies, sample analyses by oil companies, and USGS interpretations of electric logs, drill cuttings, and cores which may be inspected at the Public Information Room of the USGS -- Conservation Division, Eastern Region, 1725 K Street, N.W., Washington, D.C. All depths referred to in this report are given in feet below the Kelly Bushing (K.B.) elevation which was 98 feet above mean sea level. Because only English units of measurement are used in the report, a table of conversions to SI Metric Units follows.

OPERATIONAL DATA

by M. A. Smith and R. V. Amato

General Information

Ocean Production Company, acting as operator for the Atlantic COST well program, drilled the COST No. GE-1 well under an OCS permit No. E36-76 issued by the USGS. Expenses were shared by the of 25 original participants:

Amerada Hess Corporation

Aminoil U.S.A. Inc.

AMOCO Production Company

Atlantic Richfield Company

BP Alaska Exploration Inc.

Chevron Oil Company

Cities Service Company

Continental Oil Company

Diamond Shamrock Corporation

Exxon Company U.S.A.

Getty Oil Company

Gulf Energy and Minerals Company -- U.S.

Houston Oil and Minerals Corporation

Marathon Oil Company

Mobil Oil Corporation

Ocean Production Company

Pennzoil Company

Phillips Petroleum Company

Superior Oil Company

Tenneco Oil Company

Shell Oil Company

Sun Oil Company

Texaco Incorporated

Transco Exploration Company

Union Oil Company of California

Drilling stipulations required the operator to provide the USGS with copies of all well logs, together with washed and unwashed samples, core slabs, and operational and technical reports. These were received by the USGS at the same time as they were received by industry participants.

The surface location of the COST No. GE-1 well, was lat. 30° 37' 07.6892" N.; long. 80° 17' 59. 1451" W., or at U.T.M. coordinates X = 1,860,592.66 feet and Y= 11,113,327.33 feet, in Block 387 in OCS Official Protraction Diagram NH 17-5 (fig. 2). The GE-1 well was drilled as a vertical hole with a course inclination of less than 3 degrees at all measured depths above 11,150 feet. For the remainder of the well, the drift angle varied from 4 1/2 to 9 1/2 degrees to the east. At a measured depth of 13,207 feet, the deepest inclination survey point, the true vertical depth was determined to be 13,194.22 feet and the horizontal displacement was 12.12 feet south and 202.70 feet east of the surface location.

Ocean Production Company used ODECO's jack-up drill barge, the Ocean Star to drill the COST No. GE-1 well. The rig arrived on location and

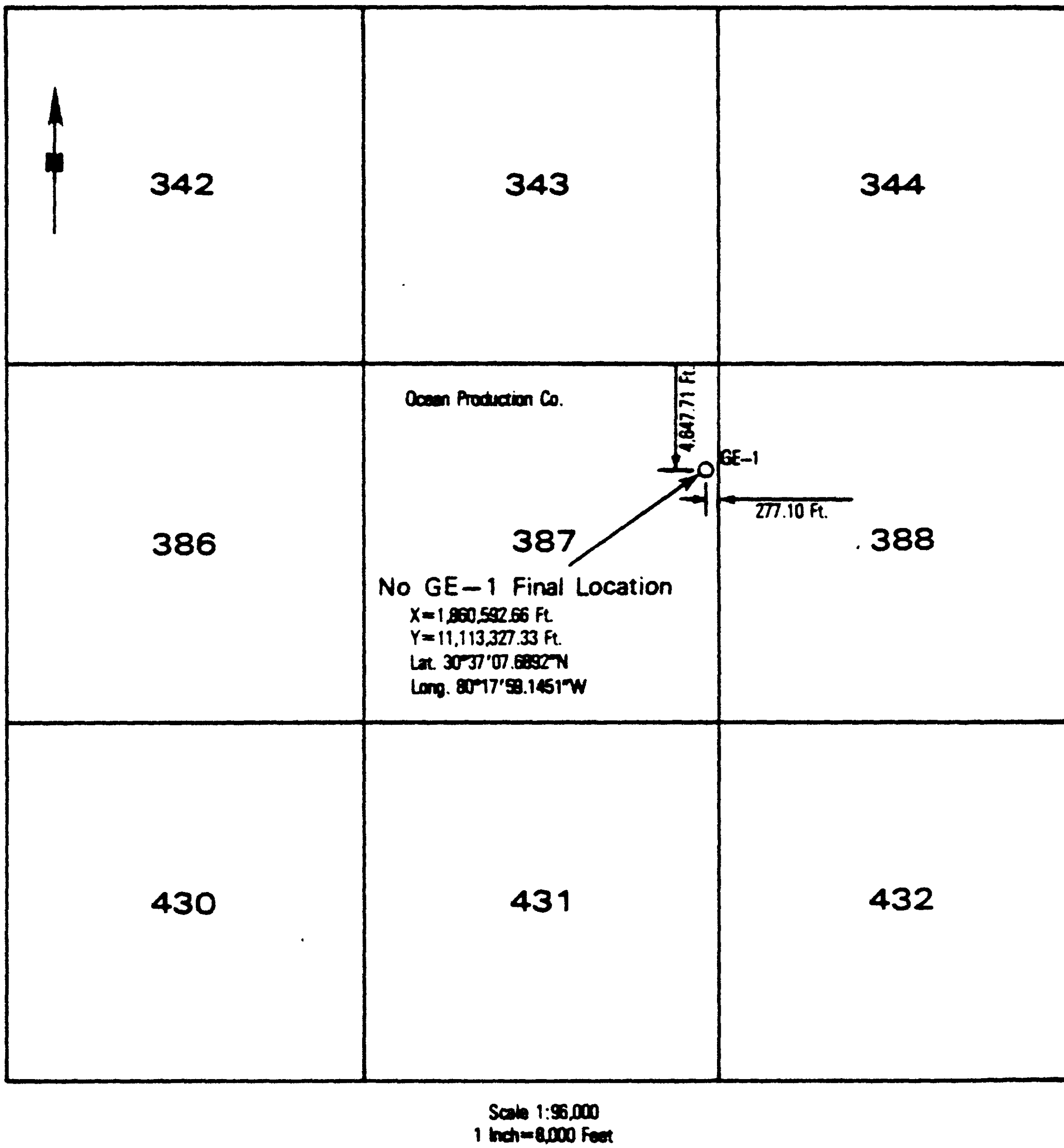

Figure 2. Final location plat showing the surface position of the COST No. GE-1 well in OCS Protraction Diagram NH 17-5

was positioned in 136 feet of water on February 22, 1977. Drilling to the final total depth of 13,254 feet was finished on May 31st. Final wireline logging, seismic velocity, and temperature surveys were completed, sidewall cores were obtained and five successful drill-stem tests were conducted. The well was then plugged and abandoned in accordance with USGS Mid-Atlantic OCS Order No. 3 and the drilling rig was released on June 14, 1977.

Drilling Programs

The COST No. GE-1 well was drilled as a 12 1/4-inch hole and required 37 drill bits to reach its total depth. Fifteen additional bits were used for reaming out the hole before setting the casing strings, for drilling out cement at the bottom of casing, for clean-out trips, and for cutting the conventional diamond cores. Figure 3 shows the daily drilling rate for the well, logging and casing depths, and depths for trips to change the 12 1/4-inch drill bits. The drilling rate decreased from 92 feet/hour to less than 3 feet/hour near the bottom of the well. The average drilling rate to 4,025 feet was 63 feet/hour, dropping to 19 feet/hour for the interval to 10,008 feet, then to 10 feet/hour to a depth of 11,000 feet, and finally to 4 feet/hour to total depth.

Three strings of casing were set in the shallow part of the GE-1 well (fig. 4). Only Class H cement was allowed for use in the well. After the hole was widened to 36 inches to a depth of 440 feet, 30-inch conductor casing was set and cemented at 390 feet with 500 sacks The 12 1/4-inch hole was also opened to 26 inches at 1,010 feet

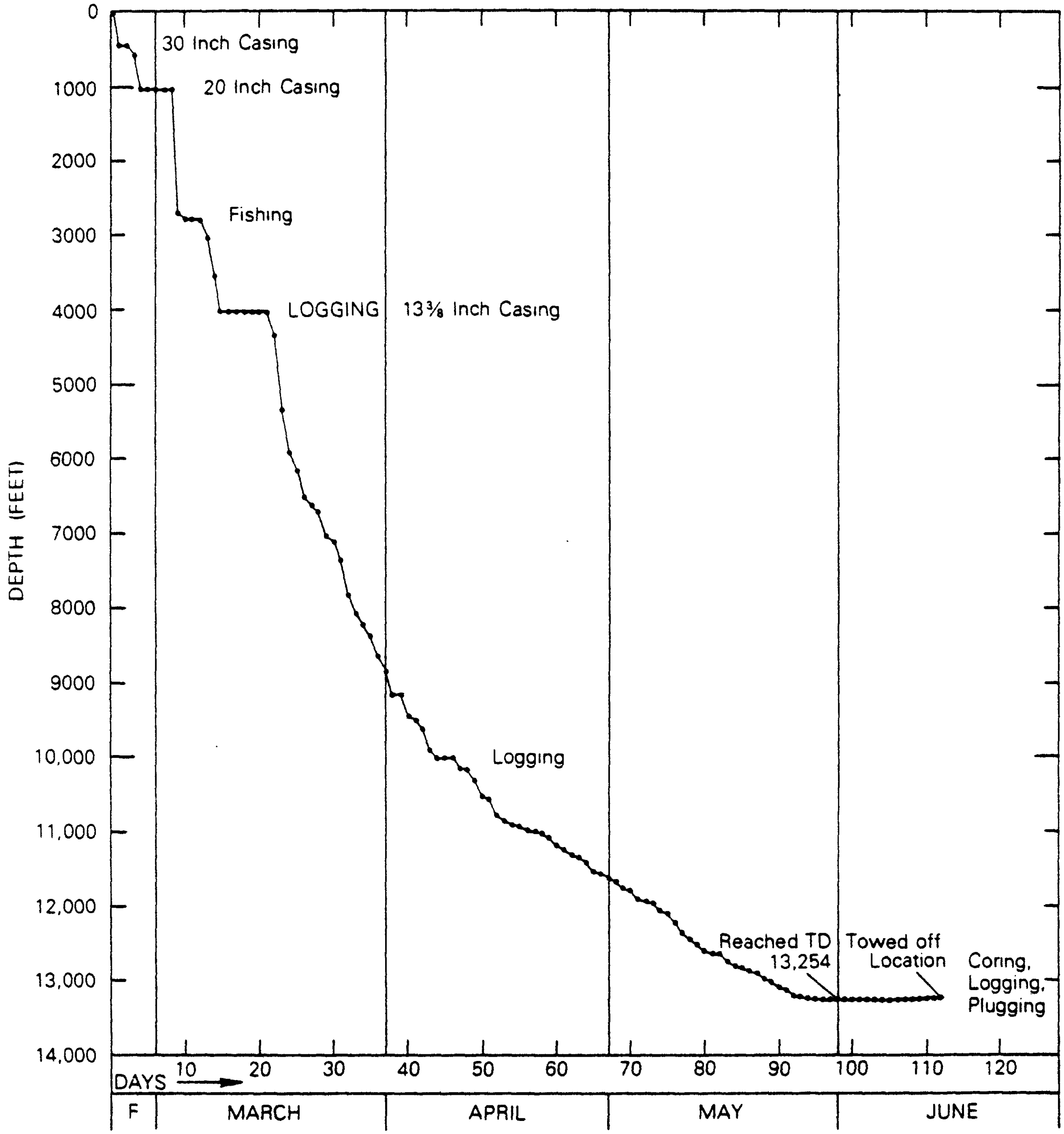

Figure 3. Daily drilling rate graph for the COST No. GE-1 well

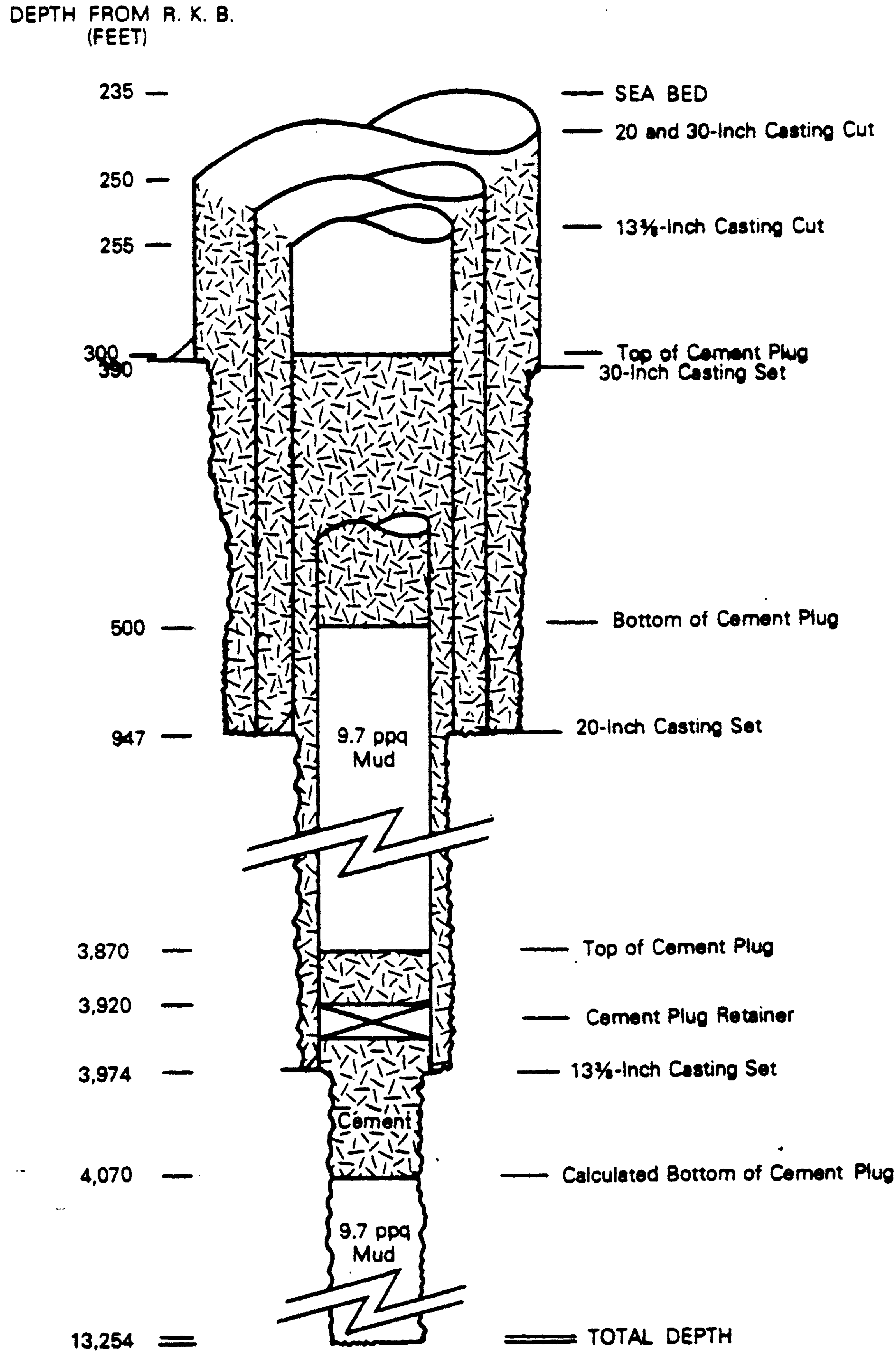

Figure 4. Schematic diagram showing relative position of casing strings, cement displacement, and plugging and abandonment program

and to 17 1/2 inches at 4,025 feet so that additional strings of surface casing could be cemented in place. Slightly above these depths, 900 sacks of cement were used to set the 20-inch casing at 947 feet and 1,700 sacks were used to cement the 13 3/8-inch casing at 3,974 feet.

A high-gel caustic mud was used for drilling between 440 and 4,025 feet, and lignosulfonate drilling mud was used at all greater depths. Figure 5 shows the changes in various mud parameters with depth. The mud weight was increased gradually from 8.5 pounds per gallon to 9.7 ppg, which was maintained from 6,800 to 9,900 feet. The mud weight was decreased to an average of 9.45 ppg below 11,100 feet. Mud viscosity varied from 36 to 62 seconds and showed a close correlation with the mud weight. Chloride concentrations, which got as high as 12,200 ppm during shallow drilling dropped to 2,500 ppm near the bottom of the hole. The calcium values decreased from a maximum of 1,000 ppm at 1,010 feet to trace amounts at 3,555 feet. A second increase in calcium concentrations in the mud to a maximum of 460 ppm occurred when anhydrite beds were encountered between 6,600 and 8,500 feet. The pH varied from 9 to 13.5 and averaged 12.2 for the mud system used below 3,974 feet, the final casing point.

IMCO Services, a division of Halliburton Company, provided the mud logging service for the COST No. GE-1 well and collected all cuttings samples. A Formation Analysis Log at scales of 2 and 5 inches to 100 feet was run while the well was being drilled to monitor the mud system and drilling progress. This log gives the rate of drill penetration

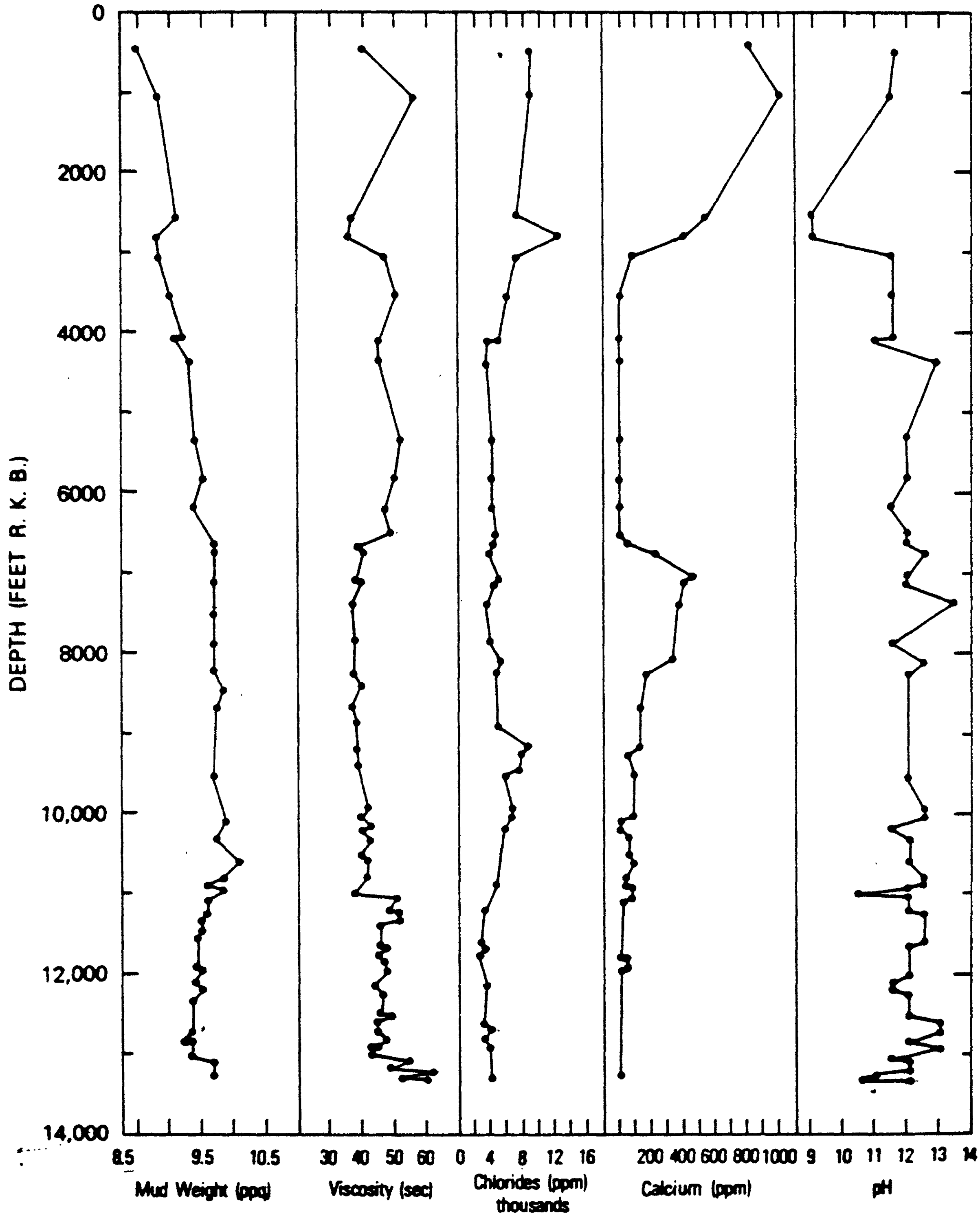

Figure 5. Graph showing changes in weight, viscosity, chloride, calcium concentration, and pH of the drilling mud with depth

in feet/hour, the lithology with additional rock descriptions from cuttings analysis, and the total hot wire gas units and chromatographic anlysis, as well as data on other recorded drilling parameters. Other IMCO logs included a log of mud temperature, resistivity with shale density, and a log showing the d_c exponent, which gives an estimate of pore pressure for each drilled interval, and the mud weights used.

The final estimated cost for the GE-1 well was $7.53 million. In addition to the cumulative daily cost, this amount included approximately $100 thousand for preliminary site surveys, $1.09 million for the geoscience program including all logging costs, $224 thousand for drill bits and other downhole equipment, $183 thousand for mud costs, $231 thousand for casing program costs, $145 thousand to plug and abandon the well, and $400 thousand for rig demobilization costs. The time spent on various activities in the drilling operation is as follows:

	Hours	Percent of Total
Drilling	1,019.0	38.16
Tripping	658.0	24.63
Wire Line Logging	183.5	6.87
Reaming	159.0	5.95
Circulating & Conditioning Mud	136.0	5.09
Coring	91.5	3.43
Fishing	47.0	1.76
Removing BOP Stack	46.5	1.74
Deviation Surveys	38.0	1.42
Cementing	33.0	1.24
Installing & Testing BOP Stack	32.0	1.20
Rigging Up & Running Casing	30.5	1.14
Rig Repair	15.0	0.56
Cutting Off Drill Line	12.5	0.47
Drill-Stem Testing	10.0	0.37
Other	159.5	5.97
Total	2,671.0	100.00

Samples, Tests, and Logs

Samples of well cuttings were obtained from the COST No. GE-1 at 30-foot intervals from 390 to 4,020 feet and at 10-foot intervals from 4,020 feet to total depth. These samples were used for both lithological description and paleontological analyses. Sidewall and conventional cores were also obtained to have "in-place" data including porosity, permeability, and grain density measurements, as well as paleontological and lithological descriptions. A total of 946 sidewall cores were attempted during the three logging runs for the well, of which 733 were recovered. Fifteen conventional cores were attempted with at least partial recovery on 11 of them. The The cored intervals and recoveries are listed below:

Core No.	Depth (Feet)	Recovery (Feet)
1	3,024 - 3,054	30.0
2	6,607 - 6,657	48.4
3	7,040 - 7,100	59.2
4	8,331 - 8,391	59.8
5	9,453 - 9,513	53.1
6	10,518 -10,520	0.25
7	10,520 -10,580	46.0
8	10,931 -10,933	0.0
9	10,933 -10,935	0.0
10	11,000 -11,002	0.0
11	11,357 -11,387	29.0
12	11,635 -11,643	7.0
13	12,624 -12,627	0.75
14	13,247 -13,251	0.0
15	13,252 -13,254	0.75

Five successful drill stem tests (DST) were conducted in the COST NO. GE-1 well after it was drilled to total depth. DST No. 1 tested the interval between 10,428 - 10,461 feet; DST No. 2 between 8,598 and 8,735 feet; DST No. 3 (failed); DST No. 4, between 7,458 - 7,608 feet; and DST No. 5, 6,874 - 7,007 feet; DST No. 6, 5,788 - 5,910 feet.

Electric logs, sidewall cores, and seismic velocity surveys were obtained at three different times and intervals during the drilling of the well: Log Run No. 1 from the surface to 4,025 feet, Log No. 2, from 4,025 to 10,008 feet, and Log Run No. 3, from 10,008 to total depth at 13,254 feet. The first log run was conducted on March 10 - 11 and included a combination Dual-Induction Laterolog and Sonic-Gamma Ray Log, a Formation Density Compensated (FDC) Log and Compensated Neutron Log (CNL) with Gamma Ray, a Long-Spaced Sonic log with Spontaneous Potential (SP), a Long-Spaced Sonic log with Gamma-Ray and Caliper, a High-Resolution Dipmeter, a Seismic Velocity Survey. Of 151 attempted sidewall cores, 118 were recovered.

The second log run took place on April 9 - 10 and included continuations of the same logs and surveys from Log Run No. 1 with recovery of 509 sidewall cores out of an attempted 618. The third log run was from June 2 to June 4 and again included the same logs and surveys from Log Run No. 1 with the addition of a Temperature Log and a special Schlumberger Seismic Survey. Of 177 attempted sidewall cores, 106 were recovered.

Weather

Weather observations were reported from the rig to the PHI helicopter base at Jacksonville, four times per day. Calm to moderately calm weather and sea conditions prevailed during the 114 days that the Ocean Star was on the GE-1 location and no downtime was caused by adverse weather. Average reported weather and sea conditions were as follows:

	Wind direction and speed (knots)		Wave height (ft)	Temperature (°F)	Barometric pressure (in.)
February.......	S-SE	21	4.5	59.5	29.8-31.2
March..........	SE-SW	15	3	65	29.8-31.9
April..........	SE	13	4	70	29.7-30.6
May............	SE-W	10.8	2.3	72	29.7-30.9
June...........	SE-W	12.8	2.2	74	28.9-30.0

Note: On February 2, 1977, wind speed was 40-45 knots and waves were 8-10 feet high. On April 5th and 24th, wind speed was 30-40 knots.

LITHOLOGIC DESCRIPTIONS

by D. Lachance

Well cuttings samples from the COST No. GE-1 were obtained at 30-foot intervals from 390 to 4,020 feet and 10-foot intervals from 4,020 feet to total depth. A lithologic log was prepared for the GE-1 well participants by John Amoruso and Associates and is available for inspection along with other logs and samples and cores at the Public Information Room of the USGS, Conservation Division, Eastern Region, 1725 K Street N.W. Washington, D.C. Detailed lithologic studies of well cuttings and cores from the GE-1 were also made by the author.

The following is a general summary of the strata penetrated by the COST No. GE-1 well. The strata have been grouped into eight sections, on the basis of similar lithologies. A summary lithologic column is shown on plate 1.

<u>Section IA</u> (390 - 570 feet)

This section is predominantly composed of calcareous, quartz sands, sandy, oolitic to non-oolitic micrites, and abundant faunal remains.

The sands consist of subangular, fine to pebbly, poorly sorted, clear to slightly frosted quartz grains and traces of feldspar, rock fragments, and chert, cemented with a white to buff calcite cement. The average sand grain size decreases with depth.

The micrites are white to dark gray, depending on their phosphate content, and contain trace to moderate amounts (approx. 30%) of fine-to medium-grained sands. Oolites are common and range in color from white to buff to black. The faunal remains appear to be associated with the sands and include: bryozoans, worm tube casts, forams, barnacles and other unidentified arthropod fragments, and whelk, gastropods, pelecypods, and other unidentified shell fragments. Traces of silty, light-buff micrite with small, gray oolites are present below 510'.

Section IB (570-750 feet)

This section is composed of sedimentary clasts including calcareous sands; sandy, oolitic micrites; faunal remains; silty, oolitic micrites; and phosphate nodules in a matrix of buff, silty sparites and foraminiferal ooze.

The clasts include sands and micrites similar to those in Section IA. The sands are calcareous, fine-to coarse-grained and locally pebbly, subangular, moderately sorted, clear to slightly frosted and contain a few scattered, white-to dark-gray oolites. The micrites are white to dark gray, depending on their phosphate content, and contain minor to abundant white to black oolites. The faunal remains present consist of shell fragments, and a few bryozoans, arthropod fragments, and forams. Minor amounts (up to 5%) of silty, light-buff micrites similar to those in Section IA are scattered throughout the section, along with dark-brown to black phosphate nodules.

Section IC (750 - 1,020 feet)

This section consists of varying amounts of sedimentary clasts, faunal remains, and other trace constituents in buff, silty sparites similar to those in Section IB, and silty, buff micrites. The sparites, clasts, faunal remains and other trace constituents decrease with depth.

The sedimentary clasts include sands and micrites similar to those in section IB Phosphatic micrites are scarce, however. Faunal remains include shell fragments, forams, a few pelcypods, brachiopods, bryozoans, glauconitized forams, and sharks' teeth.

Moderate amounts of slightly silty, soft, white to light-gray micrites with minute gray oolites are present below 990 feet.

Section IIA (1,020 - 1,230 feet)

The contact between sections IIA and IC is gradational, and is defined by the first appearance of light-brown cherts. The cherts are light-brown to buff, authigenic, and have sharp to gradational contacts with the surrounding limestones. Two types of limestones are present throughout this section. The first is a white to light-gray, slightly silty, soft micrite with gray oolites (also present in Section IC below 990'). The second type is a light -buff, slightly silty, soft limestone which superficially resembles chalk. A variety of trace constituents is found in the light-buff lime and include sub-angular to rounded quartz sand grains, feldspar grains, glauconite, forams, bryozoans, snail and other unidentified shell fragments, sponge spicules, and echinoid spines.

Section IIB (1,230 - 2,970 feet)

This section is composed of limestones, cherts, and various trace constituents. The contact between sections IIA and IIB is gradational. The cherts are light-brown to buff, authigenic, have sharp to gradational contacts with the surrounding limestones, and are similar to the cherts found in Section IIA. Numerous trace constituents present in the limestones are also present in the cherts. Above approximately 2,000 feet, cherts are relatively scarce. Below this depth, however, they are present in minor to abundant amounts. The limestones are silty, light-gray to light-buff, soft, superficially resemble chalk, and are similar to the second type of limestones described in Section IIA. The color of this lime is apparently related to its silica content. Those limes which have a relatively high silica content tend to be light-buff in color, whereas limes which are relatively silica deficient tend toward a light-gray coloration. Throughout the section, the limes contain minor amounts of forams and traces of bryozoans, shell fragments, glauconite, fibrous calcite, calcareous shale, subangular quartz sand grains, and pyrite.

Section IIC (2,970-3,660 feet)

This section is composed of shales and limestones, along with traces of chert and other minor constituents. The contact between sections IIB and IIC is gradational.

The shales are light-gray, calcareous, slightly silty, and contain a few traces of pyrite. The limestones and cherts are similar to those described in Section IIB. Trace constituents include shell fragments, forams, glauconite, and quartz sand grains.

Section III (3,660 - 5,730 feet)

This section consists of alternating shales and limestone layers. Section III has not been divided into subsections because of the indistinctiveness of the shales and calcilutites throughout the section. The contact between Sections III and IIC is abrupt.

The shales are calcareous, light-to medium-gray in color and locally silty. The micrites are white to light-gray, argillaceous, and contain minor amounts of fine-to coarse-grained, subangular to angular quartz sand grains as well as traces of forams, crinoid fragments, brachiopods, and other unidentified shell fragments, pyrite, calcite, glauconite, gypsum, and coal.

Section IVA (5,730 - 6,090 feet)

This section consists of alternating quartz sands, silts, and shales with stringers of limestone and coal. The contact between Sections IVA and III is gradational. The relative amount of silts and shale gradually increases with depth at the expense of the sands.

The sands are light-gray, fine-to medium-grained, angular to subangular, poorly to moderately sorted, and moderately calcareous with trace to minor amounts of pyrite, glauconite, muscovite, calcite and gypsum. The silts are also light-gray, angular to subangular, calcareous, and contain an assemblage of trace constituents similar to those in the sands.

The shales are dominantly light-to medium-gray, calcareous, and contain a few shell molds. Below 5,850 feet, minor to moderate amounts of green, waxy shales are also present. The limestone stringers are light-gray, soft to hard and dense, argillaceous micrites with trace to moderate amounts of sands and silts, and traces of pyrite. The coal occurs as thin stringers in both the sands and shales throughout the section, and is dark-brown to black with abundant pyrite.

Section IV B (6,090 - 6,520 feet)

This section contains interbedded limestones, gray shales, and moderate amounts of gray silts and sands. The contact between Sections IVA and IVB is gradational, and the relative amount of sand and silt present shows an overall increase with depth at the expense of the limestones.

Two types of limestone are present in the section. The first type is a white-to light-gray, crystalline sparite which is present only from the top of the section down to approximately 6,130 feet. The second type of limestone is a light-gray to buff micrite with abundant oolites, minor amounts of interstitial silt, glauconite, and sand grains. Trace constituents include pyrite, shell fragments, and calcite.

The shales are dominantly medium-gray with moderate amounts of green color, and are calcareous, slightly silty, and contain traces of coal and shell fragments. The sands are very-fine to fine-grained, angular, poorly sorted, argillaceous and calcareous-cemented. The silts are similar to the sands in that they are angular, poorly sorted, argillaceous, calcareous, and contain a similar assemblage of trace constituents.

Section VA (6,520 - 6,850 feet)

This section is composed of limestones interbedded with moderate amounts of gray shales, a few anhydrite beds, and minor amounts of dolomite. The top of this section is defined as the first anhydrite bed encountered and the contact between Sections VA and IVA is gradational.

The limestones consist of micrites which are generally similar to those described in Section IVB, and crystalline sparites which are believed to be diagenetically altered micrites. The micrites are light-gray to buff, and contain trace to abundant amounts of oolites, pellets, trace to minor amounts of quartz sand grains, silt and glauconite. The sparites are light-gray to buff, crystalline, vuggy, and contain trace to moderate amounts of oolites, and pellets. The vugular porosity appears to have developed from dissolution of the oolites and pellets.

The shales are medium-gray, silty, and contain traces of muscovite, gypsum and a few coal laminations. Below 6,800 feet, a few traces of reddish-brown shale are also present. The anhydrite is white, finely-crystalline, and occurs as thin beds in the limestones. The dolomites are buff, slightly silty, have a sucrosic texture, and are believed to be diagenetically altered micrites.

Section VB (6,850 - 7,090 feet)

This section is composed of carbonates interbedded with moderate amounts of shale and a few anhydrite stringers. The contact between Sections VA and VB is gradational, and is defined by the first downhole appearance of abundant dolomites.

The carbonates consist of dolomites and minor amounts of limestones from the top of the section to approximately 6,950 feet, and limestones with minor amounts of dolmite from 6,950 feet to the bottom of this section. The dolomites are buff, slightly silty, have a sucrosic texture, and are similar to the dolomites described in Section VA. The limestones are light-gray to buff micrites and crystalline sparites with minor amounts of oolites and pellets, and traces of silt, sand, shell fragments, calcite, pyrite, and glauconite. Both the sparites and dolomites are believed to be diagenetically altered micrites.

The shales are medium-gray, and slightly silty with a few traces of coal and gypsum. A few traces of reddish-brown and green shales are also present throughout the section. The anhydrite is white and finely-crystalline, and occurs as thin stringers in the limestones and dolomites.

Section VIAa (7,090 - 7,960 feet)

This section consists of alternating thin sands and shales with a few anhydrite and carbonate stringers. With increasing depth, the color of both the sands and the shales goes from dominantly light-gray to dominantly reddish-brown.

The sands are angular to subangular, very fine-to very coarse-grained, poorly-to moderately-sorted, calcareous and are light-gray, pink, and reddish-brown in color. The average grain size and the ratio of red to gray sand both increase with depth. Trace constituents present throughout the column include muscovite, gypsum, oolites, pellets, calcite, and various heavy minerals.

The shales are slightly calcareous, silty, and light-to medium-gray and reddish-brown with a few thin sections of green shale scattered throughout the section.

The ratio of red to gray shales generally increases with depth, and a few thin stringers of coal are present in the shales throughout the section. The carbonate stringers occur as thin beds of light-gray to light-buff, micritic to sparitic limestones and dolomites with trace to minor amounts of silt, glauconite, fossils, oolites, pellets, and pyrite. The anhydrites are white, finely crystalline, and occur as thin beds in the shales.

Section VIAb (7,960 - 8,320 feet)

This section consists of shales interbedded with thin quartz sands, and a few limestone, dolomite, and coal stringers. The shales are dominantly reddish-brown and light-to medium-gray. However, minor amounts of brown and green, waxy shales are also present throughout the section. The reddish-brown and gray shales are silty, calcareous, and contain trace to minor amounts of coal, gypsum, and white and pink anhydrite stringers. The sands are fine-to medium-grained, calcareous, angular, and moderately-sorted, light-gray to pink and reddish-brown, and contain traces of pyrite, gypsum, coal, and a few heavy minerals. The carbonates consist of dense, light-gray to buff micrites which occur as thin stringers in the shales. A coal bed approximately 10 feet thick with trace to minor amounts of pyrite is encountered at approximately 8,020 feet. If it is laterally extensive, this bed may serve as a useful stratigraphic marker.

Section VIB (8,320 - 10,770 feet)

This section is composed of alternating sands and shales, and minor amounts of thin limestone and dolomite beds.

The sands are fine-to coarse-grained and pebbly, angular to subangular, moderately-to poorly-sorted, slightly calcareous, and reddish-brown, pink, light-gray, and maroon in color. With increasing depth, the average grain size increases from fine at the top of the section to very coarse and pebbly at the bottom of the section, while the degree of sorting and angularity decreases. Above approximately 9,500 feet, the sands are predominantly pink, reddish-brown, and gray with an approximate 9:1 ratio between the reds and grays. Local variations in the ratio are common, and at some depths it is reversed.

Below 9,500 feet, maroon and reddish-brown sands in approximately equal amounts predominate while grays are present in minor to moderate amounts throughout the column. Trace constituents present in the sands include pyrite, gypsum, and rock fragments. Rock fragments are common below 9,300 feet and vary in size from small grains to fairly large fragments. White gypsum is present throughout the section and becomes increasingly common with depth.

The shales are silty, and reddish-brown, medium-gray, and maroon in color. Above 9,500 feet, reddish-brown and gray predominate with an approximate 9:1 ratio between the reds and the gray, and maroon shales are present in only minor to moderate amounts. Below approximately 9,500 feet, gray shales are virtually absent, and reddish-brown and maroon shales are present in nearly equal amounts. Coal stringers and muscovite occur sparsely in the shales throughout the section. The limestones and dolomites are dense, slightly silty, white, buff, gray, and maroon micrites and occur as thin beds in the shales.

Section VII (10,770 - 11,050 feet)

This section is composed of a basal conglomerate and minor to moderate amounts of interbedded shales. The contact between Sections VII and VIB is gradational. The shales are reddish-brown and maroon, contain a few traces of coal, and are similar to those described in Section VIB. Below approximately 10,840 feet, the shales are only present in amounts less than 10%. The conglomerates are composed of clear, yellow, and red metaquartzites with a hematite stain. The actual size and shape of the unbroken metaquartzite fragments are uncertain.

Section VIII 11,050' - 13,254'

This section consists of pale-green argillites with traces of quartz veins, pyrite, and hematite, and minor to moderate amounts of reddish-brown and maroon, silty argillites to approximately 12,500 feet. Below 12,500 feet, moderate amounts of white metaquartzites and medium-gray siltstones with a locally abundant matrix of anhydrite and minor to moderate amounts of hematite are interbedded with both the pale-green and reddish-brown argillites. At approximately 13,000 feet, volcanic flows or hypabyssal dikes of basaltic composition are common and associated with the argillites, metaquartzites and siltstones.

BIOSTRATIGRAPHY

by W. Steinkraus

General Statement

Paleontological analyses for age determination and paleoenvironmental interpretations for the COST No. GE-1 well were conducted by International Biostratigraphers, Incorporated (1977) and by L. A. Latta of the U.S. Geological Survey in Metairie, Louisiana. Micro-Microfossils including foraminifers, calcareous nannoplankton and palynomorphs (spores, pollen and dinoflagellates) were analyzed.

The samples investigated included 509 composited well cuttings, 42 conventional core chips, and 172 sidewall cores. The cuttings were composited and studied at 30-foot intervals for foraminifers and from 6,520 feet to total depth; 90-foot composites were examined for palynomorphs. The sidewall cores were processed for the following fossil groups: 77 cores for foraminifers, 154 for palynomorphs and 74 for calcareous nannofossils. The conventional chips were processed for palynological studies.

It was determined that the COST No. GE-1 well penetrated about 3,180 feet of moderate- to deep-water marine Tertiary strata, about 2,380 feet of moderate marine Late Cretaceous beds, and about 2,950 feet of shallow marine Early Cretaceous sediments. No age determinations were made in the interval between 8,900 and total depth at 13,254 feet because the section is barren.

The following is a summary of the paleontological data showing the depths to the tops of geologic Series or Stages:

Depth (feet)	Geologic Series or Stage
390	Pliocene
570	Middle Miocene
750	Oligocene
1,230	Late Eocene
2,100	Middle Eocene
3,150	late Early Eocene
3,480	early Late Paleocene
3,570	late Maastrichtian - Late Cretaceous
3,700	Early Maastrichtian
3,750	Campanian
4,350	Santonian
4,870	Coniacian
5,320	Turonian
5,830?	Cenomanian
5,950	Albian - Early Cretaceous
7,500	Aptian
8,900	Indeterminate-barren
13,254 (T.D.)	

Age Determinations

Age determinations in both the Tertiary and Late Cretaceous sections were based mainly on planktonic foraminifers. Several biostratigraphic units, however, were defined or confirmed by palynomorphs, dinoflagellates and calcareous nannofossils. Early Cretaceous age determinations were based primarily on palynomorphs, dinoflagellates and nannofossils.

TERTIARY

PLIOCENE (390-570 feet)

Faunal assemblages from this interval are fairly rich in planktonic foraminifers. This interval is interpreted as Pliocene based on the occurrence of *Globorotalia crassaformis* and *Globorotalia acostaensis* and the absence of Pleistocene index species. Other planktonic foraminifers present include *Globigerinoides conglobatus*, *Globigerinoides trilobus* (s.l.), *Globorotalia menardii* (s.l.), and *Globorotalia humerosa*.

MIDDLE MIOCENE (570-750 feet)

Miocene planktonic foraminifers, *Globorotalia siakensis*, *Orbulina suturalis*, *Orbulina universa* and *Globoquadina dehiscens* occur in this interval. In addition to the above planktonic species, the presence of *Globorotalia peripheroacuta* and *Globorotalia peripheroronda* indicates a Middle Miocene age for the interval.

It is believed that the Miocene sediments are unconformable relative to the Pliocene strata above and the Oligocene sediments below.

OLIGOCENE (750-1,230 feet)

The foraminifers present in this interval include *Bulimina sculptilis*, *Uvigerina topilensis*, *Cibicides pippeni*, and *Chiloguembelina cubensis*. *Globigerina ampliapertura* and *Globigerina ciperoensis* occur in the interval from 750 to 960 feet. Their occurrence indicates that Latest Oligocene sediments are not present in the COST No.

GE-1 well.

The interval from 960 to 1,230 feet is interpreted as early Oligocene based on the occurrence of the planktonic species Pseudohastigerina micra and Cassigerinella chipolensis.

EOCENE (1,230-3,480 feet)

Late Eocene (1,230-2,100 feet)

The top of the Eocene is determined from the highest occurrence of Globorotalia cerroazulensis, Globigerina eocaena and Globigerina linaperta.

A single sidewall core taken at 1,583 feet yielded a rich and well preserved dinoflagellate assemblage. A middle to late Eocene age is established by the joint occurrence of Homotryblium floripes and Diphyes colligerum. Other forms present, such as Areosphaeridium multicornutum and Wetzeliella floripes, concur with this age assignment.

The calcareous nannofossils present in the sidewall core at 1,583 feet included Reticulofenestra umbilica, Discoaster saipanensis, Pemma basquense and Rhabdosphaera tenuis. The age of this sample is interpreted as early Late Eocene or late Middle Eocene.

Middle Eocene (2,100-3,150 feet)

The middle Eocene section is determined at the highest occurrence of Globorotalia spinulosa, Globorotalia bullbrooki, Truncorotaloides rohri, and Globorotalia cerroazulensis pomeroli at 2,100 feet. The early part of the Middle Eocene is recognized by the highest occurrence of Globorotalia aragonensis and Globigerina frontosa at 2,800 feet. Very few benthonic foraminifers were recovered from the Middle Eocene.

Dinoflagellates are rare in sidewall core samples taken at 2,900 and 2,973 feet but are abundant in conventional core No. 1 (3,024-3,054 feet) and the sidewall core sample at 3,070 feet. A Middle Eocene age was determined from the occurrence of Adnatosphaeridium reticulense and Areosphaeridium arcuatum in these samples.

Sidewall core samples at 2,973 and 3,070 feet were examined for calcareous nannofossils and were interpreted to be early Middle Eocene in age. The nannofossils present included Discoasteroides kupperi, Chiasmolithus solitus, Chiasmolithus californicus, Chiamolithus grandis, and Sphenolithus radians.

Early Eocene (3,150-3,480 feet)

The first unequivocal Early Eocene species, Globigerina soldadoensis angulosa, has its highest occurrence at 3,150 feet. It occurs together with Globorotalia pentacamerata, Globorotalia bullbrooki, Globorotalia aragonensis and Globigerina frontosa.

The interval from 3,150 to 3,480 feet is interpreted as latest Early Eocene. No evidence of any older Early Eocene was noted. It is concluded that a large part of the Early Eocene and the Latest Paleocene Globorotalia velascoensis Zone is not represent- in the GE-1 well.

Three sidewall core samples at 3,176, 3,234 and 3,284 feet contained rich dinoflagellate assemblages. Dinoflagellates identified as Areosphaeridium arcuatum, Areosphaeridium multicornutum, Phthanoperidinium eocenicum, and Wetzeliella symmetrica have not previously been reported from sediments older than Middle Eocene. It has been suggested that the entire ranges of the above dinoflagellates may not yet be known and may extend downward into the uppermost Early Eocene.

Calcareous nannofossils were observed from sidewall core samples at 3,176 and 3,284 feet. The Discoaster lodoensis Zone within the Early Eocene was identified with this interval. The nannofossil species present included Discoaster lodoensis, Discoaster binodosus, Transversopontis pulcher, Discoasteroides megastypus and Tribraciatus orthostylus.

Early Late Paleocene (3,480-3,570 feet)

Globorotalia aequa, Globorotalia acuta, and Globorotalia angulata have their highest occurrences at 3,480 feet, and Globorotalia pseudomenardii and Globorotalia velascoensis occur at 3,510 feet. It is interpreted that this 90-foot interval is Late Paleocene in age and falls within the Globorotalia pseudomenardii Zone and that the Latest Paleocene sediments are not represented in the GE-1 well. No foraminifers characteristic of an older Paleocene age were noted.

A sidewall core sample taken at 3,510 feet yielded a poor dinoflagellate assemblage. The most significant species observed were Wetzeliella hyperacantha, which has not been known to occur in rocks younger than Late Paleocene , and Wetzeliella homomorpha, which ranges from Late Paleocene upward into the Eocene. The other Late Paleocene forms present in the assemblage include Adnatosphaeridium pastielsi, Cordosphaeridium inodes, Cordosphaeridium gracilis and Areoligera senonensis.

Several nannofossil species were identified in the sidewall core at 3,510 feet. A Late Paleocene age was determined by the occurrence of Heliolithus kleinpelli. Other species observed in the sample included Heliorthus concinnus, Cruciplacolithus helis, Cyclococcolithus robustus, and Zygodiscus sigmoides.

MESOZOIC

MAASTRICHTIAN (3,570-3,750)

Late Maastrichtian (3,570-3,700 feet)

Globotruncana gansseri, Globotruncana stuarti, Globotruncana arca, and Globotruncana falsostuarti have their highest occurrence at 3,570 feet. The Latest Maastrichtian indicators Globotruncana mayaroensis and Rugoglobigerina scotti are not present. The Latest Cretaceous horizon may be missing in the GE-1 well.

Sidewall core samples at 3,604 and 3,700 feet yielded a rich dinoflagellate assemblage. The species Dinogymnium acuminatum, Cannosphaeropsis utinensis and Hystrichodinium pulchrum observed in these samples have not been reported from younger than Maastrichtian sediments.

A diverse nannofossil assemblage was present in the sidewall core at 3,604 feet. The occurrence of Micula mura is indicative of a late Maastrichtian age. Lithraphidites quadratus was also present in the sample.

Early Maastrichtian (3,700-3,750 feet)

The nannoplankton assemblages occurring at 3,700 and 3,750 feet are interpreted as early Maastrichtian to latest Campanian. The species include Tetralithus trifidus, Broinsonia parca, Tetralithus nitidus, Tetralithus obscurus, Tetralithus aculeus, and Lucianorhabdus cayeuxi.

CAMPANIAN (3,750-4,350 feet)

The top of the Campanian is placed at 3,750 feet, where planktonic forms, Globotruncana ventricosa, Globotruncana stuartiformis, and Globotruncana lapparenti as well as the benthonic foraminifers Kyphopyxa christneri, Planulina taylorensis, and Globorotalites michelinianus have their highest occurrences.

Spores and pollen are very rare throughout the Senonian, but dinoflagellates are abundant and well preserved in most of the sidewall cores. The dinoflagellate Odontochitina costata, which ranges no higher than Campanian, has its highest occurrence at 3,800 feet. Palaeohystrichophora infusorioides has its highest occurrence at 4,000 feet. It ranges from the Albian to about the middle of the

Campanian.

The joint occurence of the nannofossil species Eiffellithus eximus and Broinsonia parca in the sidewall cores between 4,000 and 4,340 feet is indicative of Campanian age. Other species in this assemblage include Tetralithus pyramidus, Manivitella pemmatoidea and Microrhabdulus decoratus.

SANTONIAN (4,350-4,870)

The Santonian interval is characterized by the occurrence of Sigalia deflaensis which is considered to be restricted to that Stage. Globotruncana concavata, Globotruncana coronata, and Globotruncana carinata have their highest occurrences slightly below the top of this interval. The lower part of the Santonian is evidenced by Globotruncana sigali. It occurs as high as 4,710 feet. The base of the Santonian was picked on the lowest occurrence of Sigalia deflaensis in the sidewall core samples.

The dinoflagellate species Senoniasphaera protrusa, which is restricted to the Santonian, has its highest occurrence at 4,350 feet.

The Stage is bracketed within this interval by the lowest occurrence (4,300') of the nannofossils Broinsonia parca and the highest occurrence of Lithastrinus floralis at 5,100 feet. Within this interval, Marthasterites furcatus occurs at 4,497 feet.

CONIACIAN (4,870-5,320 feet)

The top of the Coniacian is picked at the highest occurrence of

Globotruncana renzi, Globotruncana imbricata, and Globotruncana marginata at 4,870 feet. Heterohelix reussi, Globotruncana schneegansi, Hedbergella amabilis, and Clavihedbergella simplex occur slightly lower within the Coniacian interval. No diagnostic dinoflagellates were identified in the Coniacian section.

The interval marking this Stage is interpreted from nannofossils by the highest occurrence of Lithastrinus floralis at 5,100 feet and the highest occurrence of Corollithion achylosum at 5,342 feet.

TURONIAN (5,320-5,830? feet)

Planktonic foraminifers are abundant in the Turonian interval. The species Globotruncana helvetica, persisting through the interval, is restricted to the Turonian stage. Praeglobotruncana stephani and Praeglobotruncana turbinata occur slightly below the top of the interval.

CENOMANIAN (5,830?-5,950 feet)

Diverse foraminiferal assemblages characteristic of the Turonian and younger stages disappear at 5,830 feet. In the horizon below, the assemblages are poor and predominantly arenaceous including genera Haplophragmoides, Cyclammina, Trochammina and Buccicrenata. The benthonic foraminifer Gavelinopsis cenomanica is present within this interval and a few non-diagnostic ostracodes have been identified. None of the palynomorph or nannofossil species observed in the interval are stratigraphically restricted to the Cenomanian.

ALBIAN (5,950-7,500 feet)

Sparse arenaceous foraminiferal assemblages persist downward to 6,190 feet. Clavihedbergella simplex, Hedbergella amabilis and Gavelinopsis cenomanica were identified from the sidewall core at 6,189 feet.

Palynomorph species Taurocusporites segmentatus, Foveotriletes subtriangularis and Spheripollenites psilatus have their highest occurrence at 5,950 feet. These species have been reported from horizons no younger than Albian. Other spores and pollen occurring slightly lower in the section and indicative of the early Cretaceous include Exesipollenites tumulus, Aequitriradites spinulosus, Trilobosporites apiverrucatus, and Pilosisporites trichopapillosus.

The foraminiferal assemblages may be interpreted as either Albian or Cenomanian; however, the later is ruled out by the palynomorph and nannofossil assemblages.

The occurrence of the nannofossil species Braarudosphaera quinquecosta and Braarudosphaera stenorhethra in the sidewall core at 6,495 feet is interpreted as representing a late Albian age. A sample from well cuttings at 6,500-6,530 feet yielded Nannoconus bucheri and Nannoconus cf. N. globulus which are indicative of an Albian age, or older.

Palynomorph assemblages are fair to good in the interval from 5,900 to 7,100 feet. The lithology consists of buff to gray limestone and dolomite with some anhydrite. Red shales appear in the section below about 7,100 feet. Very sparse to barren faunal and floral assemblages persist through the shale section.

APTIAN (7,500-8,900 feet)

The dinoflagellate species, Dingodinium albertii was identified from a sidewall core taken at about 7,500 feet. The species has its highest known occurrence at the top of the Aptian. Other sidewall cores taken at 8,756, 8,700 and 8,900 feet contain diverse dinoflagellate assemblages including Oligosphaeridium complex, Cribroperidinium edwardsi, and Deflandrea pirnaensis. Other species are present in fair numbers, such as Aptea polymorpha, which has been interpreted to be indicative of Aptian age; however, this species is reported to range as high as Albian (Millioud, Williams and Lentin, 1975). None of the sidewall cores below 8,900 feet yielded age-diagnostic palynomorph assemblages.

INDETERMINATE (8,900-13,254 feet)

No foraminifers were recovered from cuttings or sidewall core samples below 8,840 feet. In the interval between 8,900 feet and the total depth of 13,254 feet, only one sidewall core yielded diagnostic palynomorphs other than obvious contaminants. This sample taken at 11,500 feet yielded a fair assemblage of probable Aptian age. The palynomorphs are similar to the assemblages observed between 8,620 and 8,900 feet. Only a very small sidewall core fragment was available for processing. The well-site geologist described the sample as dark red, micaceous sandstone. No palynomorphs were observed from cuttings through this interval. Regarding the anomalous occurrence of this assemblage, it is concluded that the sample was out of place.

The absence of fossils in the interval between 8,900 feet and total depth of the well makes it impossible to provide a paleontological age determination.

CORRELATIONS WITH OTHER ATLANTIC COAST WELLS

by L. R. Kruysman

The COST No. GE-1 well was correlated with four Atlantic Coastal Plain wells: Standard Oil of New Jersey No. 1 Hatteras Light, Amerada Petroleum Corporation No. 2 Cowles Magazine, Sun Oil Company No. 1 Doster-Ladson, and the California Oil Company No. 1 John A. Buie. The geographic locations of these wells are noted on the inset map on plate 2. A dip section was constructed which correlates two onshore wells in the coastal plain of Georgia to the COST No. GE-1 well. The expected thinning of the stratigraphic section and an increase in the clastic deposits westward are demonstrated by the cross section. Plate 3 is a regional strike section from Cape Hatteras, North Carolina, through the COST No. GE-1 well to St. Lucie County, Florida. This section exemplifies the transition between the predominantly clastic depositional province of the Cape Hatteras area and the carbonate province of the Florida platform.

The lithology and stratigraphic age determinations of the No. 1 Hatteras Light well were based on the published data of Brown, Miller and Swain (1972); Maher (1971), Spangler (1950), Swain (1947, 1951, & 1952), and Swift (1974). The No. 2 Cowles Magazine well lithology and stratigraphic age determinations were based on well logs and core analysis reports by Baroid Well Logging Service, diamond core descriptions of L.L. Ridgway Company, Inc., and published descriptions by Applin and Applin (1965). Information on the No. 1 Doster-Ladson well was obtained from Applin and Applin (1967 and 1947), Herrick (1961), Marsailis (1970), and Stafford (1974). Lithology and stratigraphic age determinations for the No. 1 John A. Buie well were based on well logs and published data from Applin and Applin (1964), Maher (1971), Marsailis (1970), and Stafford (1974).

Both the No. 1 Hatteras Light well and the No. 2 Cowles Magazine well terminated in granitic rock of pre-Mesozoic age overlain by possible Jurassic (?) sediments of finely crystalline, partly oolitic limestone and gray shale beds grading downward to red and green coarse continental feldspathic sand and conglomerate. The No. 2 Cowles Magazine well penetrated about 2,200 feet of possible Late Jurassic (?) beds of dolomite, oolitic limestone, anhydrite, and shale with a basal arkosic sand. The COST No. GE-1 well displays a similar interval overlying a Paleozoic (Late Devonian) basement (Fullagar, written communication, 1977) consisting of a basal conglomerate grading upward into red and gray shales, sand and anhydrite. This interval is tentatively labeled Jurassic (?) although no age determinations are available at this time between 8,900 and 11,000 ft.

The remainder of the section in the No. 1 Hatteras Light well, particularly in the Lower and Upper Cretaceous, consists of interbedded fine sandstones, shales, and limestones indicating fluctuations in the depositional environment from marine to marginal marine.

The COST No. GE-1 well shows similar interbedding with some traces of coal in the Lower Cretaceous, but is decidedly more carbonaceous with layers of anhydrite, dolomite, and limestone. The No. 2

Cowles Magazine well is in a mostly carbonate facies of fossiliferous and oolitic limestones, dolomites and anhydrite with a few thin shale stringers. The first recovered sample was not obtained until almost 4,000 feet in depth, probably due to lost circulation in cavernous limestones, a common problem in the area. Although no stratigraphic age determinations were available for the section above 7,000 feet, it is believed to be mostly Upper Cretaceous carbonates on the basis of electric log correlations.

The prominence of the Cape Fear Arch in plate 3 between the Cape Hatteras and COST wells is based on seismic interpretation of basement rocks 50 miles offshore. Depth to the basement at this location is about 4,000 feet. The Arch is a gentle nose about 170 miles wide, trending in a general southeast to east direction from the Piedmont. It is asymmetrical with the north limb being steeper than the south limb (Maher, 1971). Seismic horizons correlated to the COST well indicate that a complete Cretaceous section exists over the Arch with appreciable thinning.

The two Georgia coastal plain wells in the cross section on plate 2 bottomed in pre-Cretaceous extrusive igneous rocks overlain by Lower Cretaceous non-fossiliferous marginal clastics. The thicker and more clastic Upper Cretaceous section in the No. 1 Doster-Ladson well may be attributed to the structural influence of the Suwanne Saddle and heavy sediment influx from the central Georgia uplift (Applin and Applin, 1967). The No. 1 Doster-Ladson well also contains the type section for the Atkinson Formation between the depths of 3,135 and

3,940 feet (Applin and Applin, 1947). The remainder of the stratigraphic section is mostly carbonate, indicating extensive overlap through the Oligocene. Post-Oligocene uplift to the north and south would have provided the clastics of the Miocene.

DEPOSITIONAL ENVIRONMENTS

by D. Lachance and W. Steinkraus

Micropaleontologic and lithologic analyses were carried out on the sediments encountered by the COST GE-1 well in order to determine their depositional environments. A summary of the conclusions drawn from these studies follows:

Micropaleontologic Analysis

Paleoenvironmental interpretations are based on benthonic foraminifers and the presence or absence of dinoflagellates. Paleobathymetric environments are deduced by the comparison of benthonic fossil foraminifers with recent foraminal assemblages known to favor certain ecological conditions. These interpretations become progressively less reliable with increasing geological age.

The interval between 390 and 8,900 feet ranges from a non-marine to a lower slope environment. It appears that non-marine conditions extended through the interval from 8,900 to 13,254' TD. The section is essentially barren.

The depositional environment of the Pliocene interval from 390 to 570 feet was interpreted as outer shelf at depths of 300 to 600 feet. Benthonic species present included *Cibicides americanus*, *Nonion atlanticus*, and *Uvigerina tenuistriata*.

The depositional environment of the Middle Miocene interval from 570 to 750 feet was interpreted as upper slope (600-1,500 feet). The benthonic species comprise rich assemblages such as Bolivina imporcata, Bolivina mexicana, Cibicides wuellerstorffi, Uvigerina ciperana, and Uvigerina rustica.

The Oligocene interval from 750 to 1,230 feet was deposited in outer shelf to upper slope (300 to 1,500 feet) as inferred by the rich benthonic assemblages containing Bolivina floridana, Bulimina sculptilis, Spiroplectammina sp., Uvigerina curta, Uvigerina curta, and Uvigerina topilensis.

The depositional environment of the Late Eocene interval from 1,230 to 2,100 feet is interpreted as middle shelf (50-300 feet). This interpretation is based on the occurrence of the larger foraminifers Nummulites moodybranchensis, Nummulites tuberculatus and Operculina moodybranchensis, and the smaller foraminifers Bulimina jacksonensis, Cibicides yazooensis, and Siphonina danvillensis. Dinoflagellate and calcareous nannofossil species are common in a sidewall core at 1,583 feet.

It is difficult to interpret precisely the depositional environment of the Middle Eocene interval from 2,100 to 3,150 feet. The foraminiferal assemblages contain very few benthonic species. The chalks and marls are similar to those of the Late Eocene, and the depositional environment was probably middle shelf (50-300 feet), although the absence of larger foraminifers in this interval may indicate water depths slightly deeper than that of the Late Eocene section. In the core samples, a decrease in the diversity of nannofossil species is noted relative to the Late Eocene interval whereas dinoflagellates are rare to abundant.

The Early Eocene from 3,150 to 3,480 feet is interpreted as lower slope (1,500-6,000 feet) environment. Few benthonic foraminifers were recovered within this interval. The deep water indicators include the foraminifer Bathysiphon eocenica and several radiolarian species. The interval is characterized by rich dinoflagellate assemblages and very few spores and pollen.

The paleoenvironment of the early Late Paleocene interval from 3,480 to 3,570 feet is regarded as outer shelf (300-600 feet). Benthonic foraminfers such as Cibicides compressa, Dorothis bulleta, Eponides bollii, Marssonella identata, and Sprioplectammina trinitatensis are present. The sidewall core from 3,510 feet contained no spores or pollen, but rather a sparse dinoflagellate assemblage and several nonnofossil species.

The environment of deposition of the Maastrichtian and Senonian (Coniacian-Campanian) interval 3,570 to 5,320 feet, is interpreted as outer shelf (300-600 feet). Rich and diverse assemblages of benthonic and planktonic foraminifers, dinoflagellates, and calcareous nannofossils occur throughout the interval.

The Turonian interval from 5,320 to 5,830? feet contains diverse planktonic foraminiferal assemblages. The benthonic forms are relatively rare. From the identified foraminifers, an outer shelf environment (300-600 feet) is suggested. A diverse nannofossil assemblage persists throughout the interval.

The depositional environment of the Cenomanian interval from 5,830? to 5,950 feet is interpreted as inner to middle shelf (0-300 feet).

Some marginal marine, but predominantly inner shelf environment (0-50 feet) is inferred in the Albian section from 5,950 to 7,500 feet. Poor arenaceous foraminiferal assemblages persist down to a depth of 6,190 feet. A few non-diagnostic ostracodes occurred in some of the samples. Somewhat diverse assemblages of spores and pollen are present throughout the interval. Dinoflagellates, less common, are present in most sidewall cores. Nannofossils, including species of Braarudosphaera and Nannoconus, occur in a few samples down to a depth of 6,530 feet.

The Aptian interval 7,500 to 8,900 feet is interpreted as a terrestrial to marginal marine environment. A few crinoid stems, ostracodes, pelecypods, gastropods and a specimen of the foraminifer genus Hormosina were observed between 8,780 and 8,840 feet. Sparse dinoflagellate assemblages occur in a few samples between 7,500 to 8,720 feet. A good assemblage of dinoflagellate species noted in sidewall cores between 8,720 and 8,900 feet suggests a shallow marine transgression within a basically non-marine redbed section.

Lithologic Analysis

The paucity of deep exploratory wells in the Southeast Georgia Embayment area permits only general conclusions concerning the depositional environments as interpreted from lithology; it should be noted, therefore, that comparisons with inferences drawn from the paleontologic data cannot be expected to show precise agreement. However, examination of the cuttings has served to supplement information obtained from the micropaleontologic analysis (the results of these analyses are compared in fig. 6). The sections listed have been described earlier in this report.

Section IA — Shallow marine shelf.

390 - 570 feet — The combination of abundant oolites, sands, and faunal remains indicates that much of the sediment penetrated in this section has probably been distributed by strong currents on a shallow shelf, and that numerous subenvironments are represented. represented.

Section IB-IC — Deep marine.

570 - 1,020 feet — The sedimentary clasts, faunal remains and other relatively large constituents appear to be shallow water fragments that have been transported to deeper water where foram oozes and micrites were being deposited.

WELL DEPTH (Feet)	MICROPALEONTOLOGIC ANALYSIS: U.S.G.S. Ecologic Zones	MICROPALEONTOLOGIC ANALYSIS: Environment of Deposition (Depth range, feet)	LITHOLOGIC ANALYSIS: Environment of Deposition
390–570	III	Outer Shelf (300–600)	Shallow Water
570–750	IV	Upper Slope (600–1500)	Deep Marine (570–1020)
750–1230	III–IV	Outer Shelf to Upper Slope (300–1500)	Deep Marine (570–1020); Deep Marine (1020–3660)
1230–2100	II	Middle Shelf (50–300)	Deep Marine (1020–3660)
2100–3150	II	Middle Shelf (50–300)	Deep Marine (1020–3660)
3150–3480	V	Lower Slope (1500–6000)	Deep Marine (1020–3660)
3480–3570	III	Outer Shelf (300–600)	Deep Marine (1020–3660)
3570–5320	III	Outer Shelf (300–600)	Deep Marine (1020–3660); Deep Marine (3660–5730)
5320–5830	III	Outer Shelf (300–600)	Deep Marine (3660–5730); Shallow Marine (5730–5830)
5830–5950	I–II	Inner to Middle Shelf (0–300)	Shallow Marine (5830–6520)
5950–7500	I	Marginal Marine to Inner Shelf (0–50)	Shallow Marine (5830–6520); Shallow Marine (6520–7090); Continental to near shore with marine intercalations (7090–10770)
7500–8900		Terrestrial to Marginal Marine	Continental to near shore with marine intercalations (7090–10770)
8900–TD 13254		Terrestrial(?)	Continental to near shore with marine intercalations (7090–10770); Continental (10770–11050); Basement (11050–TD 13254)

Figure 6. Comparison of interpretations of environments of deposition based on micropaleontologic and lithologic analyses

Section IIA-IIC — Deep marine.

1,020 - 3,660 feet — From the abundance of chert and carbonates, and the relative absence of terrigenous constituents, this section is interpreteted to have been deposited in relatively deep water, and fairly far from shore or somehow shielded from receiving any influx of abundant sands and silts.

Section III — Deep marine.

3,660 - 5,730 feet — This section is believed to have been deposited in relatively deep water, but close enough to shore to receive abundant amounts of fine terrestrial clastics.

Sections IVA-IVB — Shallow shelf.

5,730 - 6,520 feet — The relative amount of terrestrial material present throughout this section appears to have been dependent upon proximity to a source of clastics. Carbonate deposition predominated whenever a significant source of clastics was not in the immediate area or the existing current pattern prevented clastics from being deposited.

Section VA-VB 6,520 - 7,090 feet	Shallow shelf. This section was probably deposited on a shallow carbonate bank with a distant source of terrestrial material. The anhydrites probably formed in areas of restricted circulation.
Section VIAa-VIB 7,090 - 10,770 feet	Continental to near-shore with marine intercalations. Much of the section appears to be fluvial or tidal flat in origin. However, brief marine intercalations indicated by carbonate beds and gray sands are present throughout the column.
Section VII 10,770 - 11,050 feet	Continental
Section VIII 11,050 feet - total depth	Basement

SEISMIC VELOCITY AND CORRELATION

by P. Laun and M. Harmount

Continuous reflectors and the time-depth curves from seismic line FC-IV (shot in September 1975, for the USGS by Compagnie Generale de Geophysique) have been compared to the Geophysical Log of the COST No. GE-1 well prepared by Seismic Reference Service, Inc.

Line FC-IV lies about 3 nautical miles east-southeast of the COST No. GE-1 well. The data are 24 fold (2400%) common-depth-point (CDP) seismic reflection lines. Figure 7 shows a portion of line FC-IV centered at shotpoint 1340 nearest the COST well. This line was examined for continuous reflections along the line, and the reflections are labeled with numbers 1 through 5.

The geophysical log by Seismic Reference Service, Inc., contains the spontaneous potential log, the interval velocity log (which includes an adjusted sonic log with the uphole survey times used to adjust the sonic log), the uphole velocity survey data (including time-depth) and time-interval velocity) and the time-reflection coefficient log.

Figure 8 shows the uphole velocity survey compared to the stacking velocities near shotpoint 1340 of seismic line FC-IV. As can be seen, the two curves begin to diverge about 1,400 seconds and are about 600 feet different at 13,000 feet.

The seismic data for figure 7 consist of only one velocity scan, since the scans are too widely separated to be averaged to give a better result. Five reflections on the FC-IV data were used to correlate with the re-

LINE FC-IV
SHOT SEPT. 1975
by COMPAGNIE GENERALE DE GEOPHYSIQUE

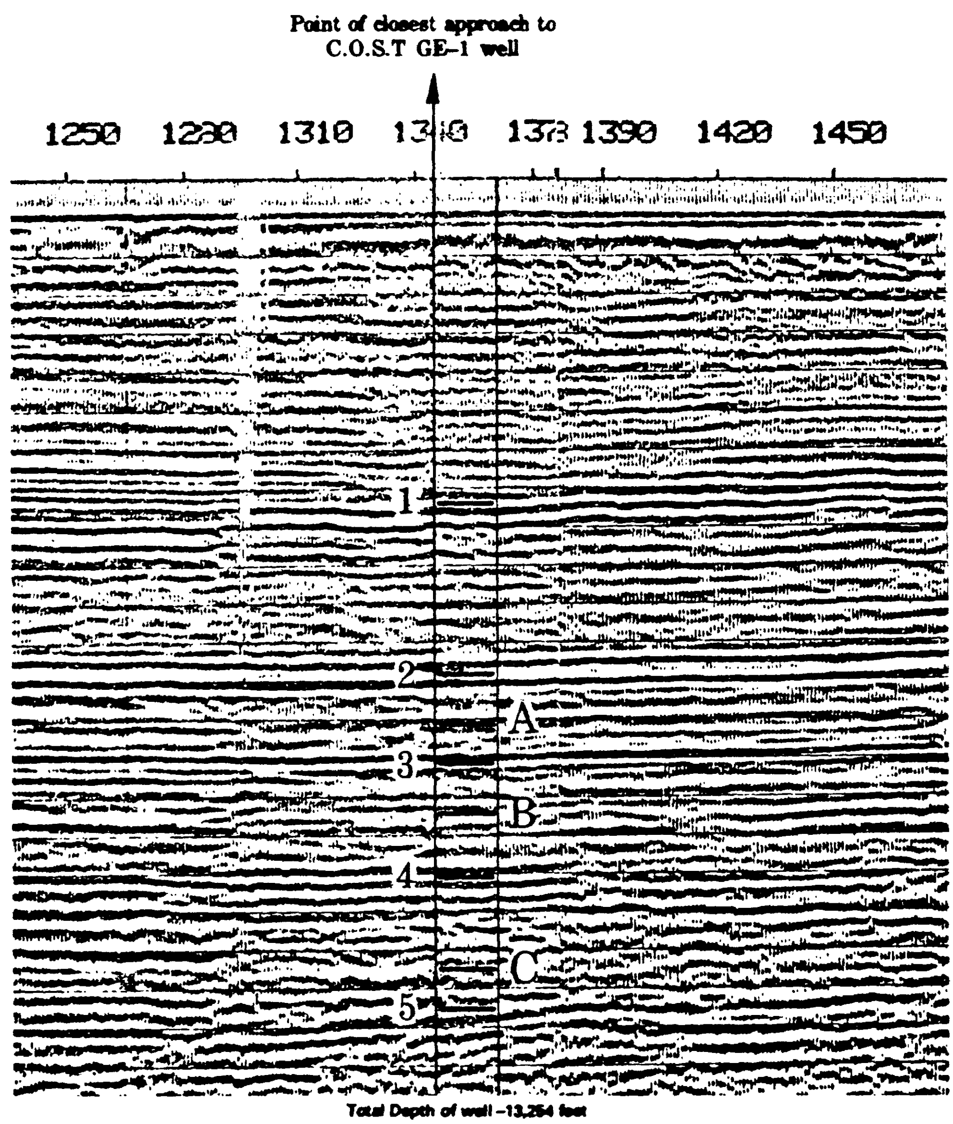

Figure 7. Seismic reflectors recognized within the COST No. GE-1 well

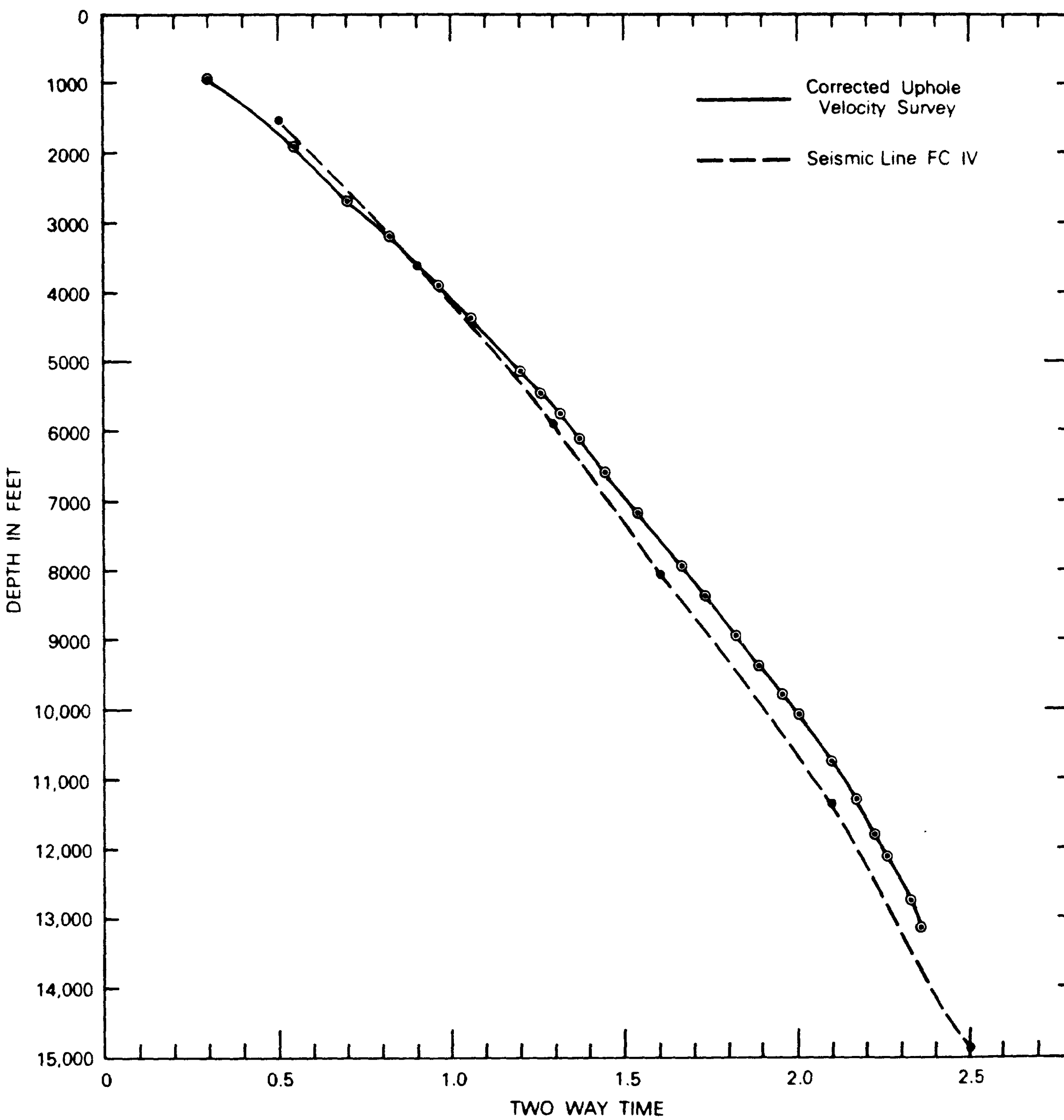

Figure 8. Time-depth curve for the COST No. GE-1 well derived from the uphole-velocity survey and seismic line no. FC-IV

flection coefficient log. These five reflections shown on figure 7 are continuous over the line and were chosen to indicate possible regional bedding rather than local variations near the well site. Table 1 is a summary of these five reflection coefficients, times, depths, and lithologies. Included in this table are three other horizons with high reflection coefficients that existed on the log.

The correlation of these continuous reflectors with good reflectivity coefficients is quite good, indicating that these beds may be present over a large areal extent. In addition, Horizons A, B, and C, are associated with sharp porosity increases and therefore these beds may be of special interest for oil and gas exploration in the area.

Table 1: Selected Seismic Reflection Times and Depths Compared to Reflectivity Log and Lithologic Logs

REFLECTION TIME FROM SEISMIC	REFLECTION FROM REFLECTIVITY LOG	DEPTH FROM CORRECTED UPHOLE VELOCITY SURVEY	REFLECTION COEFFICIENT VALUE	GEOLOGIC DESCRIPTION
0.800	0.830	3,100	.12	white-gray limestone or marl with slight porosity increase.
1.270	1.220	5,500	.22	sand-shale boundary @ 5,750'
1.420	1.390	6,400	.26	limestone-sandy lime-shale with porosity changes @ 6,350-6,410
1.520	1.460	7,100	.30	limestone-sand boundary
1.650	1.590	7,900	.28	series of sand and shales with sharp porosity change @ 7,600'
1.820	1.780	8,900	.30	sand-dolomite beds with shale stringers @ 8,800'
	2.028	10,250	.38	sand layer overlain by anhydrite and shale with a porosity increase in sand.
2.150	2.135	11,200	.20	chert bed changing to shale with chert

RADIOMETRIC AGE DETERMINATIONS

by E. K. Simonis

Radiometric dating of selected samples between 11,250 and 13,254 feet appears to indicate a Late Devonian (approximately 355 million years (m.y.)) age for the sampled section. It is possible, however, that the radiometric ages may reflect a Late Devonian thermal event, and that at least some of the rocks may be older.

The dominant lithology below an unconformity at 11,050 feet to the depth of 12,750 feet consists of green and green-gray, very fine, highly indurated or weakly metomorphosed, pelitic, possibly bentonitic, sediments. Meta-igneous rocks containing albite, epidote, chlorite, and numerous quartz veins increase in abundance below 12,750 feet. A brief examination of a thin-section from Core no. 15 (13,252-13,254 feet) reveals a relic igneous texture consisting of fine-grained felty plagioclase and epidote with phenocrysts and/or xenocrysts of altered feldspar and less-abundant olivine and/or pyroxene. It is not clear if the igneous rocks represent flows or shallow intrusives. Presence of epidote, albite, and chlorite and the absence of minerals associated with higher grades of metamorphism indicate a relatively low grade of metamorphism.

Whole rock K-Ar ages of three samples were determined by Geochron Laboratories (written communication, 1977) with the following results:

11,250' meta-bentonite (?)	374 ± 14 m.y.

13,128'	quarta sericite schist (?)	346 ± 12 m.y.
13,274'	felsic rock	159 ± 6 m.y.

The Mesozoic (159 ± 6 m.y.) K-Ar age of the felsic rock from 13,247 feet is made questionable by Rb-Sr age determinations. Paul D. Fullagar of University of North Carolina (written communication, 1977) obtained Rb-Sr model ages on seven whole rock samples with the following results:

1.	12,900'-13,025'-A	353 ± 4 m.y.
2.	12,900'-13,025'-B	360 ± 4 m.y.
3.	13,128'-A	383 ± 4 m.y.
4.	13,128'-B	350 ± 10 m.y.
5.	13,207'	353 ± 10 m.y.
6.	13,247'	331 ± 85 m.y.
7.	13,252'-13,254'	372 ± 30 m.y.

The isochron age of all seven samples is 363 ± 7 m.y. However, Fullagar points out that, with the exception of the data point for sample 13,128'-A, the remaining six points are highly collinear on the isochron plot and give an age of 355 ± 3 m.y. He considers this to be the most reliable age for the sampled section.

ELECTRIC LOG INTERPRETATIONS

by L. C. Tamm

Introduction

A complete suite of electric logs was run on the COST No. GE-1 well by Schlumberger Ltd. for reservoir rock determinations, lithologic determinations, dip calculations and temperature. The quality of the logs was good, except in intervals where washouts of the hole caused log quality to deterioriate. Washouts were especially serious in the lower 3,200 feet of the well. Log analyses were done both by the author and by D. W. Pert of the USGS, Metairie, Louisiana.

Rock Characteristics

Table 2 summarizes the petrophysical characteristics of the rocks penetrated by the GE-1 well. These were determined by analysis of the Dual Induction - Spherically Focused log (SFL), the Compensated Formation Density Log, the Compensated Neutron Log, the Borehole Compensated Sonic Log, the Microlaterolog- Microlog, and the Log-Microlog Proximity. Representative points or intervals were selected for cross-plot analyses of the data. The three most commonly used cross plots were generated: sonic time/ bulk density, sonic time/CNL neutron index, and bulk density/CNL neutron index. The point numbers on the cross plots in figures 9, 10, and 11 correspond to the data numbers of table 2.

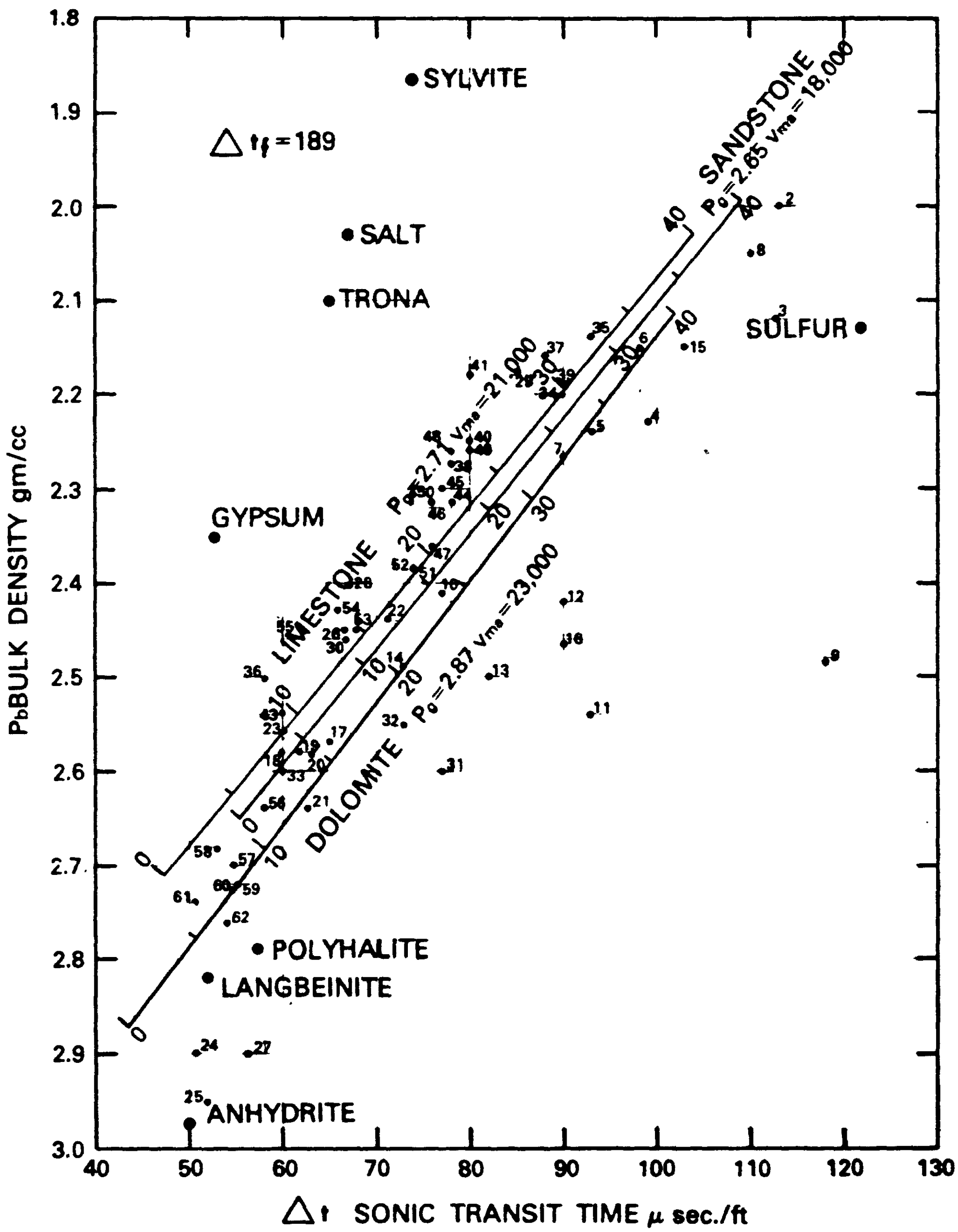

Figure 9. Lithology identification from Formation Density Log and Sonic Log (form Copyright 1972 by Schlumberger, Ltd.)

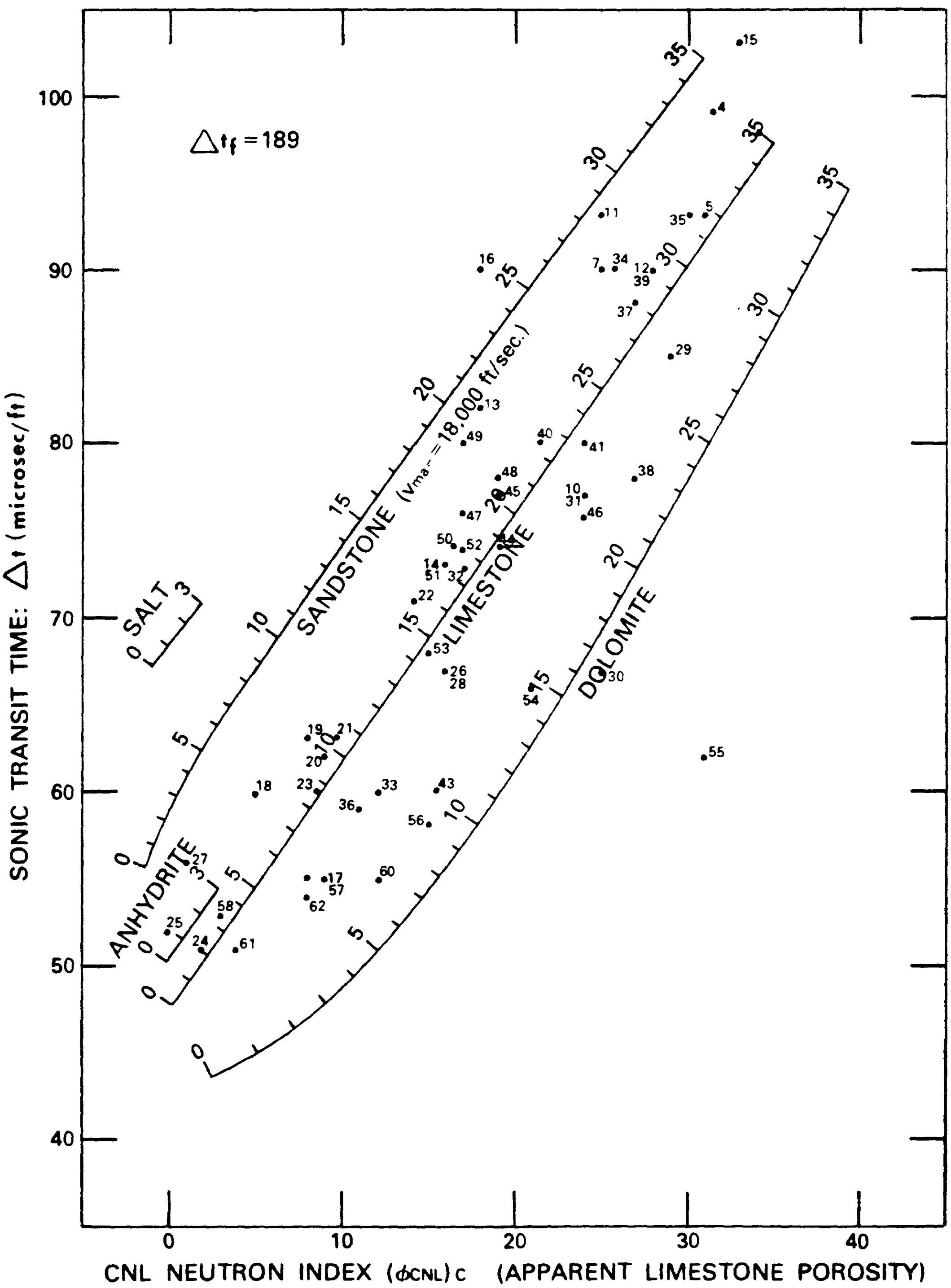

Figure 10. Porosity and lithology determination from Sonic Log and Compensated Neutron Log (CNL)(form Copyright 1972 by Schlumberger, Ltd.)

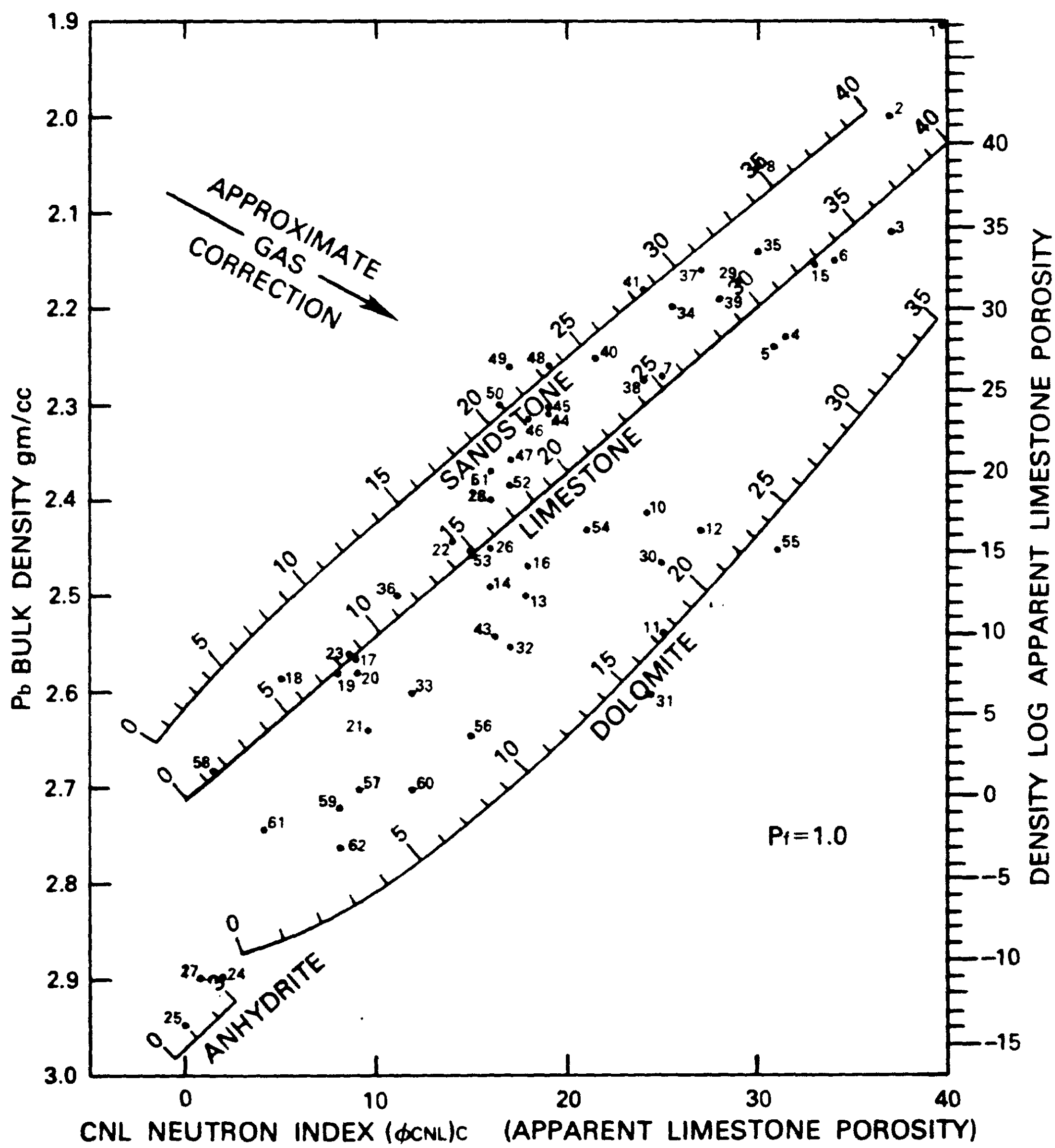

Figure 11. Porosity and lithology determination from Formation Density Log and Compensated Neutron Log (CNL) for fresh-water, liquid-filled holes (form Copyright 1972 by Schlumberger, Ltd.)

Table 2: Lithology and Electric Log Characteristics for the COST No. GE-1 Well

Cross plot No.	Depth interval	Lithology from logs (lithology from cuttings)	Density Bulk	Density Porosity	CNL Porosity Limestone Units	Sonic Travel Time
	1,000-3,016	Chalky limestone.				
1	1,150	(Limestone with chert, oolites and sand)	1.90	47	40	134
2	1,369-1,376	Limestone with chert	2.00	42	37	113
3	1,560-1,585	Limestone with chert	2.12	36	37	113
4	1,906		2.23	29	31.5	99
5	2,140	Cherty limestone	2.24	29	31	93
6	2,810-2,820	Cherty limestone	2.15	33	34	98
	3,016-3,090	Denser limestone				
7	3,024		2.27	26	25	90
	3,090-3,300	Calcareous shale.				
8	3,254	(Calcareous shales with some limestones and cherts)	2.05	37	30	110
	3,300-3,400	Hole washing out. Calcareous clays and shales				
	3,400-3,595	Calcareous clays				
9	3,595-3,610	Possible bentonite bed (high gamma ray count, low spontaneous potential)	2.48	14	47	118
	3,610-3,666	Calcareous sandstone				
10	3,645		2.41	18	24	77
	3,666-4,290	Calcareous shale with a few limestone stringers				
	4,290-4,870	"Chalky" marls and limestones. Becoming less porous with depth				

Tabel 2: Lithology and Electric Log Characteristics for the COST No. GE-1 Well -- Continued

Cross plot No.	Depth interval	Lithology from logs (lithology from cuttings)	Density Bulk	Density Porosity	CNL Porosity Limestone Units	Sonic Travel Time
	4,870-4,980	Calcareous,				
	4,906	dolomitic				
11		sand	2.54	23.5	25	93
	4,980-5742	Argillaceous				
12	5,412	limestones	2.42	17	27	90
13	5,670	and calcareous shales 5,000' to 5,500' may be fairly porous judged from micro-log responses. 5,500' to 5,600' is a less permeable clayey sequence, according to comparison with X-ray diffraction of sidewall cores to micrologs	2.50	12	18	82
	5,742-5,902	Porous calcareous				
14	5,866	sands and calcareous shales stringers of coal noted in cuttings	2.49	15	16	73
	5,902-6,196	Dolomitic lime-				
15	6,030	stone calcareous	2.15	33	33	103
16	6,084	shales and	2.47	15	18	90
17	6,152	sands	2.57	8	9	65
	6,196-6,350	Limestone and				
18	6,230	calcareous	2.58	8	5	60
19	6,270	shales. Lime-	2.58	8	8	63
20	6,334	stone locally oolitic	2.58	7.5	9	62
	6,350-6,510	Alternating fine grained, calcareous sands and calcareous mudstone				

Table 2: Lithology and Electric Log Characteristics for the COST No. GE-1 Well -- Continued

Cross plot No.	Depth interval	Lithology from logs (lithology from cuttings)	Density Bulk	Density Porosity	CNL Porosity Limestone Units	Sonic Travel Time
	6,510-6,543	Sandy limestone				
21	6,513	Dolomitic sandy limestone	2.64	4	9.5	63
22	6,520	Sandy limestone	2.44	17	14	71
23	6,526	Limestone	2.56	8	8.5	60
	6,543-7,200	Interbedded shale, anhydrite and sandy to silty, oolitic, dolomitic limestone				
24	6,603		2.90	-11	2	51
25	6,694		2.95	-15	0	52
26	6,724	Limestone	2.45	15	16	67
27	6,880	Anhydrite	2.90	-15	1	56
28	6,950	Limestone (dolomitic)	2.40	15	16	67
29	7,116	Sandstone (dolomitic)	2.17	31	29	85
	7,200-7,400	Argillaceous red sands, calcareous shales, and a few dolomitic limestone beds				
30	7,250		2.46	17	25	67
31	7,300		2.60	7	24	77
32	7,322		2.55	10	17	73
33	7,363		2.60	7	12	60
	7,400-7,960	Sand and shale sequence. Sands are up to 35 feet thick. Most are 5 to 8 feet thick.				
34	7,404		2.20	31.5	25.5	90
35	7,460		2.14	34.5	30	93
36	7,510		2.50	11	11	58
37	7,566		2.16	33	27	88
38	7,686		2.27	27	24	78
39	7,790		2.19	31	28	90

Table 2: Lithology and Electric Log Characteristics for the COST No. GE-1 Well -- Continued

Cross plot No.	Depth interval	Lithology from logs (lithology from cuttings)	Density Bulk	Density Porosity	CNL Porosity Limestone Units	Sonic Travel Time
	7,960-8,321	Shale sequence, a few thin sand layers; severe washouts common in this interval				
	8,322-10,000	Sand-shale sequence. Porosity generally decreasing from about 28% at the top to about 20% at base. At 8,680 to 8,780 ft. very dolomitic and limy sandstone. At 9,790 to 9,830 ft. dolomitic layer.				
40	8,340		2.25	27.5	21.5	80
41	8,484		2.18	31	24	80
42	8,564		2.25	27.5	21	80
43	8,690		2.54	9	15.5	60
44	8,870		2.31	24	19	74
45	9,020		2.30	23.5	19	77
46	9,140		2.31	24	18	76
47	9,340		2.36	22	17	76
48	9,700		2.26	26.5	19	78
49	9,850		2.26	26	17	80
	10,000-10,315	Washed-out shales				
	10,315-11,051	Sand and shale sequence, sands have 12 to 15% hematite by X-ray analysis. Very high gamma ray intensities at 10,133 - 10,140 ft. and 10,784-10,790 ft.				
50	10,430		2.30	23	16.5	74
51	10,580		2.37	19	16	73
52	10,731		2.38	20.5	17	74
53	10,896		2.45	15	12.5	68
54	11,000		2.43	17	21	66

Table 2: Lithology and Electric Log Characteristics for the COST No. GE-1 Well -- Continued

Cross plot No.	Depth interval	Lithology from logs (lithology from cuttings)	Density Bulk	Density Porosity	CNL Porosity Limestone Units	Sonic Travel Time
	11,051-13,254	Tight, clean				
55	11,110	quartzite	2.45	15	31	62
56	11,400	alternating	2.64	4	15	58
57	11,610	with tight	2.70	0	9	55
58	11,900	shales (or	2.68	1.5	3	53
59	12,200	slates). A	2.72	- 3	8	55
60	12,600	few dolomite	2.70	0	12	55
61	12,878	beds with low	2.74	- 2.5	4	51
62	13,100	porosity. Probably metamorphosed sediments.	2.76	- 4.5	8	54

Dipmeter Analysis

A Four-Arm, High-Resolution, Continuous Dipmeter survey was run between 948 and 13,252 feet. Dip readings were recorded on a dipmeter arrow plot.

Gentle easterly and southerly dips are evident in the Tertiary and Mesozoic section down to 11,050 feet, and steeper (up to 30°) westerly dips in the underlying Paleozoic section.

To a depth of 3,100 feet, dipmeter readings are randomly oriented and, therefore, unreliable for dip determination. This Oligocene and Eocene section consists chiefly of marl and limestone which is in part chalky and has oolitic and fossiliferous zones. Between 3,100 and 3,450 feet, calcareous claystone of Early Eocene age dips 1° - 2° eastward.

A change from scattered dip readings above 3,570 feet to relatively consistent easterly dip readings below that depth coincides with the unconformity at the top of the Cretaceous section. From 3,660 to about 7,450 feet the dips are gentle (1° to 3°); directions of dip are uncertain, but below 6,100 feet a tendency for southerly dip direction is vaguely apparent.

Non-marine clastics dominate the section between 7,450 and 11,050 feet. Random dipmeter readings throughout this section hinder determination of the bedding dip. A sharp change to consistent dip readings below 11,050 feet marks the top of the Paleozoic rocks.

From 11,050 to 11,600 feet, a folded and possibly faulted section is indicated by a gradual change of the dip direction from southwestward to northwestward and by the change in the angle of dip from 3° to 15° and more. Highly scattered dipmeter readings were obtained between 11,600 and 11,900 feet. From 11,900 to 12,760 feet westerly dip readings ranged from approximately 10° to 25°. Random orientation of dip readings from 12,760 feet to the bottom of the logged section at 13,252 feet is probably caused by poor bedding characteristics or non-bedded meta-igneous rocks.

Temperature Gradient

The temperature gradient of the COST No. GE-1 well was determined from three temperature log runs. The gradient between 1,000 feet and 13,250 feet is .85°F/100 feet. The mean temperature gradient using the data tabulated below is .88°F/100 feet.

A least squares line of the temperature versus depth data indicates a temperature gradient of .84°F/100 feet depth. The coefficient of determination for this line is .999, which indicates a very good fit.

The raw data shown below were plotted on a graph (fig. 12). Two zones, 5,000-5,500 feet and 12,500-13,000 feet, showed a very low temperature gradient because of an apparent washout; these data were not used in the gradient calculations.

Measured depth (ft)		Measured temperature (°F)		Temperature
Top	Bottom	Top	Bottom	gradient (°F/100 ft)
1,000	1,500	120	125	1.0
1,500	2,000	125	129.4	.88
2,000	2,500	129.4	133.6	.84
2,500	3,000	133.6	138.4	.96
3,000	3,500	138.4	143.2	.96
3,500	4,000	143.2	147.6	.88
4,000	4,500	147.6	152.7	1.02
4,500	5,000	152.7	158.5	1.16
5,000	5,500	158.5	161	.50
5,550	6,000	161.0	166.0	1.00
6,000	6,500	166.0	169.7	.74
6,500	7,000	169.7	174.7	.86
7,000	7,500	174.7	178.0	.80
7,500	8,000	178.0	181.7	.74
8,000	8,500	181.7	185.4	.74
8,500	9,000	185.4	190.0	.92
9,000	9,500	190.0	194.1	.82
9,500	10,000	194.1	197.9	.76
10,000	10,500	197.9	201.8	.78
10,500	11,000	201.8	206.0	.84
11,000	11,500	206.0	209.6	.72
11,500	12,000	209.6	213.7	.82
12,000	12,500	213.7	218.4	.94
12,500	13,000	218.4	221.0	.52
13,000	13,250	221.0	223.7	1.08

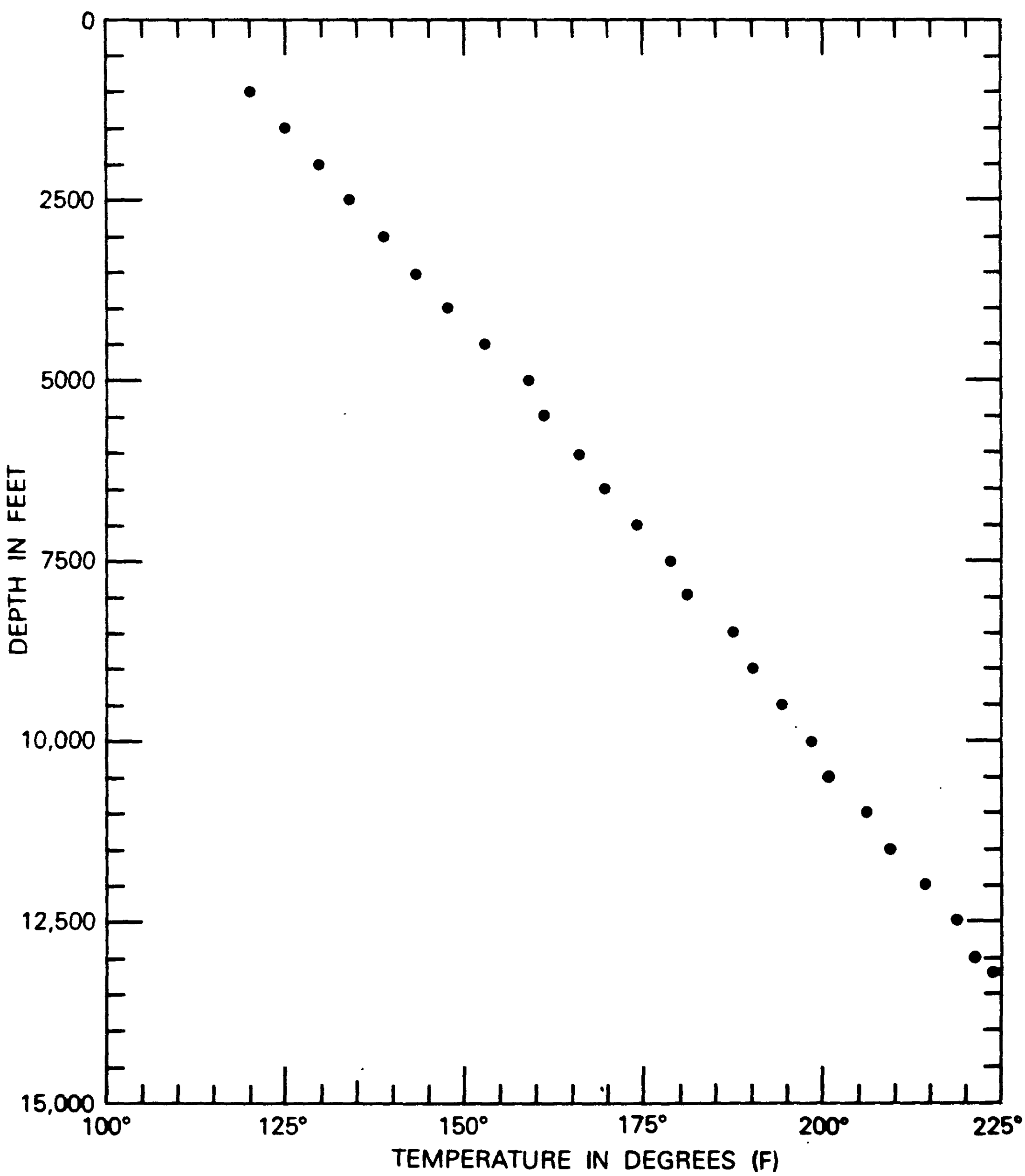

Figure 12. Temperature gradient, COST No. GE-1 well

FLUID ANALYSIS AND PRESSURE DATA

by M. A. Furbush

Five successful conventional Drill Stem Tests (DST) were conducted in the COST No. GE-1 well by Halliburton Services Company and the recovered water samples were analyzed by Amoco Production Company. The deepest test interval was 10,428 - 10,461 feet and the shallowest was 5,788 - 5,910 feet. Final closed-in pressures from these tests plotted against depth (fig. 13) show a pressure gradient of 0.50 psi/ft. This is somewhat higher than the 0.435 psi/ft. in the COST No. B-2 (Baltimore Canyon) well and the average gradient of 0.465 psi/ft. determined from wells in the Gulf of Mexico.

Only formation water recovered from DST No. 3 (rerun and reported as No. 4) contained indicators of the possible presence of petroleum in the area. The interval tested was 7,458 to 7,608 feet, in Upper Cretaceous sandstones. Organic constituents of these water samples in (mg/l) are as follows:

	Bottom	Middle	Top	Mud
Benzene	0.1	0.1	0.1	0
Toluene	0.1	0.2	0.1	0
HC Gases	weak	weak	absent	absent
Phenols	1.3			
Organic Acids	0			

No visible oil or fluorescence

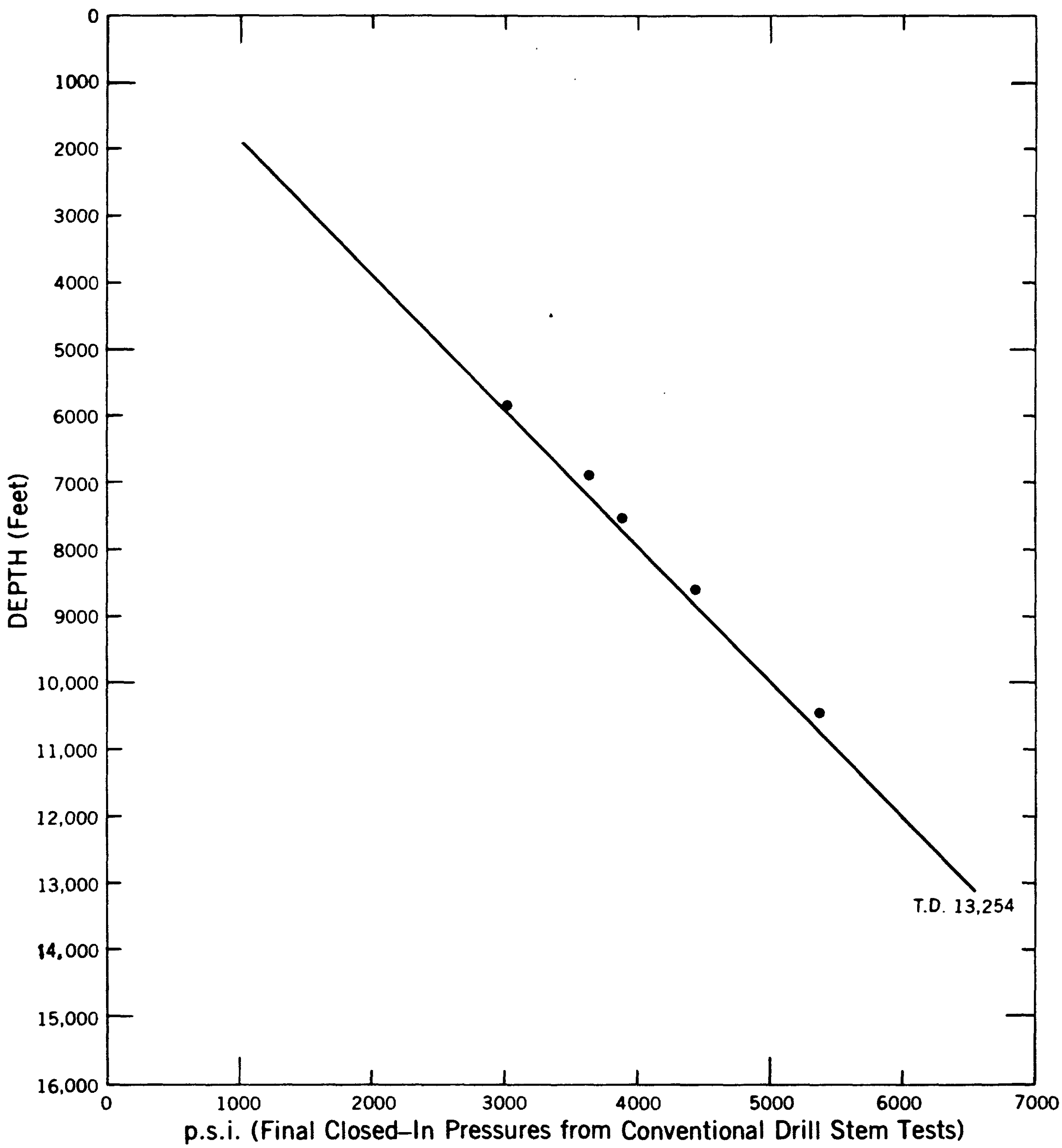

Figure 13. Pressure gradient in COST No. GE-1 well determination from conventional drill-stem test data

A summary of the drill stem tests is as follows:

DST No. 1: 10,428 - 10,461 feet (in fine-grained, sandstone of Early Cretaceous or Late Jurassic age with 18 percent porosity). Initial hydrostatic pressure 5,412 psi. First period: Tool open 8 minutes; initial open-flow pressure 3,278 psi, final pressure 3,568 psi in 37 minutes. Second period: Tool open 30 minutes, initial open-flow pressure 3,528 psi, final open-flow pressure 4,469 psi; closed in pressure 4,709 psi after 10 minutes; final hydrostatic pressure 5,292 psi. Tool opened with strong blow. Recovered: 900 feet of dry pipe, 8,000 feet of water cushion, 400 feet of rat-hole mud, 1,050 feet of salt water, 72 feet of salt water in the sample chamber. Chlorides in mg/l: bottom and middle samples 113,000; top sample 93,800. Formation waters recovered on DST No. 1 contained traces of hydrocarbon gases but no visible oil or fluorescence.

DST No. 2: 8,598 - 8,735 feet (Interval includes two lithologically similar Cretaceous sandstones: red, fine-to medium -grained, argillaceous, slightly calcareous sandstone with some interbedded light-gray dolomite at the base). Net effective sand thickness is 22 feet in the upper sandstone and 9 feet in the lower with an average porosity of 26 percent. The initial hydrostatic pressure recorded was 4,425 psi. Tool open 14 minutes. Initial open-flow pressure 3,784 psi; final open-flow pressure 3,847 psi; closed-in pressure 3,941 psi in 10 minutes; final hydrostatic pressure was 4,425 psi. Tool opened with strong blow. Recovered rat-hole mud, 835 feet of saltwater with chloride concentrations in the bottom and middle samples of 82,300 mg/l and top sample 75,500 mg/l.

DST No. 3 failed. Re-run is DST No. 4, 7,458 to 7,608 feet (In interbedded sandstones and shales with a total net sand thickness of 65 feet with an average porosity of 27 percent. The sandstones are clear to tan, coarse-grained and loosely cemented and are of Late Cretaceous age. Initial hydrostatic pressure 3,875 psi. Initial flow pressure 3,392 psi, final flow pressure 3,405 psi after 15 minutes; final hydrostatic pressure 3,875 psi. Tool opened with strong blow. Recovered 420 feet of dry pipe, 4,000 feet of fresh water cushion, 2,000 feet of salt-water-cut rat hole mud, 1,000 feet of salt water with approximately 5% mud. Chlorides: bottom sample 76,200 mg/l; middle sample 76,000 mg/l; top sample 75,500 mg/l.

DST No. 5 6,874 to 7,007 feet (In tan, finely-crystalline to dense dolomite and white, chalky limestone of Early Cretaceous age). Initial hydrostatic pressure 3,576 psi. First period: initial open flow 2,576 psi, final flow pressure 2,200 psi; final closed-in pressure 2,996 psi after 15 minutes; final hydrostatic pressure 3,576 psi. Tool opened with sharp blow. Recovered 2,000 feet of dry pipe, 3,400 feet of fresh-water cushion, 1,300 feet of rat-hole mud and 12 feet of rat-hole mud in sample chamber. Chlorides: bottom and middle samples 3,500 mg/l and top sample 3,300 mg/l. The similarity of the chloride concentrations in the drilling fluid and the recovered samples indicates that the samples were all drilling fluid and no formation water

DST No. 6 5,788 - 5,910 feet (In white, fine-to medium-grained, poorly sorted, calcite-cemented Upper Cretaceous sandstone with an average porosity of 31 percent. Initial hydrostatic pressure 3,034 psi. First period: initial closed-in pressure 2,591 psi in 15 minutes. Final hydrostatic pressure 3,034 psi. Tool opened with strong blow. Recovered 580 feet of dry pipe, 2,050 feet of fresh water cushion, 1,000 feet of salt water. Chlorides: bottom sample 54,300 mg/l, middle sample 53,300 mg/l, top sample sample 51,600 mg/l.

CORE ANALYSIS

by E. K. Simonis

Ten conventional cores and 68 sidewell cores recovered from the COST No. GE-1 well were analyzed by Core Laboratories, Inc. (1977). Results are summarized in tables 3 and 4, and in figures 14 ,15, and 16. For the conventional cores, the analyses of 1-inch diameter plugs taken at approximately 1-foot intervals yielded a wide range of porosity and permeability values (table 3, figures 14 and 15). Judged from of the core analyses, rocks with the best reservoir characteristics appear to be between 5,700 and 10,000 feet (see fig. 14 and 15) ; however, intervals in which core analyses are not available may contain additional favorable reservoir rocks.

Above 5,700 feet, no sandstones were recovered in either the conventional or sidewall cores. Many of the limestones in this section are highly porous chalks, but their permeabilities are very low; they plot outside the general trend on the porosity-versus-permeability graph (fig. 16). The chalks may prove to be potential reservoir rocks. For example, chalks with low permeability values are highly productive in the North Sea. Between 5,700 and 10,000 feet, sandstone is the lithology with the best reservoir characteristics. Porosities from 25 to 30 percent are common and permeabilities range up to 4,000 millidarcies.

Most of the permeable sandstones are very fine- to medium-grained, moderately to poorly sorted, and are incompletely cemented by quartz overgrowths and hematite. Porosities and permeabilities of carbonates

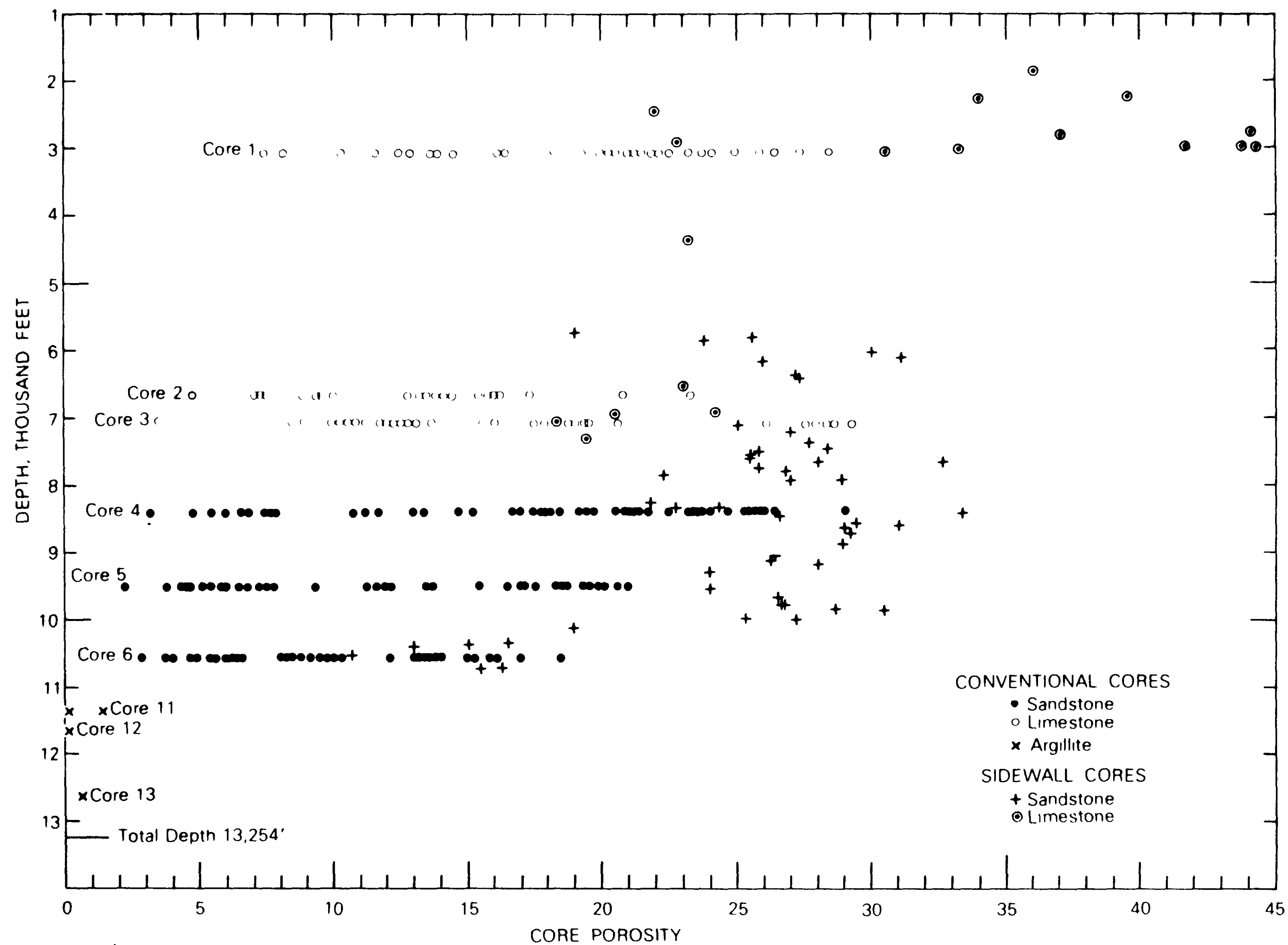

Figure 14. Porosities of sidewall cores and conventional cores, COST No. GE-1 well

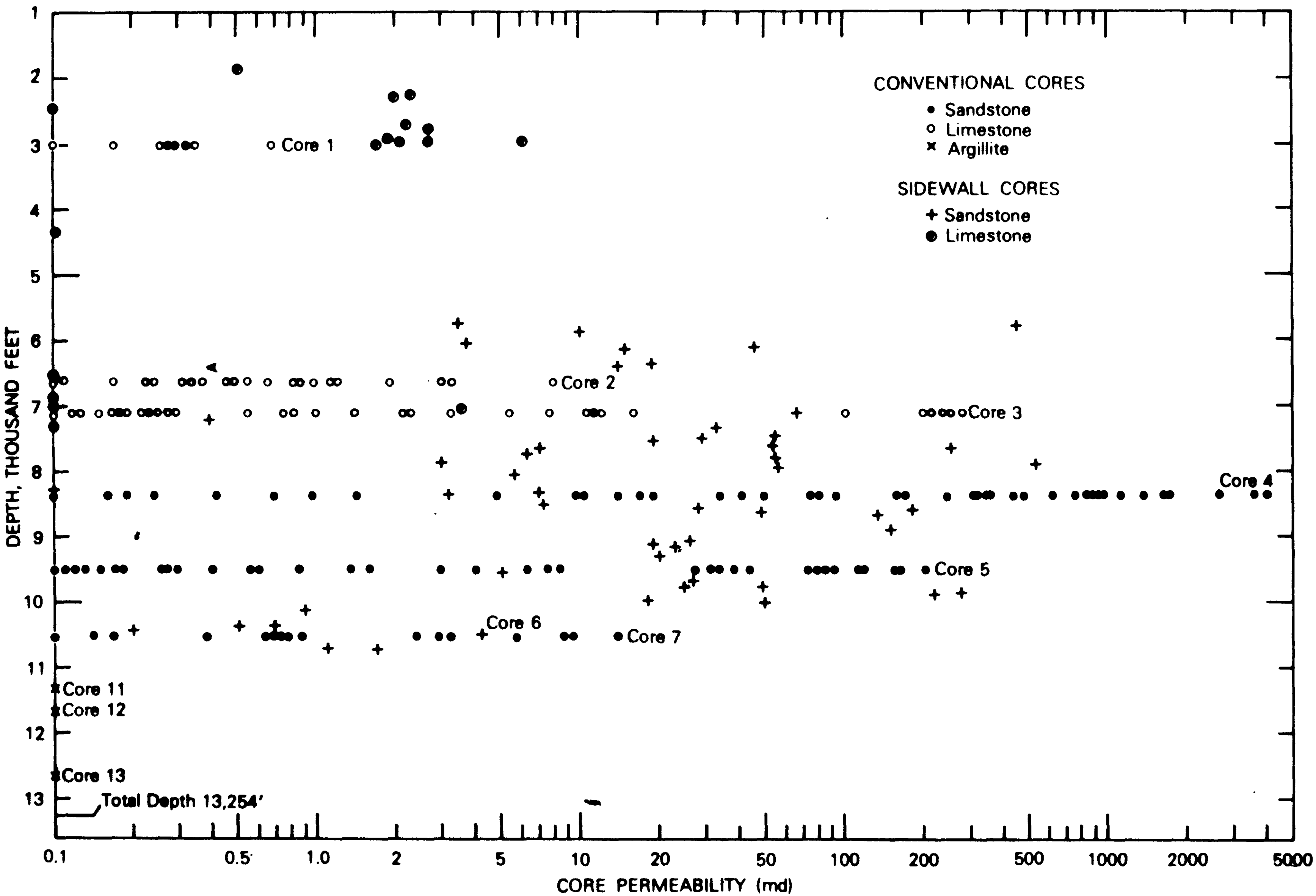

Figure 15. Permeabilities of conventional cores and sidewall cores, COST No. GE-1 well

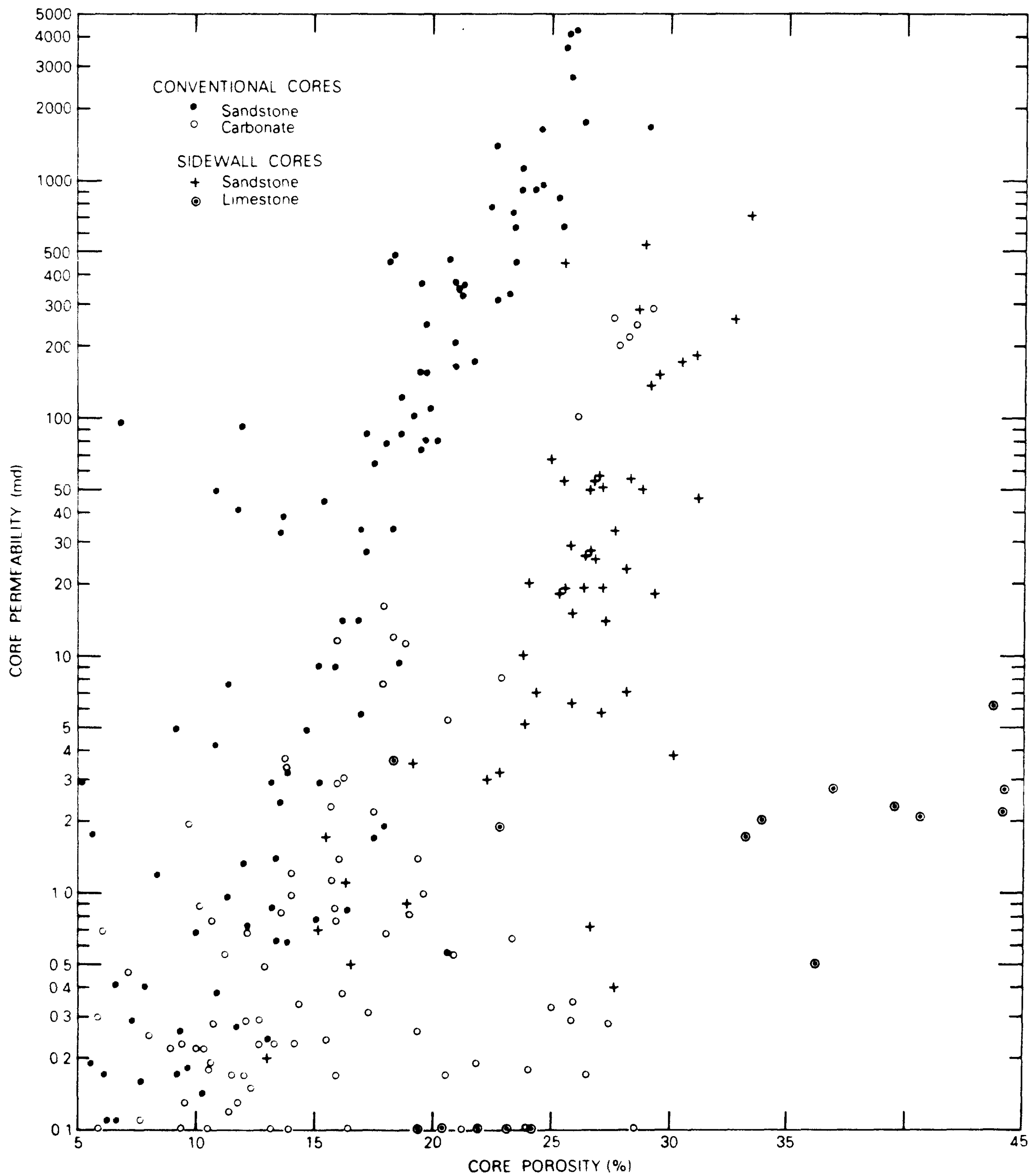

Figure 16. Core porosities plotted against core permeabilities, COST No. GE-1 well

are generally lower, but a sandy dolomite recovered in conventional core No. 3, between 7,093 and 7,099 feet, reaches a porosity of 29 per cent and a permeability of 280 millidarcies.

The core analyses indicate a sharp reduction of porosity and permeability below 10,000 feet. Between 10,000 and 11,050 feet the porosity of analyzed sandstones drops below 20 percent and most of the permeability values are less than 10 millidarcies. Intensified cementation by quartz overgrowths, and compaction by pressure solution appear to be important factors in the reduction of porosity and permeability.

Below 11,050 feet to the total depth of the well at 13,254 feet the section consists of essentially impervious metamorphosed or highly indurated sedimentary and igneous rocks of Paleozoic age.

Table 3: Record of conventional cores, their dominant lithology and range of porosity and permeability

CORE NUMBER	CORED INTERVAL (ft) Top	Bottom	Feet Cut	CORE RECOVERY (feet)	POROSITY % High	Low	Mean	PERMEABILITY (md) High	Low	Mean	DOMINANT LITHOLOGY
1	3,024	3,054	30	30	30.5	7.5	19.8	0.68	0.01	0.1	Limestone
2	6,607	6,657	50	48.4	23.3	4.8	12.8	8.1	0.05	0.8	Limestone
3	7,040	7,100	60	58.9	29.3	3.5	11.4	284	0.07	22.8	Limestone
4	8,331	8,391	60	59.8	29.1	3.3	18.3	4110	0.01	600	Sandstone
5	9,453	9,513	60	53.1	20.9	2.3	10.5	203	0.01	29	Sandstone
6	10,518	10,520	2	0.33	10.8	10.8	10.8	4.2	4.2	4.2	Sandstone
7	10,520	10,580	60	46.1	18.5	2.8	9.3	14	0.01	1.5	Sandstone
8	10,931	10,933	2	0	--	--	--	--	--	--	
9	10,933	10,935	2	0	--	--	--	--	--	--	
10	11,000	11,002	2	0	--	--	--	--	--	--	
11	11,357	11,387	30	29	1.4	0.1	0.42	0.01	0.01	0.01	Argillite
12	11,635	11,643	8	7.4	0.2	0.2	0.2	0.01	0.01	0.01	Argillite
13	12,624	18,627	3	1	0.6	0.6	0.6	0.01	0.01	0.01	Argillite
14	13,247	13,251	4	0.1	--	--	--	--	--	--	Meta- Basalt(?)
15	13,252	13,254	2	0.66	--	--	--	--	--	--	Meta- Basalt(?)

Table 4: Porosities, permeabilities, grain densities, and dominant lithologies of sidewall cores from COST No. GE-1 well. (Data from Core Laboratories, Inc., 1977. Permeability values marked by asterisk(*) were determined empirically) -- continued

DEPTH (Feet)	POROSITY (percent)	PERMEABILITY (millidarcies)	CALCULATED GRAIN DENSITY (g/cc)	LITHOLOGY
1,867	36.2	0.5	2.56	Chalk
2,244	39.5	2.3	2.72	"
2,288	33.9	2.0	2.55	"
2,433	21.9	* 0.1	2.71	"
2,754	44.1	2.2	2.73	"
2,790	36.9	* 2.7	2.53	"
2,924	22.8	1.9	2.64	"
2,985	43.7	6.1	2.37	"
2,988	41.6	* 2.1	2.61	"
2,998	44.2	2.7	2.52	"
3,010	33.2	1.7	2.56	"
4,360	23.2	0.1	2.57	"
5,755	19.1	* 3.5	2.64	Sandstone
5,804	25.6	447	2.63	"
5,850	23.8	10	2.63	"
6,028	30.1	3.8	2.67	"
6,110	31.2	46	2.6	"
6,162	25.9	15	2.61	"
6,374	27.2	19	2.57	"
6,398	27.3	14	2.60	"
6,546	23.0	* 0.1	2.71	Limestone
6,900	24.2	* 0.1	2.77	"
6,940	20.2	0.1	2.59	"
7,040	18.3	3.6	2.72	"
7,114	25.0	67	2.63	Sandstone
7,210	27.7	* 0.4	2.61	Siltstone
7,306	19.4	* 0.1	2.56	Limestone
7,373	27.7	33	2.66	Sandstone
7,456	28.3	55	2.65	"
7,501	25.8	* 29	2.66	"

Table 4: Porosities, permeabilities, grain densities, and dominant lithologies of sidewall cores from COST No. GE-1 well -- Continued

DEPTH (feet)	POROSITY (percent)	PERMEABILITY (millidarcies)	CALCULATED GRAIN DENSITY (g/cc)	LITHOLOGY
7,546	25.5	* 19	2.63	"
7,608	25.5	54	2.63	"
7,648	28.2	* 7.0	2.65	"
7,660	32.7	255	2.68	"
7,753	25.8	* 6.3	2.64	"
7,791	26.8	54	2.63	"
7,849	22.3	* 3.0	2.63	"
7,910	28.9	*530.0	2.63	Sandstone
7,954	27.0	56	2.66	"
8,032	27.1	* 5.7	2.68	"
8,280	21.8	* 0.1	2.67	"
8,343	24.3	* 7.0	2.60	"
8,388	22.8	* 3.2	2.59	"
8,414	33.4	*700	2.66	"
8,484	26.6	* 7.2	2.62	"
8,566	29.4	28	2.62	"
8,594	31.1	181	2.65	"
8,612	28.8	* 49	2.64	"
8,673	29.2	*135	2.67	"
8,875	29.0	*150	2.64	"
9,053	26.4	* 26	2.63	"
9,117	26.3	19	2.65	"
9,172	28.1	* 23	2.63	"
9,294	24.0	* 20	2.64	"
9,560	23.9	5.1	2.61	"
9,676	26.6	27	2.65	"
9,770	26.7	49	2.67	"
9,782	26.8	* 25	2.65	"
9,850	28.7	280	2.63	"
9,864	30.5	*220	2.66	Sandstone
9,970	25.3	18	2.63	"
9,990	27.2	50	2.64	"
10,114	18.9	0.9	2.60	"
10,357	16.5	0.5	2.61	"
10,363	15.1	0.7	2.61	"

Table 4: Porosities, permeabilities, grain densities, and dominant lithologies of sidewall cores from COST No. GE-1 well -- Continued

DEPTH (feet)	POROSITY (percent)	PERMEABILITY (millidarcies)	CALCULATED GRAIN DENSITY (g/cc)	LITHOLOGY
10,406	13.0	0.2	2.60	"
10,706	16.3	1.1	2.61	"
10,726	15.5	1.7	2.62	"

GEOCHEMICAL ANALYSES

By M. A. Smith

Source Rock Potential

The stratigraphic section penetrated by the COST No. GE-1 well was evaluated for its petroleum generation potential on the basis of detailed geochemical analyses of samples selected from well cuttings collected at 30-foot intervals and analyses of sidewall and conventional core samples. All analyses were made by GeoChem Laboratories, Inc. in 1977. As the primary geochemical contractor, they determined the gross lithology, the organic carbon content, the light and gasoline-range hydrocarbon content and composition, the amount and composition of solvent-extractable organic material, and the type and visual alteration index of kerogen present. An additional thermal maturation study was made on most of these samples by Core Laboratories, Inc., in 1977 measuring vitrinite reflectance, thermal alteration index and describing the kerogen. Duplicate samples of well cuttings and processed material were also sent to two of the participating companies for associated geochemical studies. Table 5 shows the results of the major analyses of cuttings samples.

The total organic carbon content provides one measurement of source rock potential by indicating the basic organic richness of the samples. Shale with less than 0.5 to 0.6 weight percent organic carbon and limestone with less than 0.2 weight percent organic carbon are considered to have poor organic richness and are unlikely to be the source of commercial amounts of petroleum generation. All 90

Table 5: Hydrocarbon concentrations and other geochemical parameters obtained from analysis of COST No. GE-1 well cuttings.

Depth * (feet)	Geochemical Zone	Total Organic Carbon (percent)	$C_1 - C_4$ (ppm)	Gas Wetness (percent)	$C_5 - C_7$ (ppm)	C_{15+} (ppm)	Thermal Alteration Index	Vitrinite Reflectance (Ro percent)
450	A	0.08	54.1	15.2	1.7			
600	A	0.19	45.2	55.6	17.5	470	1.08	0.21
750	A	0.46	65.2	10.0	20.3			
900	A	0.40	79.8	15.2	32.7	541	1.08	0.19
1,050	A	0.21	137.6	4.8	30.8			
1,230	A	0.14	183.6	9.5	40.0	761	1.08	0.21
1,350	A	0.12	120.2	4.9	75.4			
1,500	A	0.18	157.8	3.8	36.8	515	1.08	0.19
1,650	A	0.24	97.7	4.2	55.0			
1,800	A	0.12	117.3	3.9	27.6	432	1.17	0.20
1,950	A	0.14	85.5	32.3	31.3			
2,100	A	0.18	103.2	6.4	48.0	528	1.17	0.22
2,250	A	0.14	85.5	8.3	47.9			
2,400	A	0.14	164.0	8.2	62.8	392	1.25	0.19
2,550	A	0.12	194.8	4.4	199.2			
2,700	A	0.14	138.4	8.1	126.8	414	1.33	0.21
2,850	B	0.14	154.3	29.5	887.2			
3,000	B	0.46	117.7	17.8	640.7	685	1.33	0.19
3,150	B	0.26	177.0	15.6	802.8			
3,300	B	0.28	168.0	30.8	561.0	500	1.42	**

Table 5: Hydrocarbon concentrations and other geochemical parameters obtained from analysis of COST No. GE-1 well cuttings -- Continued.

Depth * (feet)	Geochemical Zone	Total Organic Carbon (percent)	$C_1 - C_4$ (ppm)	Gas Wetness (percent)	$C_5 - C_7$ (ppm)	C_{15+} (ppm)	Thermal Alteration Index	Vitrinite Reflectance (Ro percent)
3,450	B	0.26	128.4	22.7	606.5			
3,600	B	1.53	77.4	15.7	446.7	1,867	1.42	0.24
3,750	B	0.74	114.7	21.6	276.4			
3,900	B	0.79	76.1	29.3	273.7	1,799	1.5	0.31
4,050	B	1.56	123.4	17.1	498.4			
4,200	B	0.70	36.2	21.0	109.9	2,598	1.58	0.28
4,350	B	0.42	103.6	17.2	396.8			
4,500	B	0.38	155.7	6.9	89.7	1,677	1.58	0.31
4,650	B	0.45	117.8	28.8	132.8	946	1.58	0.30
4,740	B	0.33	122.3	41.6	150.0	970	1.67	0.33
4,890	B	2.98	100.2	59.6	167.1			
5,040	B	0.57	121.9	55.4	252.4	970	1.67	0.33
5,190	B	0.74	110.5	42.3	120.7			
5,340	B	1.08	732.7	87.8	676.0	1,837	1.75	0.30
5,490	B	0.72	140.2	56.3	238.6	1,039	1.67	0.31
5,640	B	0.30	151.3	56.8	215.2	1,018	1.75	0.31
5,790	C_1	0.07	103.7	32.2	122.2			
5,910	C_1	0.35	96.2	27.6	99.3	412	1.75	0.36
6,000	C_1	0.56	61.5	27.8	38.8	373	1.75	0.36
6,150	C_1	0.26	69.3	17.2	39.4	293	1.83	0.36

Table 5: Hydrocarbon concentrations and other geochemical parameters obtained from analysis of COST No. GE-1 well cuttings -- Continued.

Depth * (feet)	Geochemical Zone	Total Organic Carbon (percent)	$C_1 - C_4$ (ppm)	Gas Wetness (percent)	$C_5 - C_7$ (ppm)	C_{15+} (ppm)	Thermal Alteration Index	Vitrinite Reflectance (R_o percent)
6,300	C_1	0.41	87.8	32.1	46.4	417	1.92	0.32
6,450	C_1	0.24	166.8	18.4	124.9			
6,570	C_1	0.19	129.7	28.0	59.2	406	1.92	0.31
6,750	C_1	0.26	82.4	24.0	18.8			
6,900	C_1	0.28	115.4	19.9	86.3	338	1.92	0.32
7,020	C_1	0.46	84.7	10.7	44.4			
7,200	C_1	0.45	91.9	11.5	67.6	473	1.92	0.37
7,350	C_1	0.48	62.5	40.1	48.6			
7,470	C_1	0.67	101.6	14.6	53.9	633	1.92	0.42
7,590	C_1	0.36	77.0	13.6	38.2			
7,740	C_1	0.34	76.0	19.7	47.9	376	2	0.40
7,830	C_1	0.29	104.6	14.8	39.9			
7,920	C_1	0.35	203.5	2.7	53.0	348	2	0.44
8,010	C_1	0.83	412.6	14.5	46.7	468	2	0.38
8,130	C_1	0.18	162.0	7.7	40.2			
8,280	C_1	0.23	51.6	14.7	39.8	256	2	0.39
8,430	C_1	0.20	78.3	10.0	123.5			
8,580	C_1	0.11	69.3	9.1	102.9	262	2.08	0.42
8,730	C_1	0.23	156.5	6.1	70.9			
8,820	C_1	0.22	73.2	6.0	77.1	284	2.08	0.60(C)

Table 5: Hydrocarbon concentrations and other geochemical parameters obtained from analysis of COST No. GE-1 well cuttings -- Continued.

Depth * (feet)	Geochemical Zone	Total Organic Carbon (percent)	$C_1 - C_4$ (ppm)	Gas Wetness (percent)	$C_5 - C_7$ (ppm)	C_{15+} (ppm)	Alteration Index	Vitrinite Reflectance (Ro percent)
8,970	C_1	0.19	131.3	9.4	73.0			
9,090	C_1	0.21	51.1	7.3	50.1	347	2.17	0.60(C)
9,180	C_1	0.13	81.0	7.3	84.5			
9,360	C_2	0.04	71.6	1.7	37.1	253	2.17	0.58
9,540	C_2	0.06	222.5	1.3	47.7			
9,600	C_2	0.10	79.3	9.8	95.7			
9,810	C_2	0.05	79.9	4.3	34.3	217	2.17	0.64(C)
9,900	C_2	0.05	100.5	6.8	115.4			
10,050	C_2	0.06	103.7	5.4	78.0	176	1.92	0.64(C)
10,200	C_2	0.14	87.1	3.8	42.5			
10,350	C_2	0.05	100.4	1.1	25.8	116	2	**
10,500	C_2	0.12	86.7	6.0	33.5			
10,650	C_2	0.01	57.8	2.0	43.8	182	2	0.75(C)
10,800	C_3	0.09	113.3	5.9	39.4			
10,950	C_3	0.06	326.2	4.7	11.9	174	2	0.86(C)
11,130	C_3	0.12	176.4	5.0	22.4			
11,280	C_4	0.09	158.4	3.8	56.6			
11,400	C_4	0.04	99.4	2.6	14.7	95	1.75	
11,550	C_4	0.03	121.1	2.3	11.2			
11,700	C_4	0.04	128.1	3.2	7.3			

Table 5: **Hydrocarbon concentrations and other geochemical parameters obtained from analysis of COST No. GE-1 well cuttings -- Continued.**

Depth * (feet)	Geochemical Zone	Total Organic Carbon (percent)	$C_1 - C_4$ (ppm)	Gas Wetness (percent)	$C_5 - C_7$ (ppm)	C_{15+} (ppm)	Alteration Index	Vitrinite Reflectance (Ro percent
11,850	C_4	0.05						
12,000	C_4	0.08	80.3	6.4	2.1	130	1.75	
12,150	C_4	0.07	89.3	7.3	4.2			
12,300	C_4	0.07	108.0	2.8	3.6			
12,450	C_4	0.18	23,673.7	13.0	38.0	110	1.75	
			854.9	17.6	0.0			
12,600	C_5	0.08						
12,750	C_5	0.06	107.4	21.3	0.0			
12,900	C_5	0.04	66.6	27.7	13.5	103	1.75	
13,050	C_5	0.05	44.9	30.6	3.7			
13,200	C_5	0.05	251.6	17.3	6.4			
			441.2	13.7	3.1	121		

* Depth given is top of 30-foot interval sampled by cuttings.
** Insufficient sample of primary vitrinite for analysis
(c) Caving

selected cuttings samples, as well as the 20 core samples, were analyzed for their organic carbon content (fig. 17, table 5). The highest organic carbon values were in samples from 3,500 - 5,600 feet, within Zone B (2,800 - 5,800 feet), the only potential oil source section in the well. The three major geochemical zones and five subzones designated by GeoChem Labs for the GE-1 well are shown on plate 1 and on figures 17-19. The average organic carbon content measured in the cuttings is 0.19 percent for Zone A, 0.73 percent for Zone B, 0.32 percent for Zone C_1, and 0.07 percent for the lower zones.

The light and gasoline-range hydrocarbon contents and compositions are also used to determine the source rock richness and state of maturation. The air space gas from the canned well cuttings samples and the cuttings gas released by macerating the samples in a blender were analyzed for their C_1 through C_7 hydrocarbon content before the cuttings were washed and dried. The C_1 through C_4 light hydrocarbons occur in very lean amounts, averaging only 135 ppm throughout the well except for one sample from the interval between 12,300 and 12,330 feet which has unusually high methane, ethane, propane, and isobutane concentrations. The cuttings collected 150 feet below this sample also have significantly above-average methane, ethane, and propane values, indicating that some gas is tightly bound in the siliceous shale at this depth. Cuttings from Zone B show a significant increase in the C_2 through C_4 wet gas components, and one sample collected from the 30-foot interval below 5,340 feet has exceptionally high propane and butane concentrations. The C_5 through

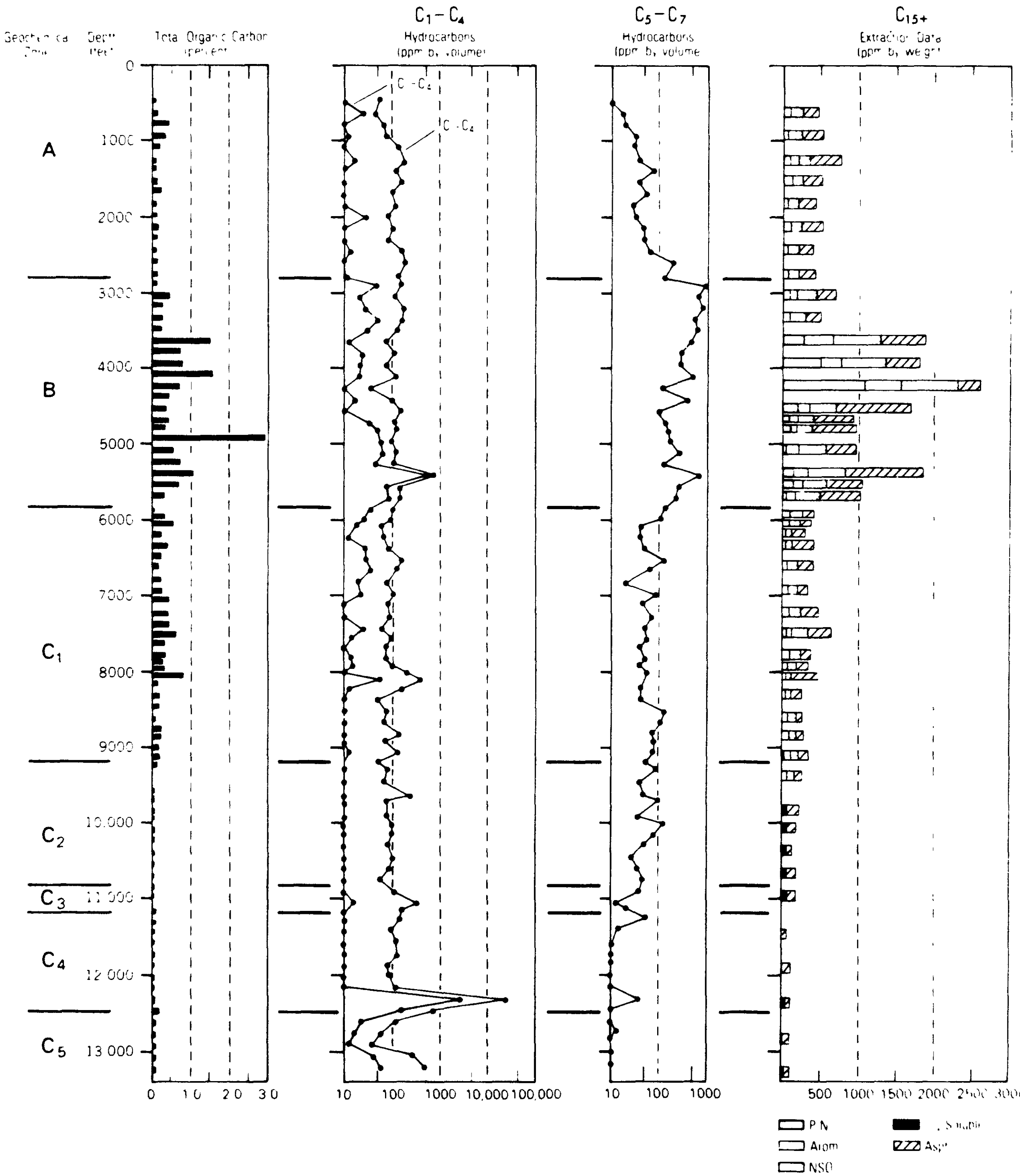

Figure 17. Measurements of organic richness of sediments in the COST No. GE-1 well

C_7 gasoline-range hydrocarbon content also increases noticeably in this zone as shown in figure 17 and table 5. Zone B averages 68 ppm C_2 through C_4 and 377 ppm C_5 through C_7 compared to 15 ppm and 48 ppm for the rest of the well. These figures may show that some condensate and light oil liquids have been generated from the kerogen in this part of the well.

Data on the quantity and composition of solvent-extractable organic matter from 46 cuttings samples and the 20 cores were also used to determine the source rock potential. The extracted bitumen was separated into an asphaltene and a pentane-soluble fraction, and then the pentane-soluble components were separated into C_{15+} nitrogen -sulfur-oxygen containing fraction by adsorption chromatography. The total heavy hydrocarbon content is given in table 5 and its composition is shown in figure 17, although the quantities recovered below 9,600 feet were too small for detailed analyses. The C_{15+} material reaches its highest concentrations in Zone B with a mean of 1,326 ppm including 415 ppm total hydrocarbon content; this compares with the 336 ppm total extracted bitumen with 58 ppm C_{15+} hydrocarbons for the rest of the well.

Unfortunately, contamination of the mud system used in drilling through Zone B makes evaluation of its petroleum generation potential difficult. Large amounts of walnut shells and other mud additives including iron filings, muscovite, IMCO Freepipe, and possibly diesel fuel were used in this interval. The walnut shell, used to control lost circulation, increased the organic carbon content recorded from cuttings samples; the average value measured in core samples is 0.45 percent compared to 0.73 percent in cuttings from Zone B. One hundred barrels of IMCO Freepipe, an oil-soluble, anionic, surface active agent, was also added at the top of this interval to free a stuck drillpipe. Although the total amount of extracted bitumen in cores from Zone B was similar to that measured in well cuttings, lower quantities and much less mature C_{15+} paraffin naphthene hydrocarbons were detected indicating contamination by the refined naphtha in the Freepipe or by diesel fuel.

Hydrocarbon Source Type

The type of kerogen found in organic-rich source beds, as well as the time-temperature history, will determine what type of hydrocarbons--oil, gas, or condensate--will be generated. Aquatic and unstructured organic material is generally oil prone whereas terrestrial and structured kerogen tends to produce gas. Figure 18 shows the relative abundance of the four main kerogen types (amorphous, herbaceous, woody, and coaly) that occur in the GE-1 well. Amorphous and herbaceous kerogen derived from slightly altered plant detritus are the dominant types throughout; woody and coaly types form 21 percent of the kerogen in Zones A and B, 48 percent in Zone C_1, and 26 percent elsewhere. Much of the kerogen in the deeper sections of the well has been oxidized and therefore can no longer generate significant amounts of hydrocarbons. However, the well-preserved algal-amorphous sapropellic kerogen in Zones A and B represents an excellent oil source material, and Zone B appears to have sufficient organic

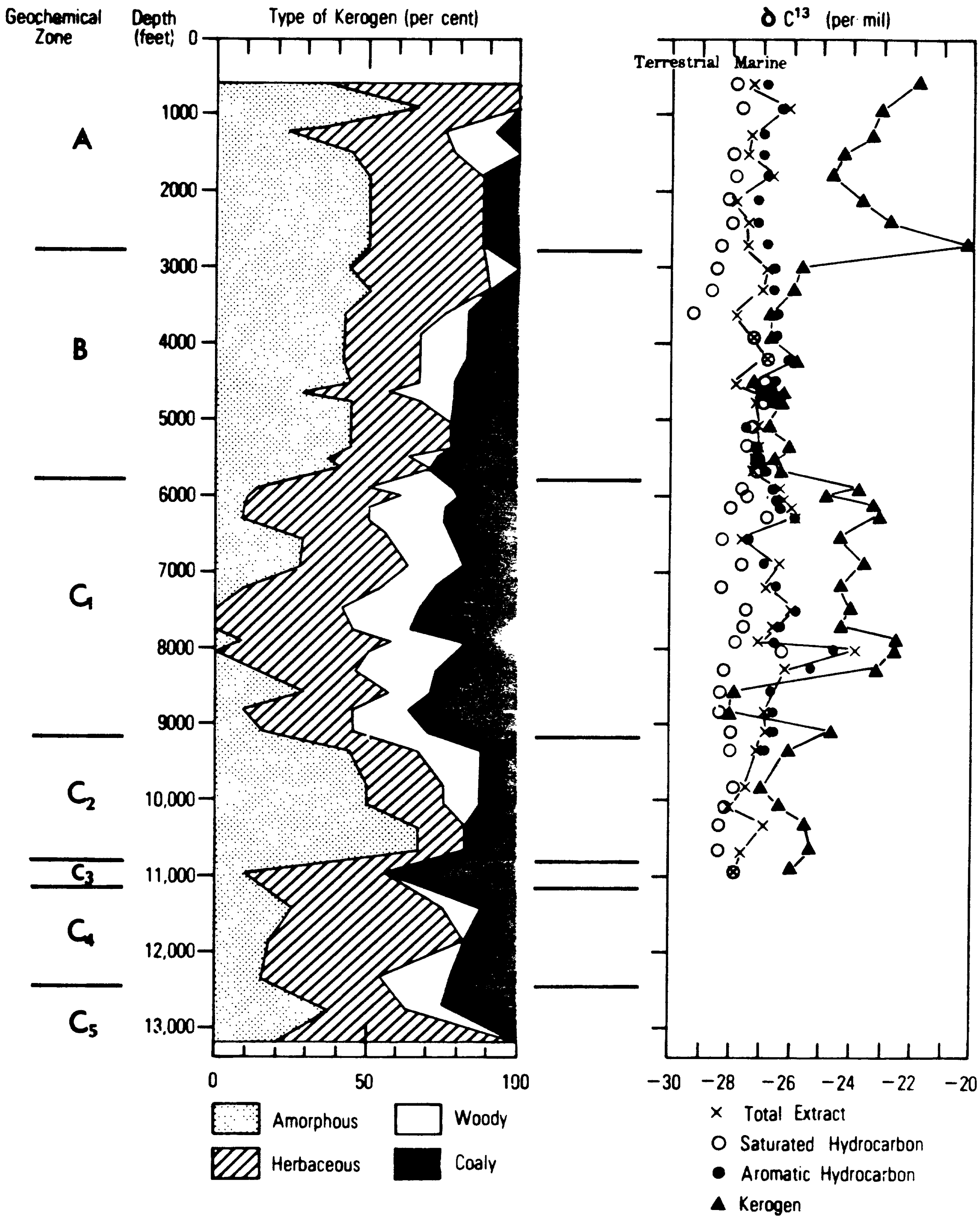

Figure 18. Measurements showing the type of organic matter in the COST GE-1 well sediments

richness to justify interest as a possible oil and associated gas source.

The carbon isotopic composition of components in the solvent-extractable fraction and in the insoluble kerogen was determined by Phillips Petroleum Company (written communication, 1978) for the extracted material and residues from 41 cuttings samples and the 20 core samples. The ratio of the two stable carbon isotopes, C^{12} and C^{13}, is given relative to the standard Peedee belemnite-Chicago and δ values are defined by the formula:

$$\delta C^{13} \text{ (per mil)} = \left(\frac{R}{R_s} - 1 \right) \times 1{,}000$$

where $R = C^{13}/C^{12}$ ratio in the sample and

$R_s = C^{13}/C^{12}$ ratio in the standard.

Data for the total pentane-soluble extract, the saturated hydrocarbons (paraffin-naphthene), the aromatic hydrocarbons, and kerogen from the extracted ground rock residues from well cuttings are plotted in figure 18 and provide information on the depositional environment, source of organic matter, and potential petroleum yield. The carbon isotopic value of the total extract averages -27.0 per mil in the GE-1 well indicating an open marine environment and enrichment in C^{13} compared to terrestrial material. In Zone B there is a much lower spread between the kerogen and total extract values and between the isotopic composition of components in the solvent-extractable fraction, particularly in the lower two thirds of the interval, showing a high potential yield of petroleum from the organic material in these source rocks.

Thermal Maturity

Numerous techniques measuring the degree of thermal alteration attained by organic matter in sediment are used to determine whether potential source rocks have been exposed to high enough temperatures over a sufficient period of time to have produced commercial quantities of oil and gas. The two most widely used methods for measuring the level of maturation, based on the color and reflectivity of organic particles, were included in the organic geochemical analysis of COST No. GE-1 well cuttings and the resultant data are listed in table 5 and shown in figure 19. A schematic diagram that correlates the generation envelopes for oil and gas for the major kerogen types with the thermal alteration index (TA) and vitrinite reflectance measurements (R_o) is included in figure 20.

A change in the color of organic material such as spores, pollen, plant cuticles, resins, and algal bodies in sediment from light yellow through orange and brown to black occurs with exposure to increasing temperatures. This characteristic can easily be observed with a microscope using transmitted light, and a numerical visual index associated with the color of material of a known degree of thermal alteration was proposed by Staplin (1969). This thermal index ranges from 1 to 5 in association with the colors shown in Figure 20. The thermal alteration index values determined in cuttings by GeoChem Laboratories for the GE-1 well (fig. 19) show a consistent increase in maturity with depth to 9,000 feet.

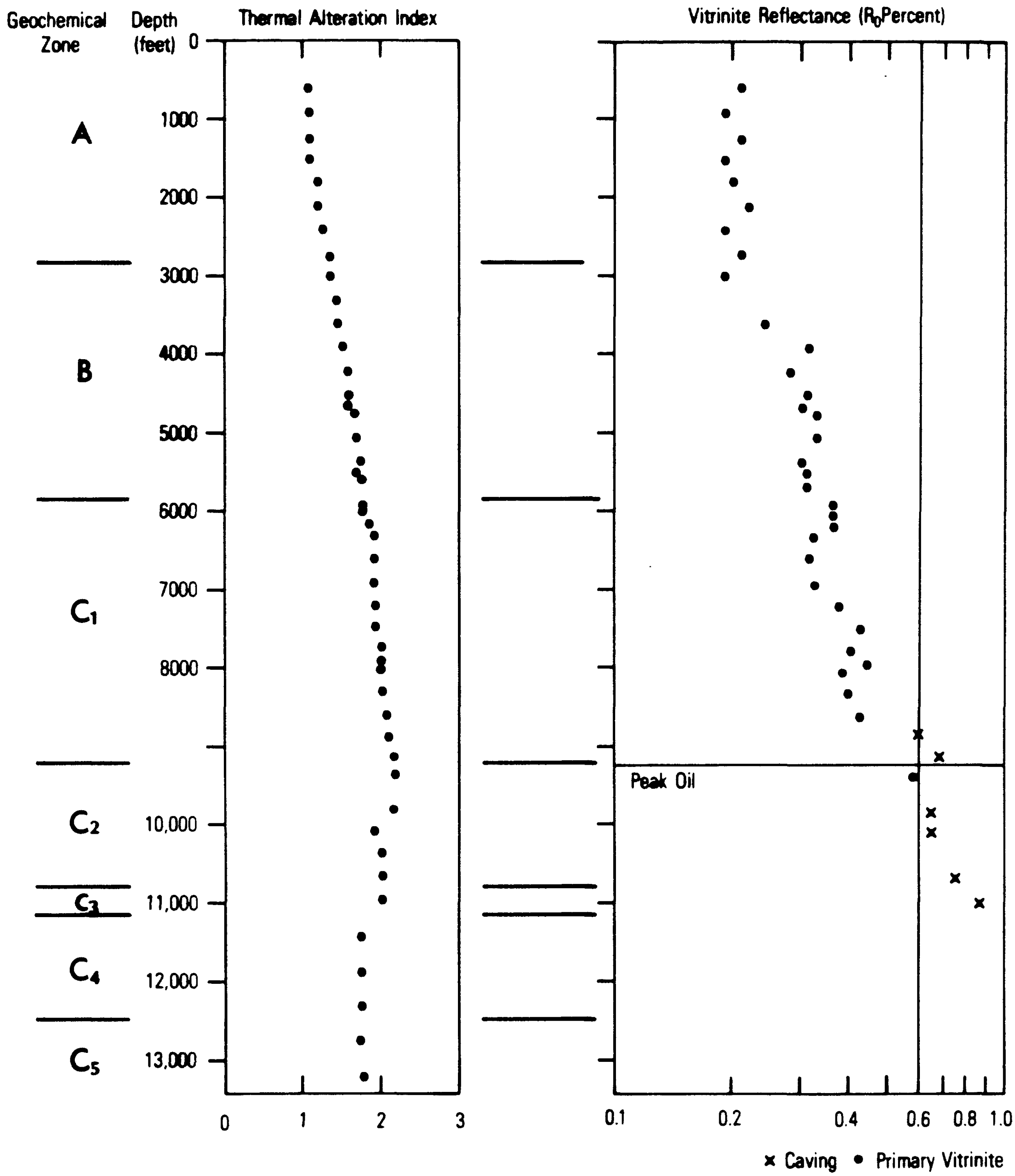

Figure 19. Measurements showing the maturity of organic matter in the COST No. GE-1 well sediments

The kerogen color does not become darker in older rocks at the bottom of the well, however, and the visual index even appears to indicate a lower degree of maturity in Subzones C_2 through C_5. It should be noted that the thermal alteration index is most sensitive for immature samples, that organic matter is poorly preserved and occurs in very small amounts in subzones C_2 - C_5, and that the material from the deepest zones contains significant amounts of inertinite. Obviously, TAI values of 2+ to 3- associated with the best zone for oil production do not appear above Subzone C_2 in the GE-1 well.

The reflectance capability (Ro) of polished vitrinite particles is dependent on the duration of heating as well as the maximum temperature encountered and can provide a reliable measurement of thermal maturity. Vitrinite reflectance analysis was done by Core Laboratories, Inc., (1977) on 41 cuttings samples and 18 core samples, and the data from these samples are plotted in Figure 19. The maturity index steadily increases with a Ro value of 0.86 percent at 10,950 feet, the deepest sample analyzed. The reflectance measurements associated with oil, wet gas, and dry gas generation, determined by Bujak, Barss, and Williams (1977), are as shown in figure 20. Maturity values high enough to account for significant amounts of thermogenic gas were not seen in the analyzed vitrinite from the well. Peak oil generation occurs at Ro values above 0.6 percent, which were found in Subzone C_2 at 9,200 feet, and immature oil may start to form at somewhat lower temperatures and Ro values of 0.45 to 0.5. Deeper samples contain a significant amount of

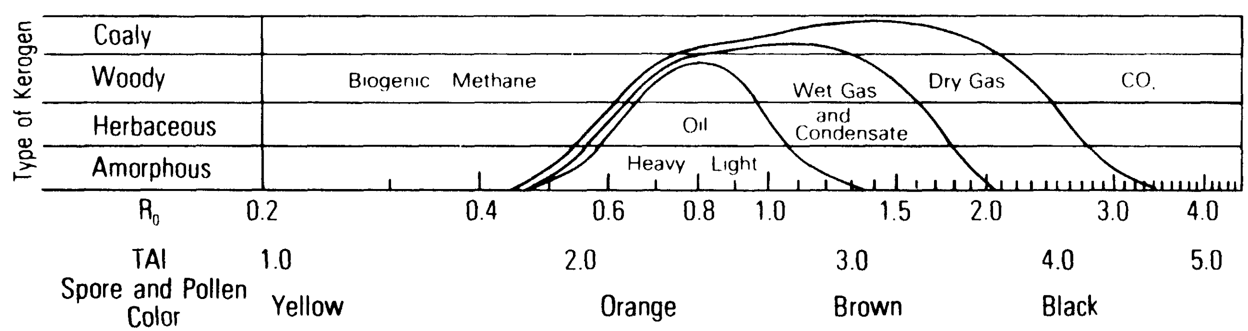

Figure 20. Schematic diagram showing oil and gas generation zones as a function of maturation index and kerogen type (modified from Bujak and others, 1977)

caving material and may actually belong to a higher thermal realm than is indicated. However, source rocks from the oil-prone Zone B interval would have to be exposed to more extensive temperature alteration to have generated significant petroleum accumulations.

Detailed chromatographic analysis of the extractable light hydrocarbons, C_2 through C_7, obtained by helium elution of 44 cuttings samples was done by Atlantic Richfield Company (written communication, 1977). Changes in composition and in various molecular ratios generally reflect diagenetic temperature increases or can indicate sample contamination. High n-heptane concentrations and other anomalous values above 6,150 feet and between 8,500 and 9,000 feet indicate severe contamination, possibly by diesel fuel. Light hydrocarbon yields were generally low with the highest values in Zone B and at 8,010 feet where a slight anomaly of natural origin, which can also be seen in GeoChem Laboratories' data plotted in figure 17, was detected. The molecular ratios calculated by both laboratories reflect higher temperatures deeper in the well.

Summary

Three geochemical zones, with five subzones in the deepest unit, were identified in the COST No. GE-1 well. Most strata are organically lean except for Zone B which contains abundant algal-amorphous sapropellic kerogen, an excellent oil source material, but which was also immature. Contamination of the mud system complicates evaluation of the potential of Zone B: but light hydrocarbon and

The older red beds and evaporites below Subzone C_1 are mature enough for petroleum generation but are generally very poor source beds. However, a high C_1 through C_4 hydrocarbon content noted between 12,300 and 12,480 feet indicates some tightly bound gas in the siliceous shales at this depth.

RESERVOIR ANALYSIS AND PETROLEUM POTENTIAL

By E. K. Simonis

In terms of reservoir characteristics and petroleum potential, the section penetrated in the COST No. GE-1 well can be divided into four lithologic units.

1) The lower Tertiary and Upper Cretaceous marine section down to 5,700 feet consists mainly of chalky limestone and shale with essentially no sandstone. The chalky limestones have high porosities but very low permeabilities. Chalks with similar reservoir characteristics are highly productive in the North Sea (Scholle, 1977). The shales between roughly 2,800 and 5,800 feet have the best oil source quality encountered in the well, although contamination is suspected (Geochem Laboratories, Inc. 1977). The Thermal Alteration Index value of 1+ to 2 is below the peak oil generating stage but is still within the oil generating range. The section is considered prospective, especially if areas are found where the chalk reservoir characteristics are improved by overpressuring and/or fracturing, and where oil generation is enhanced by deeper burial. Numerous shale interbeds provide potential seals.

2) The Cenomanian and older (?) Cretaceous section between 5,750 and approximately 7,000 feet is a transitional non-marine to shallow marine sequence consisting of sandstone, limestone, siltstone, and anhydrite. A 90-foot-thick sandstone below

5,770 feet, and other thinner sandstone beds down to approximately 6,400 feet provide excellent reservoir beds with sidewall core porosity generally over 25 percent and permeability up to 447 millidarcies. Oolitic limestones may provide additional reservoir rocks. Shales with good oil generating characteristics overlie the sandstone beds and may interfinger with them; the shales also provide potential seals. The proximity of good source beds to sandstones with excellent reservoir characteristics makes this section the most attractive target for oil exploration.

3) The Lower Cretaceous and Jurassic(?) section between approximately 7,000 and 11,050 feet consists of dominantly non-marine sandstone, conglomerate, red shale and minor anhydrite. Although the sandstones tend to be poorly sorted, many of them above 10,000 feet are highly porous and permeable. Potential seals are provided by shale and anhydrite beds above and within the section. Prospectiveness of this section in the vicinity of the GE-1 well is diminished by lack of favorable source beds; however, improved source beds interbedded with good reservoir sandstones can be expected with a lateral change toward marine facies.

4) The rocks between 11,050 and 13,254 feet, radiometrically dated as Devonian in age, appear to be non-prospective in the vicinity of the well. Very low porosity and essentially no permeability typify these highly indurated or weakly meta-

morphosed, very-fine grained, possibly tuffaceous sediments and fine-grained igneous rocks. Low-grade metamorphism in the rocks below approximately 12,750 feet is indicated by occurrence of chlorite, albite and epidote, but the degree of diagnesis and/or metamorphism in the upper part of the section from 12,750' to T.D. is not clear. On the basis of X-ray diffraction analysis of chlorite and illite/ muscovite, Core Laboratories, Inc. (1977) favor the interpretation that the rocks are not metamorphosed, but the data are inconclusive. The relatively high volumes of cuttings gas recovered from the interval 12,300 to 12,330 Feet (Geochem Laboratories, Inc., written communication, 1977) tends to support the interpretation that the rocks are not metamorphosed. However, the Thermal Alteration Index value of 2 to 2+ reported by GeoChem Laboratories, Inc. for the Paleozoic section appears to be unrealistically low for these highly indurated rocks. The recovery of dry gas from the tight argillaceous rocks is the most promising indication that the Paleozoic rocks may be prospective, but only additional drilling will disclose the presence of reservoir rocks.

ENVIRONMENTAL CONSIDERATIONS

by F. Adinolfi

Protective measures to ensure strict environmental safeguards for offshore drilling are provided by law and administered by the U.S. Geological Survey. Specific environmental regulations for the COST No. GE-1 well are outlined in the list of stipulations, provided by the USGS, and attached to the permit to drill.

Early in the Sale 43 tract-selection process, particular geological, environmental, biological, archaeological, socio-economic and other information was requested from federal, state, and local governments as well as industry, universities, research institutes, environmental organizations, and members of the general public. After 181 tracts were excluded because of expressed environmental concern, 225 tracts were identified for proposed leasing. This information was published in the draft and final environmental impact statements for the proposed South Atlantic OCS Lease Sale No. 43 prepared by the Bureau of Land Management in 1977.

Ocean Production Company applied for a permit to drill the COST No. GE-1 well, a stratigraphic test, in the southeastern part of the Sale No. 43 area, in the Southeast Georgia Embaymen. The site was selected using common-depth-point seismic data and located off any potential petroleum-trapping structures to minimize the chances of encountering hydrocarbon accumulations.

An environmental analysis of the drill site was prepared by the U.S. Geological Survey, before approval was granted for the operation. Environmental considerations included geology, meteorology, oceanography, biology, as well as pollution from oil spills and the socio-economic impact. The USGS determined that drilling the COST well would not significantly affect the human and physical environment and therefore would not require a separate environmental impact statement.

Prior to commencement of drilling operations, Ocean Production Company was required by the Geological Survey to conduct a site survey to investigate the biology, engineering hazards, and archeological significance of the proposed site. A high-resolution seismic geophysical survey provided an assessment of potential geologic and other natural and man-made hazards. No potential shallow hazards were found in block 387, the location of the COST No. GE-1 well.

The most significant seafloor irregularities in the area are low, broad sand waves that generally trend northeasterly and have relatively gentle slopes. These sand waves are several tens of yards wide, as well as several hundred yards long and generally less than one yard high. Small linguiodal ripples are oriented perpendicular and superimposed on the crests of these sand waves. Generally, the seafloor surface has no perceptible slope. Seafloor soils are characterized as medium-grained sand, moderately sorted, with a moderate amount of shell hash present. The same material probably persists to a depth of several tens of yards and offers good support characteristics for drilling platforms. The shallow structure is simple, characterized by subhorizontal to gently east-dipping, undeformed strata.

The biological study consisted of physical/chemical water column measurements, physical analysis of sediments, analysis of benthic biological samples, and biological and sedimentological observations of the ocean bottom using underwater photography. Water temperature, salinity, and dissolved oxygen values were representative of seasonal conditions in coastal and shelf waters off the southeastern United States. Barnacles, annelids, and bivalves accounted for the majority of the benthic forms observed near the wellsite. Echinoderms, including sea stars, sea cucumbers, and sea urchins, were observed in photographs. Finfish observed in the area included the summer flounder and skate. Numerous sightings of dolphin were made. Neither the photographic nor shallow high resolution geophysical surveys gave evidence of hard or "live" bottom areas in the immediate vicinity of the COST well. The archeological analysis used data from a magnetometer, side scan sonar and a subbottom profiler. No cultural resource features were evident. There are no known shipwrecks on the seafloor and the COST well is located more than 10 miles offshore from any commercial fishing grounds and not near any sport fishing area. Regional seismic activity is generally low with the exception of the Charlestown, South Carolina area, where in 1886 a destructive earthquake was followed by a 20- to 30-year period of frequent earthquakes. The intensity and regional extent of the 1886 Charleston earthquake indicates a deep focal point in crustal rocks below the Coastal Plain sedimentary sequence.

The principal artesian aquifer for all of Florida and the coastal plain of Georgia consists of continuous Tertiary limestones which extend offshore. Although potable water in this aquifer is not known to extend as far offshore as the GE-1 well, casing was set to a depth of 3,974 feet to protect the aquifer against potential contamination.

The most detrimental impact on the environment, particularly for fish, wildlife, and the numerous marshes and estuaries along the coast, would have resulted from a major oil spill. The primary factors influencing ocean circulation in the vicinity of the COST well are seawater density gradients caused by temperature and salinity differences, the nearby Gulf Stream, and prevailing winds. During the February - June 1977 period when the well was drilled, weather conditions were excellent, clear skies and calm seas prevailed. Winds were variable, most often from the southeast and southwest, at a speed of about 12 knots. Wave height averaged two feet and the air temperature was about 70°F. The Massachusetts Institute of Technology oil spill trajectory model, based on available wind and water circulations, computed the trajectory of a hypothetical offshore spill originating at the COST well. The study concluded that there would be less than 1 percent chance of such a spill reaching the coast in the winter (offshore wind pattern), but the risk would increase to 25 percent in the spring.

An oil spill contingency plan which outlined the equipment available as well as procedures to be followed in the event of an oil spill was submitted by Ocean Production Company. Drilling operation was continuously monitored by USGS inspectors.

The drilling rig utilized all required safety and pollution-abatement equipment. In the event of an oil spill, a fast-response open sea and bay skimmer was leased from Clean Atlantic Associates. This system included a floating oil boom skimmer, outrigger, pump, and storage tanks and had the capability to be 100 miles offshore within 12 hours of notification of a spill. This system, stored in Savannah, Georgia, has the capacity to capture up to 360 bbls. of liquid pollutant. In addition, personnel from Coastal Services Inc. were on call in the event of an emergency.

Water pollution resulting from drilling the COST well was minimal. During the first 2 days of drilling, before the initial string of conductor pipe could be cemented in the hole and the blowout preventer and marine riser installed to allow circulation to the jack-up rig, seawater was used as the drilling fluid. During this initial phase of drilling, to a depth of 440 feet below the seafloor, there was no return of fluids to the platform. Seawater was temporarily clouded as cuttings were dumped directly on the seafloor. Also, there was minor and temporary contamination of the seawater and ocean floor near the drill hole from excess cement, displaced while cementing the first casing string. After this, circulation was established between the hole and the drilling platform, and only washed cuttings and drilling fluid, containing no oil or toxic materials, were disposed of onto the ocean floor. Roughly 700 cu. yds. of drill cuttings and 515 cu. yds. of drilling mud were discharged to the seafloor; all this material will gradually be dispersed by water currents and storms.

Mud weight was sufficiently maintained to control all formation pressures and hole conditions to prevent fluids from flowing between formations and leaking out to the surface. Casing and plugging-for-abandonment requirements should preclude any possibility of seepage or contamination at the test site after drilling was completed. The sea floor was cleared of all obstructions and checked by an observation dive.

SUMMARY AND CONCLUSIONS

Ocean Production Company, acting as the operator for a group of 25 oil companies, drilled the COST No. GE-1 well to obtain scientific data about the geology and potential petroleum resources of the South Atlantic Outer Continental Shelf. The well was drilled to a total depth of 13,254 feet between February 22 and May 31, 1977, by ODECO's drill barge Ocean Star. The drill site was approximately 74 nautical miles east of Jacksonville, Florida, in a sedimentary basin konw as the Southeast Georgia Embayment. The well provided much useful geological information to participating companies and to the USGS to aid in the evaluation of tracts offered in OCS Lease Sale No. 43, held on March 28, 1978.

The COST No. GE-1 well was drilled in 136 feet of water at a total cost of $7.5 million. Three strings of casing were set in the shallow part of the GE-1 well: 30-inch conductor casing was set down to 390 feet, 20-inch casing down to 947 feet and 13 3/8-inch casing down to 3,974 feet. Mud weight increased from 8.5 pounds per gallon to 9.7 pounds at about 10,000 feet and then decreased to 9.45 to total depth. Seven types of electric logs, a mud log, and a seismic velocity log were run. Six drill stem tests, 15 conventional cores, numerous sidewall cores and ditch cutting samples were obtained and analyzed.

The rocks encountered by the GE_1 well have been grouped according to both age and lithological similarities. In general, the well penetrated a Pliocene through Oligocene interval from 390 feet, where sampling started, to 1,000 feet consisting of unconsolidated sand, gravel and calcareous mudstone with abundant shell fragments and microfossils. The rock strata from 1,000 to 3,570 feet are of Eocene age but include some earliest Oligocene and Paleocene rocks; finely crystalline to argillaceous limestone, brown dense dolomite and chert are the main rock types.

The uppermost Cretaceous (Maxstrichtian and Campanian, 3,570 - 4,350 feet) interval is a dominantly marine unit of light- to dark-gray, calcaroeous, partly cherty claystone and shale. The Santonian and Coniacian intervals (4,350- 5,320 feet) are composed largely of calcaroeous mudstone ranging to clayey limestone. The Turonian - Cenomanian (?) (5,320 - 5,730 feet) interval is mainly a calcareous shale.

The section between 5,730 and 11,050 feet is poorly dated but is probably of Early Cretaceous age except possibly for the lowest few hundred feet. A sandstone below 5,730 feet (approximately 100 feet thick is underlain by a thick carbonate section consisting of shallow marine limestone, in part oolitic, interbedded with thin anhydrite and minor dolomite down to 7,090 feet. Between 7,090 and 10,700 feet the section consists of red and gray shale, fine to medium sandstone and minor anhydrite and dolomite which were probably deposited in or near a sebkha-type environment. The interval from 10,700 freet to 11,050 feet is composed of rocks interpreted as Mesozoic sandstones which were contact-metamorphosed by an igneous intrusion. Based on K-Ar age determinations the rocks below 11,050 are considered to be of Early Palozoic (Devonian) age. Above 13,000 feet they are highly indurated to weakly metamorphosed shales, dolomites, and quartzites. Below 13,000 feet to total depth at 13,254 feet the rocks have been identified as greens chist-facies metamorphics intruded by hypabysaal felsite of possibly early Mesozoic age.

A total of 838 feet of porous sandstone of petroleum reservoir quality were logged in the well from 5,000 to 10,000 feet. Below 10,000 feet, the sediments are almost totally sealed by cementation and pressure solution. The section from 5,750 to 7,000 feet contains the best combination ofpotential reservoir rocks and sealing beds.

Three geochemical zones with five subzones in the deepest unit have been identified in the GE-1 COST well. Zone A (to a depth of 2,800 feet) is immature and organically lean, and shows little potential for hydrocarbon generation. Zone B (2,800 to 5,800 feet) is also immature but contains abundant algal-amorphous sapropellic kerogen which is an excellent oil source material. However, contamination of the mud system in this interval makes difficult the evaluation of its potential. Zone C (5,800 to 9,200 feet) has only small amounts of hydrocarbons. The remainder of the hole below 9,200 feet is mature enough for petroleum generation but consists of older red beds and evaporites and is generally a very poor hydrocarbon source area. However, a high methane and ethane gas content was noted in tight siliceous shales between 12,200 and 12,480 feet. Minor gas shows were detected in sidewall cores taken in the well between 2,000 and 10,500 feet.

The average temperature gradient was .85°F per 100 feet. Drill stem tests indicated an average pressure gradient of 0.50 psi per foot, which is somewhat higher than the 0.435 psi per foot determined from the COST No. B-2 well off the New Jersey coast. Data from an uphole velocity survey correlated to a nearby seismic line indicated that five strong reflections on the line were related to sharp lithologic changes in the well.

A comprehensive environmental analysis was conducted and stringent protective measures were required before a permit was issued to drill the GE_1 well. There were no indications of any serious problems for deep drilling in the South Atlantic area and no geological hazards were encountered. Adverse enrionmental impacts related to the drilling of the well were minimal, insignificant and temporary.

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