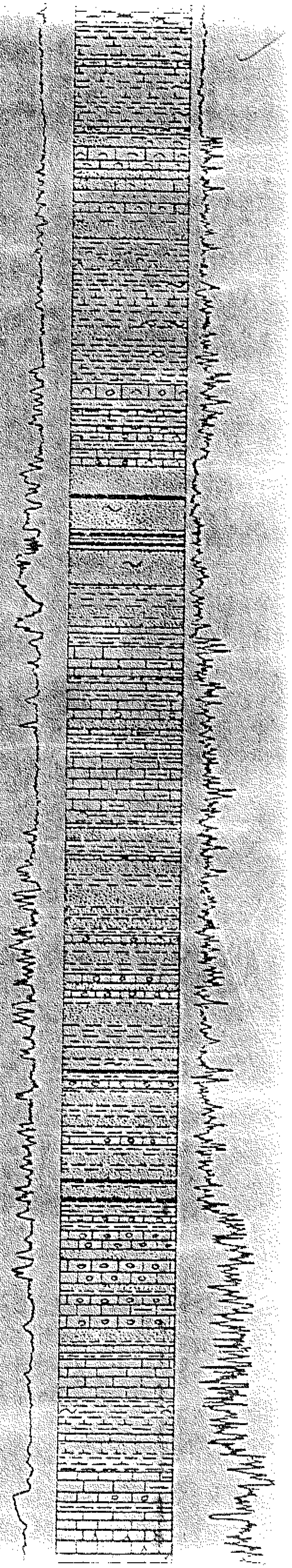
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC AND OPERATIONAL SUMMARY, COST NO. G-2 WELL,

GEORGES BANK AREA, NORTH ATLANTIC OCS

OPEN-FILE REPORT 80-269

March 3, 1849



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Roger V. Amato and Edvardas K. Simonis, Editors

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1980

CONTENTS

ILLUSTRATIONS
(Plates in pocket)

Page

TABLES

EQUIVALENT MEASUREMENT UNITS AND CONVERSIONS

U. S. Customary to SI Metric Units:

1 inch = 2.54 centimeters
1 foot = 0.3048 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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Roger V. Amato and Edvardas K. Simonis, Editors

INTRODUCTION

The Continental Offshore Stratigraphic Test (COST) No. G-2 well is the second deep well to be drilled in the Georges Bank Basin and the third in a series of COST wells on the Atlantic Outer Continental Shelf (OCS). The G-2 was drilled by Ocean Production Company, acting as the operator for 19 participating companies between January 6 and August 30, 1977. The semisubmersible rig Ocean Victory was used to drill the well to a depth of 21,874 feet at a location 132 statute miles east-southeast of Nantucket Island in 272 feet of water. An earlier deep stratigraphic test, the COST No. G-1 well, was drilled 42 statute miles west of the G-2 well, to a depth of 16,071 feet in 1976 (fig. 1). Geological and engineering data obtained from the well were used by companies and the U.S. Geological Survey (USGS) for evaluating the petroleum potential and possible drilling problems in the U.S. North Atlantic OCS area in preparation for lease sale 42 held on December 18, 1979. The stratigraphic test was intentionally drilled away from any potential petroleum-bearing feature, but in a block bordering several tracts that were included in the sale area.

Data obtained on the well's operations, lithology, potential source rock, porosity, temperature and pressure gradients, biostratigraphy, and paleoenvironment are summarized in this report. Geologic data from the well indicate that the best potential reservoir rocks occur above 10,000 feet in Upper Jurassic and Cretaceous sandstones, but potential source beds in this section are thermally immature. Middle and Lower Jurassic rocks below approximately 14,000 feet, although not rich in organic material, are thermally mature and are interpreted to be fair to good source beds for oil and gas. In the well, porosity is low in the Middle and Lower Jurassic carbonate rocks, but enhanced porosity is expected in structurally positive areas which were subjected to periodic subareal leaching and dolomitization.

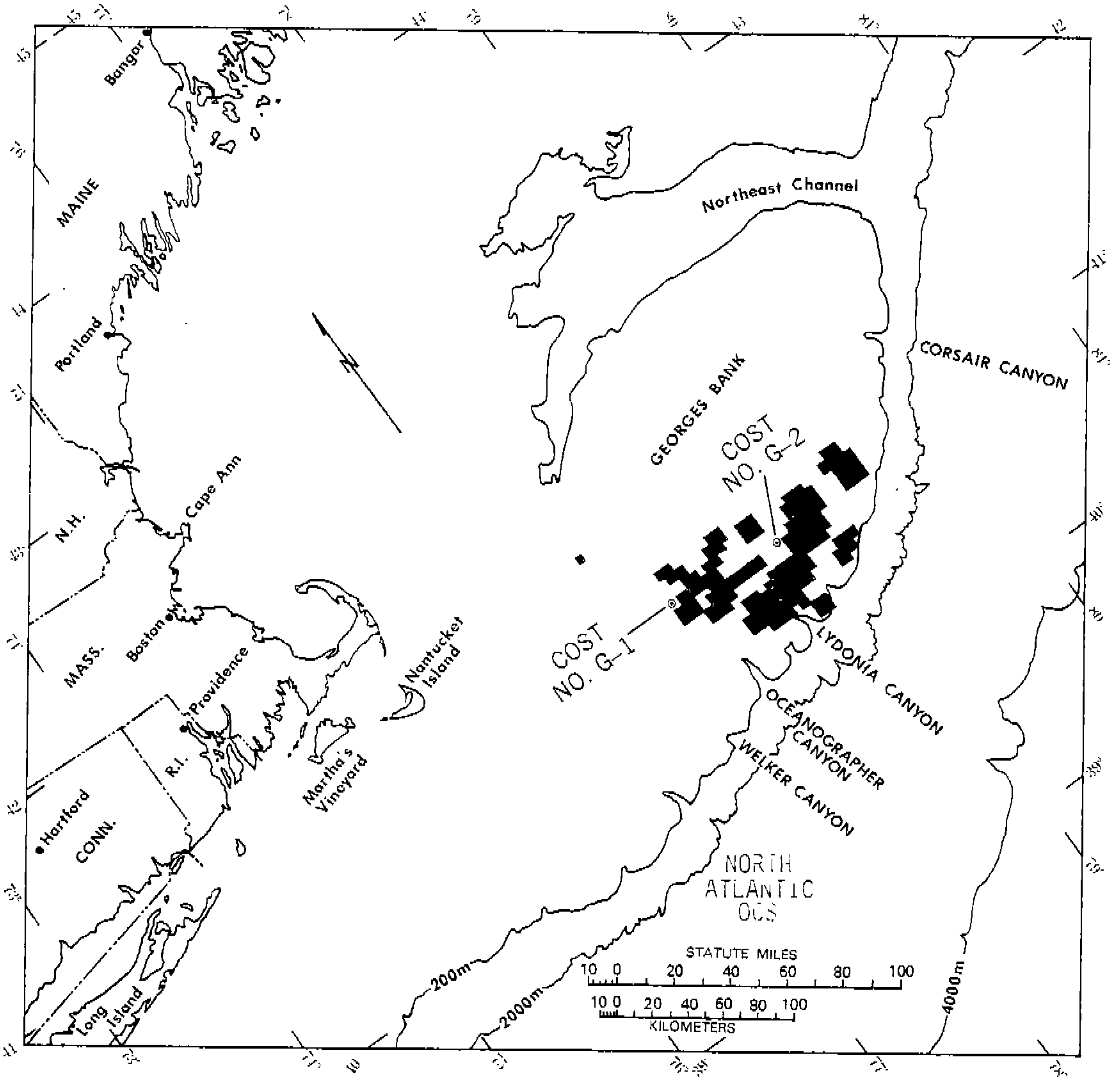


Figure 1.--Map of the Georges Bank area showing locations of the COST No. G-1 and G-2 wells. Shading indicates blocks offered in OCS lease sale 42. Bathymetric contours in meters.

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. This requirement was also included as Stipulation No. 4 in the list attached to OCS Permit No. E 34-76 for the COST No. G-2 well operations. Block 142, immediately east of block 141 on which the G-2 was drilled, was leased on February 1, 1980, to Superior Oil and Pennzoil Companies; and block 186 adjoining the southeast corner of block 141, was leased to Exxon Company, U.S.A.

The information summarized herein is based partly on USGS analyses and interpretations and partly on contract reports by service companies, sample analyses by oil companies, and interpretations of electric logs, drill cuttings, and cores. All data may be inspected at the Public Information Office of the USGS, Conservation Division, Eastern Region, 1725 K Street, N.W., Washington, D.C. 20006. Except where noted otherwise, depths referred to in this report are given in feet below the Kelly Bushing (KB) elevation, which was 79 feet above mean sea level and 351 feet above the sea floor.

OPERATIONAL DATA

By Roger V. Amato and Edvardas K. Simonis

The semisubmersible drill barge OCEAN VICTORY arrived on location at Georges Bank on January 5, 1977, and began drilling operations on the COST No. G-2 well on January 6 at 0900 hours E.S.T. Ocean Production Company acted as the operator for 19 petroleum companies listed below which shared expenses for the well:

Amerada Hess Corporation
Aminoil U.S.A., Inc.
Amoco Production Company
Atlantic Richfield Company
Chevron Oil Company
Cities Service Company
Continental Oil Company
Exxon Company-U.S.A.
Getty Oil Company
Gulf Energy and Minerals Company-U.S.A.
Marathon Oil Company
Mobil Oil Corporation
Ocean Production Company
Pennzoil Company
Phillips Petroleum Company
Shell Oil Company
Sun Oil Company
Tenneco Oil Company
Texaco, Inc.

Drilling stipulations required the operator to provide the USGS with all well logs, washed and unwashed samples, core slabs, and operational and technical reports including geological information at the same time as industry participants. The Maine Bureau of Geology, which received copies of the electric logs and proprietary reports, distributed information on the well to the Geological Surveys of the other Atlantic coastal States involved.

The exact location of the COST No. G-2 well was lat 40°50'11.410" N.; long 67°30'29.784" W., or at UTM coordinates (zone 19) X = 625,771.465 meters and Y = 4,521,466.720 meters. The final well site in block 141 of OCS Protraction Diagram NK 19-12 is shown in figure 2. Water depth at the location was 272 feet. All depth measurements in the well were made from the Kelly Bushing (KB) which was 79 feet above mean sea level (MSL) and 351 feet above sea floor. Down to 20,600 feet the G-2 well was drilled with less than 3° deviation from vertical; below this depth the deviation increased gradually to 4 1/2° at 21,800 feet. At a measured depth of 21,800 feet, true vertical depth was determined to be 21,793 feet and the bottom hole location was 261 feet north and 142 feet east of the surface location. The OCEAN VICTORY arrived on location on January 5, 1977, spudded the COST No. G-2 well on January 6, and finished drilling to a measured depth of 21,874 feet 213 days later on August 7. After wireline logging, running velocity and temperature surveys, sidewall coring, and drill-stem testing, the well was plugged and abandoned and the rig was released on August 30, 1977.

Drilling Programs

The COST No. G-2 well was drilled using thirty-two 12 1/4-inch drill bits to a depth of 12,475 feet, fifteen 8 1/2-inch bits to a depth of 18,829 feet, and twenty-one 6 1/2-inch bits to 21,874 feet. Additional bits were used to open the hole before setting the larger casing strings, to drill through cement, for clean-out trips, and for conventional coring program. Depths where the 12 1/4-, 8 1/2-, and 6 1/2-inch bits were changed are marked on figure 3, a graph showing the daily drilling progress for the well. Drilling rates ranged from 2 to 170 feet/hour. Average drilling rates for given intervals were 100 feet/hour down to 4,216 feet,

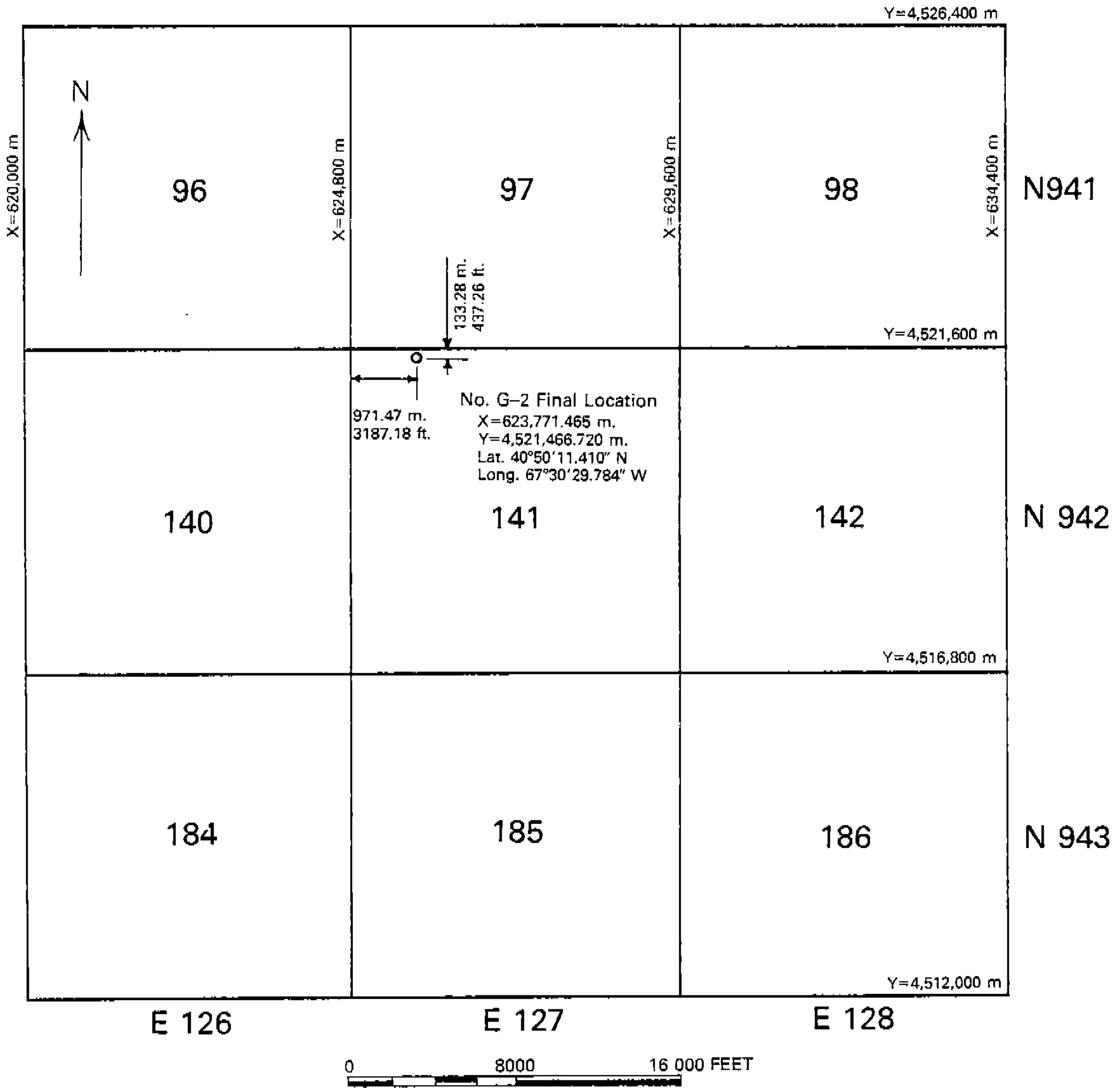


Figure 2.--Plat showing the final location of the COST No. G-2 well in OCS Protraction Diagram NK 19-22.

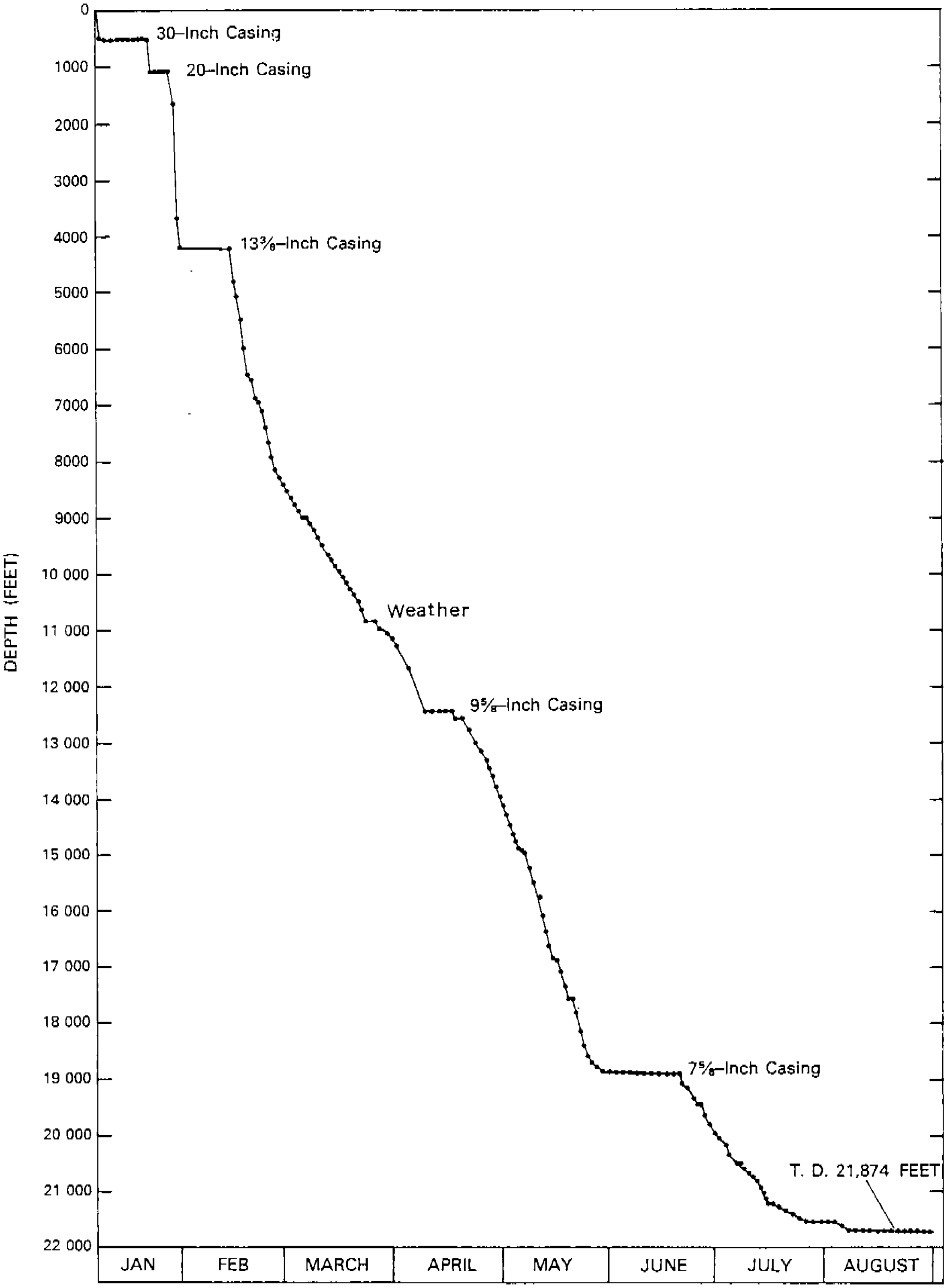


Figure 3.--Drilling progress for the COST No. G-2 well, 1977.

12 feet/ hour to 12,475 feet, 10 feet/hour to 18,829 feet, and 6 feet/hour for the remainder of the well.

Five strings of casing were cemented in the well, as shown in figure 4, a schematic diagram which also gives the position of the cement plugs in the abandoned well. At 505 feet below KB, 167 feet of 30-inch conductor casing was set with 600 94-pound sacks of Class B cement. The 20-inch casing was set at 1,061 feet with 1,300 sacks of Class B cement. At 4,135 feet 2000 sacks of Class B cement were used to cement the 13 3/8-inch casing. Twenty-one hundred sacks of Class H cement were used to set the 9 5/8-inch casing at 12,399 feet. The 7 5/8-inch liner, with the shoe at 18,820 feet and the top at 12,286 feet, was cemented with 1,350 sacks of Class H cement. No casing was set in the 6 1/2-inch hole below the 7 5/8-inch liner.

Drilling Mud

Changes of selected drilling mud properties with depth are graphically shown in figure 5. Sea water was used as the drilling fluid to drill the first 502 feet of hole. The sea water was then displaced with high-gel spud mud with a weight at 9.1 lb/gal and viscosity of 60 seconds. The spud mud was converted to low-gel drilling mud at 4,135 feet after 13 3/8-inch casing was set. Mud weight was increased to 9.6 lb/gal at 5,000 feet and gradually increased to 10.4 lb/gal at total depth. Mud viscosity decreased from 60 secs. to 40 secs. below 4,135 feet and generally remained between 40 and 50 secs. for the rest of the well. Chloride concentration stayed between 4,000 and 12,000 ppm from the top down to 21,748 feet where it jumped to 20,100 ppm and rose to 44,400 ppm at total depth, owing to contact with salt beds. High calcium mud (400-600 ppm) was used in drilling down to 4,000 feet. Calcium concentrations were then reduced to 0 to 100 ppm to about 13,600 feet; concentrations then rapidly increased to 400 ppm and more than 500 ppm, probably as a result of drilling through beds of anhydrite ($CaSO_4$) which were first penetrated at this depth. Mud pH began at 9.0, increased to 12.5 at 4,135 feet, and then remained at 12.0 for the

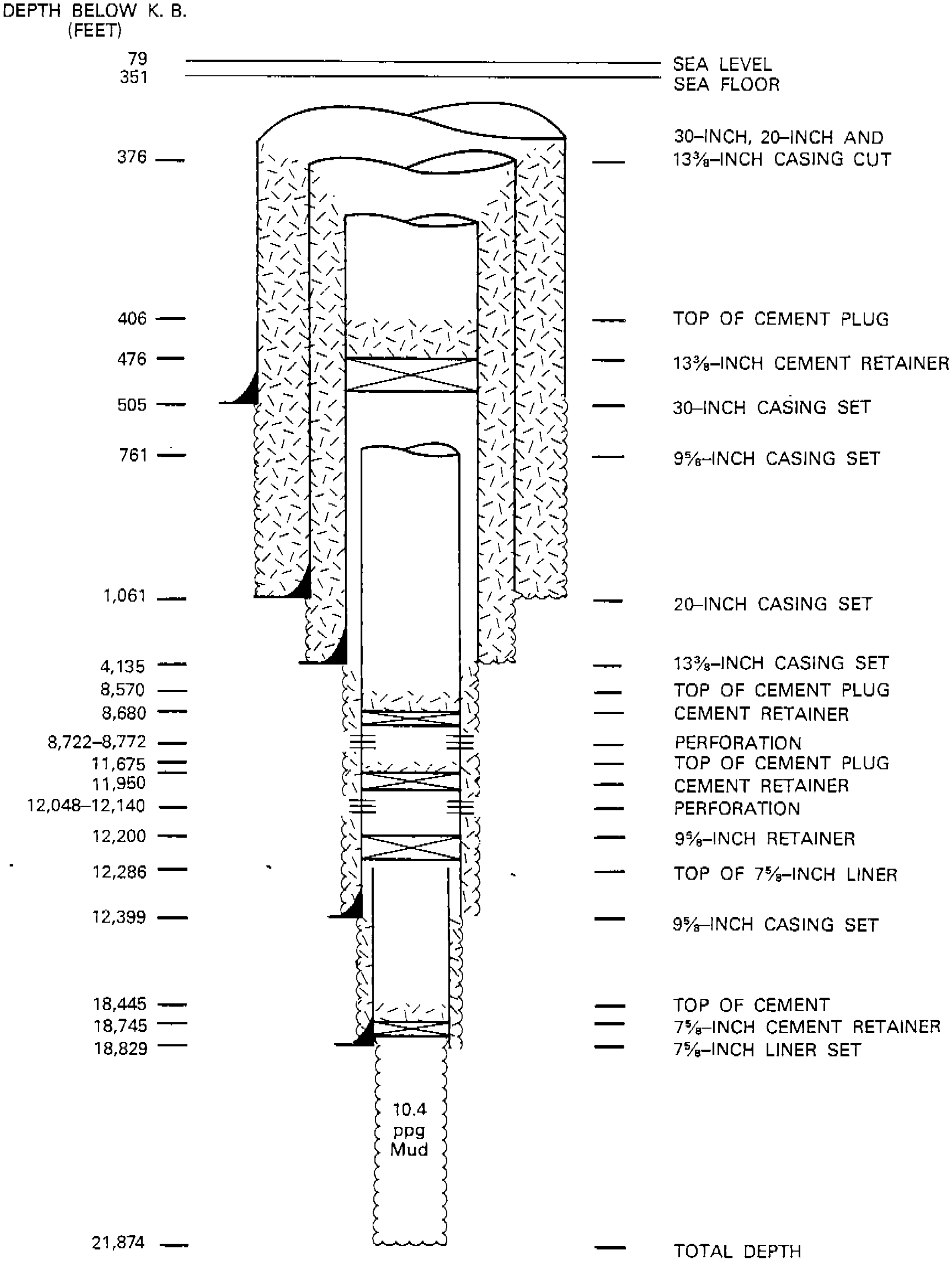


Figure 4.--Casing strings, and plugging and abandonment program, COST No. G-2 well.

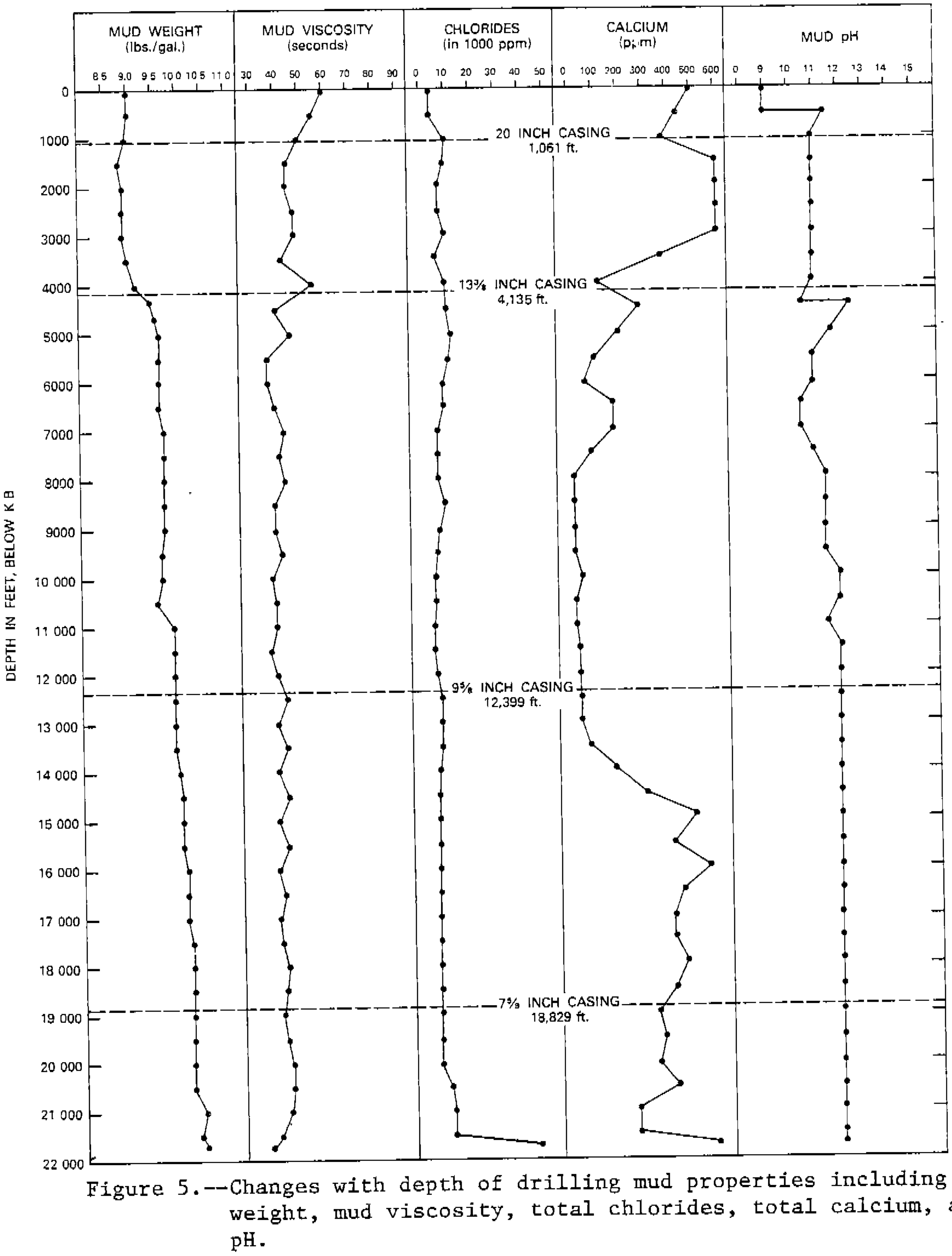


Figure 5.--Changes with depth of drilling mud properties including mud weight, mud viscosity, total chlorides, total calcium, and pH.

rest of the well. Mud-logging services were provided by Exploration Logging from 1,100 feet to total depth.

The cumulative cost for the G-2 well was $13.9 million. A breakdown of time spent on various activities in the drilling operation is given below:

ACTIVITY	HOURS	PERCENT OF TOTAL
Drilling	2095.0	36.5
Tripping	1367.5	23.8
Running and pulling BOP stack	297.0	5.2
Circulating and conditioning mud	251.0	4.4
Wire line logging	230.0	4.0
Testing BOP stack	187.5	3.3
Waiting on weather	184.5	3.2
Rig repair	126.0	2.2
Rigging up, running, & testing casing	120.0	2.1
Reaming	96.0	1.7
Conventional coring	70.0	1.2
Cementing	46.0	0.8
Cutting off drill line	32.0	0.6
Deviation survey	27.0	0.5
Other	603.5	10.5
TOTAL	5733.0	100.0

Samples and Tests

Drill cuttings for lithologic description were collected at 30-foot intervals from 1,100 to 7,990 feet and at 10-foot intervals from 7,990 feet to total depth. Another set of samples was collected at 30-foot intervals from 1,160 to 21,874 feet. These samples were sealed in cans at the well site and were later analyzed for detailed organic geochemistry.

Nine conventional cores were cut. The cored intervals and recoveries are given in the chapter on Core Descriptions and Analyses.

Sidewall cores were collected during four runs with the following results:

Run No.	Depth interval (ft)	No. Attempted	No. Recovered	Percent Recovered
1	1,061- 4,216	240	173	72
2	4,216-12,475	803	620	77
3	12,475-18,829	569	120	21
4	18,829-21,874	504	44	8.7
	TOTAL	2,116	957	45

Plugs taken from the conventional cores at approximately 1-foot intervals and 126 sidewall core samples were analyzed for porosity, permeability, and grain density. Thin sections of the conventional and sidewall cores were used for petrographic descriptions. Mineral content of selected cores and drill cuttings samples was determined by X-ray diffraction. The biostratigraphic analysis was based on conventional cores, 363 sidewall cores, 695 cuttings samples and a few junk basket samples.

Logging runs were made at depths of 4,216, 12,475, 18,829, and 21,830 feet. The section above 1,057 feet was not logged. Compensated Neutron-Formation Density Log (CNL/FDC), Dual Induction-Laterolog (DIL), Borehole Compensated Sonic Log (BHC), Long Spaced Sonic Log with Intergrated Travel Time (LSS), and Compensated Formation Density Log (FDC) were recorded on all runs. A Proximity Log-Microlog (MPL) obtained for the two intermediate depth runs was replaced by a Microlaterolog-Microlog (MLL) on the deepest run. Simultaneous Dual Laterolog (DLL) was run below 12,396 feet. Results of the Four-Arm, High-Resolution Continuous Dipmeter (HRD) runs between

4,120 and 21,791 feet were printed on a dipmeter arrow plot. Five runs of the Temperature Log, including two runs from 21,800 feet to surface, were recorded. A Dual Spacing Thermal Neutron Decay Time Log (TDT-K) was run between 4,000 and 10,000 feet. The Well Seismic Tool (WST) was run in conjunction with the seismic reference surveys (SRS). The cased hole between 8,200 and 12,224 feet was logged with the Cement Bond Log (CBL).

Only one sucessful drill-stem test was made, at 8,724-8,770 feet, through perforations in the 9 5/8-inch casing. Pressure was recorded and 15 gallons of formation water was recovered. Two tests attempted deeper in the well were unsuccessful.

Weather

Weather delays totaled 184.5 hours, 3.2 percent of the time on location. Most of the delays occurred during January and March.

Waves of 10 feet or more occurred on 17 days between January 5th and April 6th, but did not recur in the later months. Seven days with winds exceeding 45 knots, and 24 days with swells of at least 10 feet were reported during the first 3 months on location. The most extreme weather occurred on January 8 when wind speed of 70 knots and combined seas of 45 feet were reported.

LITHOLOGIC DESCRIPTION

By Edvardas K. Simonis

An interpretive lithologic log was prepared for the COST No. G-2 well by the Amoruso Group under contract to the Ocean Production Company. The drill cuttings were subsequently reexamined by U.S. Geological Survey geologists. A generalized stratigraphic column with summary lithologic description is given in plate 1.

Samples were collected at 30-foot intervals from 1,100 to 7,990 feet and at 10-foot intervals from 7,990 to 21,874 feet. Sample quality ranged from poor to good. Additional lithologic control was provided by 9 conventional cores and 957 sidewall cores. Petrographic thin sections of the conventional cores and of 131 sidewall cores were described by Core Laboratories, Inc.

In the following description, depths of lithologic boundaries were adjusted where possible to the depths recorded on geophysical logs. It is stressed that the lithologic description is only an interpretation mainly derived from examination of drill cuttings; it is not a result of direct observation of the drilled section.

From 1,100 to 1,550 feet the section consists of unconsolidated, coarse to granule-sized, rounded, quartz sand interbedded with gray, soft, clayey siltstone. Shell fragments and glauconite pellets are abundant. A glauconitic sand between 1,250 and 1,310 feet marks the unconformity between middle Eocene and Santonian (Upper Cretaceous).

Between 1,550 and 2,340 feet, Upper Cretaceous, light-gray calcareous claystone and clayey siltstone ranges to argillaceous chalky limestone. Glauconite, fragments of megafossils, foraminifera, ostracodes, carbonaceous plant fragments, fine mica, and pyrite concretions occur at numerous horizons.

The dominant lithology at 2,340-2,500 feet (lower Cenomanian) is fossiliferous limestone. It occurs in cuttings mainly as fragments of thick-walled shells. Fine to medium, calcite-cemented sandstone beds are present in the lower part of this sequence.

An Albian sandstone section occurs at 2,500-3,000 feet. The sandstones range from coarse to granule-sized, rounded, unconsolidated quartz sand to fine and medium, subangular to subrounded, moderately to well sorted, calcite cemented, friable to hard sandstone. Shell fragments, glauconite pellets, thin streaks of coal, and carbonaceous dark-gray shale occur at numerous horizons. Gray silty mudstone is interbedded with the sandstone and becomes dominant in the underlying Aptian sequence at 3,000-3,950 feet. The sandstone in this mudstone sequence is similar to that in the overlying sandy section but also includes gray, fine to medium, muddy friable wacke.

A Barremian section of limestone and shale occurs between 3,950 and 4,500 feet. The limestone types are bioclastic, partly oolitic grainstone, packstone, wackestone, and argillaceous micrite. The shale ranges from gray, fissile, in part silty, clay shale to light-gray, calcareous claystone and silty mudstone. A few beds of sandstone, glauconitic in part, are present in the upper part of the section.

Thick-bedded sandstone with shale and coal interbeds form the Hauterivian(?) to upper Berriasian(?) section between 4,500 and 5,320 feet. Much of the sandstone is poorly consolidated, very coarse- to medium-grained, and subrounded to subangular. Less common is very fine- to medium-grained angular to subangular, moderately to well-sorted sandstone which is tightly cemented by calcite and silica. Thin beds of coal are numerous between 4,950 and 5,080 feet where they are interbedded with dark lignitic shale, brown-gray shale and light-gray mudstone. From 5,320 to 5,750 feet, a Berriasian(?) transition zone between the overlying sandy section and the underlying calcareous unit consists of gray to light gray, silty, calcareous mudstone interbedded with a few sandstone and limestone beds.

A limestone section (5,750 to 6,920) feet straddles the Cretaceous-Jurassic boundary at 5,960 feet. It consists of light-gray and tan, clayey, micritic to chalky limestone interbedded with gray and dark-gray, silty, calcareous shale. Pyrite, shell fragments, and glauconite are present at some horizons. Sandstone beds are sparse. Contact with the underlying sandy unit is gradational.

The Upper Jurassic (Tithonian-Kimmeridgian) unit between 6,920 and 9,580 feet contains sandstone, red and gray shale, beds of oolitic limestone and streaks of coal. Most of the sandstone is white, fine- to medium-grained, subangular, moderately to well sorted, friable to tightly cemented by calcite. Muscovite, biotite, and chlorite are common. Some sandstone beds in the lower part of the sequence are stained red. The shale beds from 6,920 to 7,540 feet are gray to dark gray, silty and very calcareous in part. Red shales appear below 7,540 feet and are abundant below 7,840 feet. The most common limestone is oolitic and/or algal intraclast grainstone ranging to packstone and wackestone; some micrite and bioclastic limestone are also present.

A section dominated by oolitic limestone extends from 9,580 to 10,350 feet (upper Oxfordian). The grainstone is composed of brown-gray oolites and other peloids cemented by white to light-gray, finely crystalline calcite cement, which is sucrosic and in part friable. Size of the peloids ranges from approximately 0.25 to 4 mm and the mean size is 0.5 mm. Oolitic packstone is more common than grainstone in the lower part of the section. Subordinate rock types in this section are fine-grained, well-sorted sandstone, dark-gray clay shale, gray silty shale, and a few streaks of red shale.

Carbonate rocks also dominate the Oxfordian section from 10,350 to 10,820 feet, but the limestone there is mainly brown-gray, partly argillaceous micrite. A grainstone composed of oolites and coarse shell fragments occurs at 10,550-10,600 feet. Sandstone is sparse. Shale occurs as gray clay shale, gray silty shale, and light-gray, very calcareous claystone which ranges to very clayey micrite.

A shaly section from 10,820 to 11,325 feet, still in Oxfordian, contains a few beds of red shale in the top 50 feet. The dominant lithology is gray shale which ranges from nonclacareous to very calcareous. Micrite and biomicrite increase in abundance down-section. A few beds of very fine- to fine-grained sandstone are present. In the upper part of the section, shell fragments and pyrite are abundant; glauconite pellets, ostracodes and foraminifera are sparse.

A thick limestone sequence from 11,325 to 13,360 feet straddles the Upper Jurassic-Middle Jurassic boundary at 11,800 feet. Slightly argillaceous, brown-gray micrite is the most abundant rock type. Zones of oolitic grainstone and packstone occur at irregular intervals. Gray clay shale ranges to silty shale and very calcareous claystone; dark brown-gray shale is rare. Pyrite is common in much of the section. Stylolites and calcite-filled hairline fractures in slightly dolomitic limestone occur at a few intervals. Green tuff comprises as much as 5 percent of each sample collected between 11,720 and 11,900 feet and persists in trace amounts down to 12,100 feet. The tuff occurs as a green and gray vesicular devitrified glass(?) with mineral-filled vesicles, and as a pale green, very fine, felty groundmass containing fine elongate phenocrysts and dark-green clasts(?). Small fragments of green-gray tuff were recovered at 11,812 feet in the top part of conventional core 3.

From 13,360 to 13,625 feet, in Middle Jurassic, the section is characterized by brown-red sandstone, silty mudstone, and shale. The sandstone is very fine- to medium-grained, moderately sorted, cemented by silica and calcite, and is rich in chlorite and red oxidized biotite. Gray shale, gray micrite, and white sandstone occur in subordinate amounts. This sandy unit forms a major boundary within the Jurassic section between the overlying limestone-rich sequence, and the underlying thick section of anhydritic dolomite and limestone.

Limestone, dolomite, and anhydrite form the thick section at 13,625-18,750 feet. Dolomite and limestone occur in approximately subequal amounts. Anhydrite makes up 10-20 percent of the section, and shale less than 5 percent. The limestone appears to be mainly micrite, but the very indistinct nature of the oolites and other peloids, in the few zones where they were observed, indicates that more such zones may exist but were not recognized. The partly argillaceous micritic limestone ranges from light brown-gray to very dark brown-gray. Some limestone is recrystallized and dolomitized to varying extents and ranges to microcrystalline and fine crystalline dolomite with the same range of colors as the limestone. Anhydrite ranges from white, very fine crystalline to gray, translucent, medium and coarse crystalline; it also occurs as small patches and crystal laths in dolomite. Some anhydrite contains streaks of gray shale and dolomite. A thin layer of asphaltic material was encountered at 14,572 feet in core 5; asphaltic material was also visible in cuttings from other horizons.

From 18,750 to 18,910 feet, very fine- to fine-grained dolomitic sandstone and siltstone grade to sandy dolomite. Some of the hard and nonporous sandstone is cemented by silica.

A limestone section between 18,910 and 19,150 feet consists of dark-brown-gray argillaceous micrite, minor peloidal packstone, and dark-brown-gray calcareous silty shale. A pale-green-gray partly translucent shale coincides with a high gamma-ray reading at 18,960 feet and probably represents an altered very fine tuff or a tuffaceous shale.

Between 19,150 and approximately 21,800 feet is a sequence of dolomite, limestone, and anhydrite, interrupted at 20,600 to 20,710 feet by red shale and silty mudstone. The limestone is mainly micrite which ranges in color from light brown-gray to very dark-gray and dark-brown-gray; similarly colored dolomite ranges from microcrystalline to fine crystalline. Zones of dolomitized, very faint to distinct, oolite-peloid grainstone and packstone are common. The dolomite section below 20,710 feet becomes increasingly sandy, silty and pyritic, and contains a few beds of very fine- to fine-grained sandstone. Fair intercrystalline and vuggy porosity was noted in some dolomite cuttings below 20,900 feet, but the porosity was probably created during drilling and sample-washing operations by solution of salt from salt-filled vugs.

A core cut from 21,800 to 21,822 feet recovered anhydrite interbedded with limestone in which pellet molds and fractures are filled with halite. From 21,833 feet to total depth of 21,874 feet, a sharp increase in penetration rate, and a large increase in salinity of the drilling mud indicate that salt is the main lithology. Cuttings from that interval consist mainly of clear anhydrite crystals. The anhydrite crystals probably represent inclusions in salt which was dissolved during drilling and sample washing operations.

BIOSTRATIGRAPHY

By John W. Bebout

Age determinations for the COST No. G-2 well are based largely on the paleontologic analyses of 695 ditch cuttings samples and 363 sidewall core, conventional core, and junk basket samples conducted by International Biostratigraphers, Inc. (written communication, 1977). In addition, I made a palynologic study of numerous cuttings samples in order to verify the paleontologic data. In the discussions that follow, identifications and conclusions are those of International Biostratigraphers, Inc. (IBI), unless otherwise noted. The depths to the tops of the major biostratigraphic units identified in the COST No. G-2 well are as follows:

Depth (feet)	Epoch	Age
351	-sea floor, no samples collected -	
1,100	Miocene	Middle to late Miocene
1,255	Eocene	Late middle Eocene
1,310	Late Cretaceous	Santonian
1,760		Coniacian
2,090		Turonian
2,240		Cenomanian
2,600	Early Cretaceous	Albian
3,100		Aptian
4,040		Barremian
4,450?		Hauterivian-Valanginian
5,020?		Berriasian
5,960	Late Jurassic	Kimmeridgian-Tithonian
9,500?		Oxfordian
11,800	Middle Jurassic	Callovian

Age Determinations

The Tertiary and Upper Cretaceous rocks of the COST No. G-2 well were dated mainly on the basis of planktonic foraminifers. In the Lower Cretaceous and Jurassic sections, however, where only benthonic foraminifers were present, palynomorphs provided the principal means of dating.

In general, there is good agreement between age interpretations based on foraminifers, palynomorphs, and nannofossils. These data were combined to assign the "ages" discussed in the following section.

Tertiary

Middle to late Miocene (1,100-1,255 ft)

Sidewall core samples from this interval are barren of foraminifers. Cuttings samples, however, yielded Recent to middle Miocene planktonic species such as Globorotalia menardii, Orbulina universa, and Sphaeroidinella subdehiscens.

IBI did not process cuttings samples above 4,210 ft for palynomorphs, but they did examine one sidewall core from 1,250 ft. In that sample, they observed species of Pinuspollenites, Tsugaepollenites, Tilia, Carya, Liquidambar, and Compositae. From a cuttings sample at 1,160 ft, I observed a rich palynoflora which also includes Pterocaryapollenites stellatus, Graminae, Ilexpollenites sp., Chenopodipollis multiplex, Quercoidites sp. A, Alnipollenites speciipites, and rare specimens of the alga Pediastrum. Of special significance is the presence of Quercoidites sp. A; Williams and Brideaux (1975) stated that this species does not occur above the middle Miocene on the Grand Banks of Canada.

No nannofossils were recovered from samples taken within this interval.

Late middle Eocene (1,255-1,310 ft)

An excellent late middle Eocene forminiferal assemblage was recovered from a sidewall core at 1,283 ft, which includes such species as Truncorotaloides rohri, Globorotalia bullbrooki, and Globorotalia spinulosa.

In a cuttings samples from 1,280 ft, I observed specimens of Corylipollenites sp., Graminae, Corylipollenites simplex, Quercoidites henricci, and Tsugaepollenites igniculus. In addition, rare specimens of the dinoflagellate species Leptodinium maculatum and Planinosphaeridium membranaceum are also present. The highest occurrence of Leptodinium maculatum at this level confirms an age not younger than late Eocene.

Most of the nannofossil species present in a sample from 1,290 ft are also comparable with a late middle Eocene age interpretation. Specimens of Chiasmolithus oamaruensis are also present, however, and this species is generally considered to be restricted to the late Eocene, suggesting that this sample is near the middle Eocene-late Eocene boundary.

Late Cretaceous

Santonian (1,310-1,760 ft)

Sediments of latest Cretaceous age were not recognized in the COST No. G-2 well, and the Santonian strata are apparently disconformably overlain by Tertiary rocks.

The Santonian interval contains a diverse assemblage of planktonic and benthonic foraminifers, among which the species Globotruncana coronata, G. lapparenti, Sigalia deflaensis, and Globotruncana angusticarinata are particularly significant.

Three sidewall cores from this interval contain the dinoflagellate species Chatangiella victoriensis, Hystrichosphaeridium truncigerum, and Tanyosphaeridium variecalamum. Of these species, only C. victoriensis is believed to range above the Santonian.

The nannofossil species Lithastrinus grilli was also observed within this interval; this species has not been reported from post-Santonian sediments.

Coniacian (1,760-2,090 ft)

The top of the Coniacian is placed at the highest occurrence of the planktonic foraminifer species *Globotruncana schneegansi* and *G. sigali*.

Abundant dinoflagellate assemblages recovered from the interval were generally similar to those in the overlying Santonian sediments. Also present, however, is the pollen species *Complexiopollis funiculus*; according to Tschudy (1973), this species is not known to range above the Coniacian.

The nannofossil species *Lithastrinus floralis* is also present throughout this interval. This species is not known to range above the earliest Coniacian.

Turonian (2,090-2,240 ft)

The top of the Turonian stage is placed at the highest occurrences of the planktonic foraminifer species *Praeglobotruncana turbinata, P. stephani*, and *Hedbergella delrioensis*.

Most of the dinoflagellates in this interval are the same forms noted from the Coniacian and Santonian intervals. Significant, however, is the presence of the pollen species *Phyllocladidites inchoatus* and the dinoflagellate species *Litosphaeridium siphonophorum* in a sidewall core from 2,221 ft (I observed specimens of *P. inchoatus* from cuttings samples as high as 2,120 ft). Neither species has been reported from post-Turonian sediments.

The nannofossil species *Corolithion achylosum* is also present throughout this interval and has its highest occurrence at 2,184 ft. This species is not known to range above the Turonian.

Cenomanian (2,240-2,600 ft)

The top of the Cenomanian is placed at the highest occurrence of the foraminifer species *Rotalipora cushmani* in a cuttings samples from 2,270 ft. In addition, a sidewall core sample from 2,277 ft yielded a good Cenomanian foraminifer assemblage in which *Rotalipora cushmani*, *Praeglobotruncana* stephani, Heterohelix moremani, Gavelinopsis cenomanica, and Lenticulina nodosa are present. I have placed the top of the Cenomanian slightly higher in the well, however, because of the highest occurrence of the distinctive pollen species Perinopollenites elatoides in a cuttings samples from 2,240 ft. According to Singh (1971), this species has not been reported from sediments younger that Cenomanian.

Sidewall cores at 2,323 and 2,352 ft contain excellent dinoflagellate assemblages which include the species Epelidosphaeridia spinosa, Aptea eisenackii, Cribroperidinium edwardsii, and Cleistosphaeridium polypes. Of these species, only E. spinosa has been observed in post-Cenomanian strata.

Nannofossils were not useful in fixing the top of the Cenomanian because the critical interval was barren of these fossils.

Early Cretaceous

Albian (2,600-3,100 ft)

Using the highest occurrences of the foraminifer species Espistomina chapmani and Gavelinella intermedia in cuttings samples, the top of the Albian is placed at 2,600 ft. This interpretation appears to be supported by a rich palynological assemblage which includes the spore and pollen species Concavissimisporites punctatus, Foveotriletes subtriangularis, Camarozonotriletes insignis, and Cicatricosisporites hallei. Also present were the dinoflagellate species Chlamydophorella nyei, Odontochitina costata, Cydonephelium vannophorum, and Spinidinuim vestitum. Especially important is the highest occurrence at this level of F. subtriangularis; Singh (1971) reported that this species does not range above the Albian.

Throughout the Lower Cretaceous section, nannofossil recovery was sporadic and the ranges of observed forms were difficult to determine with accuracy.

Aptian (3,100-4,040 ft)

Foraminifers occur only sporadically in the Lower Cretaceous section of this well, and species of known stratigraphic significance are rare. For these reasons, foraminifers were not used to pick the top of the Aptian, although serveral Aptian-Albian forms such as *Hedbergella infracretacea*, *Epistomina spinulifera*, *Marsonella oxycona*, and *Epistomina caracolla* have their highest occurrence at about 3,000 ft.

The top of the Aptian is placed at the highest occurrence of the dinoflagellate species "*Cyclonephelium*" *tabulatum*, a form which is believed to be restricted to that stage. Other dinoflagellate species having their highest occurrences at this level include *Hystrichosphaerina schindewolfii*, *Achomosphaera neptuni*, *Apteodinium granulatum*, and *Cordosphaeridium eoinoides*. In addition, I observed the following species of spores and pollen within the same interval: *Acanthotriletes* cf. *A. varispinosus*, *Trilobosporites humilis*, *Cerebropollenites mesozoicus*, *Exesipollenites tumulus*, *Corolina meyeriana*, and *Corolina torosus*. Of these species, however, only *Cerebropollenits mesozoicus* has not been observed in post-Aptian sediments on the Atlantic OCS.

Barremian (4,040-4,450 ft)

The occurrence of the foraminifer species *Choffatella decipiens* in a sample from 4,065 ft, suggests a late Barremian to early Aptian age. Dinoflagellates, however, were used to pick the top of the Barremian at 4,100 ft. This is above the highest occurrence of the species *Muderongia* cf. *M. mcwhaei*, *Pseudoceratium gochtii*, and *Pseudoceratium pelliferum*. *Pseudoceratium nudum* was observed slightly lower, and neither of the last two species is known from post-Barremian strata. I have placed the top of the Barremian slightly higher in the well, based on the highest occurrence of the species *Muderongia simplex* in a cuttings samples from 4,040 ft. This species has also not been reported from sediments younger than Barremian.

Hauterivian-Valanginian (4,450?-5,020? ft)

IBI was very reluctant to assign stage names to the Lower Cretaceous interval in the COST No. G-2 well solely on the basis of dinoflagellates. However, I observed specimens of Muderongia cruicis in a cuttings sample from 4,450 ft, and this species is not known from post-Hauterivian sediments. Because of a lack of age-diagnostic fossils, no attempt was made to separate the Hauterivian stage from the Valanginian stage.

Berriasian (5,020?-5,960 ft)

The highest occurrence of the nannofossil species Polycostella senaria is at 5,800 ft. Because this species is not known to range above the Berriasian, the top of that stage could be placed at that level, but much of the section above that depth was barren of nannofossils.

At 5,020 ft, I observed a marked increase in the relative abundance of the spore species Rogalskisporites cicatricosus var. rotundus. Although Singh (1971) observed rare specimens of this species in sediments younger than Berriasian, I have not observed it in sediments younger than Berriasian on the Atlantic OCS. As a consequence, I have tentatively placed the top of the Berriasian at 5,020 ft.

Late Jurassic

Tithonian-Kimmeridgian (5,960-9,500 ft)

The Jurassic-Cretaceous boundary is placed between the lowest occurrence of Polycostella senaria at 5,896 ft and the highest occurrence of Polycostella beckmanii at 5,960 ft. This may be a questionable practice, however, because these species overlap in both the Tithonian and the Berriasian (W. Steinkraus, oral communication, 1978). Nonetheless, an excellent dinoflagellate assemblage of definite Late Jurassic age was recovered from a sidewall core at 5,962 ft, which includes such species as Gonyanlacysta cf. G. nuciformis, G. cf. G. serrata, Leptodinium clathratum, Prolixosphaesidium *granulosum*, *Systematophora areolata*, *Ctenidodinium panneum*, and *Hystrichosphaeridium petilum*.

The foraminifer species *Everticyclammina virguliana* and *Psuedocyclammina litus* have their highest occurrence at 6,348 ft, and a number of *Lenticulina* species such as *L. brueckmanni*, *L. muensteri*, *L. quenstedi*, and *L. involvens* first appear somewhat lower. These forms also suggest a Kimmeridgian-Tithonian age for this interval.

Oxfordian (9,500?-11,800 ft)

IBI suggested a top for the Oxfordian above the highest occurrence of such definite Oxfordian dinoflagellates species as *Gonyaulacysta* cf. *G. dangeardi*, *Ctenidodinium* cf. *C. tenellum*, and *C. ornatum* at 9,500 ft. The Oxfordian-Kimmeridgian boundary could occur quite a bit higher, however, because the foraminifer species *Pseudocyclammina jaccardi* has its highest occurrence at 7,690 ft. Although this species occurs as high as the Kimmeridgian, it is considered a good Oxfordian marker in some areas. In addition, the dinoflagellate species *Gonyaulacysta jurassica* occurs in the cuttings up to 7,260 ft, and Bujak and Williams (1977) reported that this species does not range above the Oxfordian on the eastern Canadian OCS. This species is known from younger sediments elsewhere, however.

Middle Jurassic - Late Triassic?

Stages undifferentiated (11,800 ft-T.D.)

Bujak and Williams (1977) recognized a *Valensiella vermiculata* zone on the Scotian Shelf and Grand Banks which they consider to be Callovian (Middle Jurassic) in age. This zone is characterized, in part, by the dinoflagellate species *Valensiella ovalum*, *V. vermiculata*, and "*Lithodinia Jurassica*" (a junior synonym of *Ctenidodinium ornatum*). *V. ovalum* and *L. jurassica* have their highest occurrences at about 9,700 ft in the COST No. G-2 well (both are known to range into the Oxfordian), and *V. vermiculata* tops at 10,000 ft.

Although *V. vermiculata* is not known to range above Callovian, extension of its range may be warranted: IBI reports the occurrence of foraminifer species *Pseudocylammina jaccardi* in a sidewall core from 11,345 ft; this species is not known from sediments older than Oxfordian.

The position of the Callovian-Oxfordian boundary is, therefore, difficult to place precisely. It is tentatively placed in this report below the lowest abundant occurrence of species of the genus *Systematophora* (around 11,600 ft).

The deepest core samples which IBI could date with confidence came from 13,240 to 13,380 ft, in which the dinoflagellate species *Pareodinia ceratophora* is common. This species is not generally believed to range into pre-Middle Jurassic sediments, although Bujak and Williams (1977) do show its range extending slightly into the Early Jurassic. In addition, a sidewall core sample from 18,412 ft yielded an assemblage of generally Middle Jurassic aspect containing the dinoflagellates *Gonyaulacysta* sp., *Lithodinia?* sp., and *Pareodinia ceratophora*. Also in the same sample were such spore and pollen species as *Corolina torsus*, *Callialasporites dampieri*, *Inaperturopollenites turbatus*, and *Neoraistrickia*? sp.

Recovery below 18,412 ft was very poor, and only a few specimens of the genus *Corolina* were observed in place. Although no definite Early Jurassic sediments were identified, the presence of this Late Triassic to Late Cretaceous genus does not preclude the possibility that the COST No. G-2 well could have penetrated rocks as old as Late Triassic.

PALEOENVIRONMENTAL ANALYSIS

By LeRon E. Bielak and Edvardas K. Simonis

Sample Preparation

Paleoenvironmental interpretations for the COST No. G-2 well are based on the nature of planktonic and benthonic microfossil assemblages--primarily foraminifera, calcareous nannofossils and dinoflagellates--and on lithofacies. Drill cuttings were collected and examined in 30-foot composite samples from depths of 1,100 to 21,870 feet. All 695 cuttings samples were analyzed for foraminifera. None of the cuttings were processed for nannofossil analysis. Palynological samples were taken in 90-foot composites from drill cuttings from 4,210 ft to total depth. In addition, 363 sidewall core (SWC), conventional core, and junk basket samples were processed and examined. Of 281 sidewall cores 177 were processed for foraminifera, 141 for nannofossils and 220 for palynomorphs. Seventy-six core chips were examined for palynomorphs and 33 were processed for nannofossils.

Depositional Environments

The upper 155 ft of sampled sediments in the well (1,100-1,255 ft), dated as middle to late Miocene, was deposited in a middle continental shelf environment in water depths of 100-300 ft. The zone shows little faunal diversity but contains typical middle shelf genera, such as "Robulus," *Cibicides*, and *Dentalina*.

An upper middle Eocene glauconitic sandstone between 1,255 and 1,310 ft is bracketed above and below by disconformities. This thin interval contains fauna indicating a shelf-edge environment or slightly deeper. Nearly half of the foraminiferal species reported from this interval are planktonic. Several benthonic foraminifera, including *Cibicides robertsonianus* and *Gyroidina girardana*, suggest shelf edge or deeper water habitats. Water depths are estimated to be in excess of 600 feet.

Below the unconformity at 1,310 ft, down to approximately 2,500 ft, Coniacian through Cenomanian (Upper Cretaceous) sediments were deposited in an outer shelf environment (300-600 ft water depths). Both foraminiferal and nannofossil assemblages are common through this interval, as are marine palynomorphs. Planktonic foraminifera continue to constitute nearly half of the genera observed. However, upper slope benthonic foraminifera are not present. Typical outer shelf benthonics include the genera "Robulus", *Kyphopyxa*, *Planulina* and *Gavelinella*. The lithology, ranging from clayey siltstone and argillaceous chalky limestone to fossiliferous limestone interbedded with calcareous sandstone, is generally consistent with the outer shelf environment indicated by microfossils.

The foraminiferal assemblages in cuttings samples point to middle shelf conditions for the mainly Albian interval from approximately 2,500 to 3,000 ft. However, foraminifera and nannofossils are sparse or lacking in the sidewall cores taken from this interval. There is also a slight increase in terrestrial palynomorphs and a corresponding decrease in marine palynomorphs. The foraminiferal assemblages in the cuttings may well be an artifact of caving. Actual depositional conditions were probably marginal marine punctuated by several middle-shelf marine incursions, as indicated by the mixed lithology of sandstone (in part glauconitic and fossiliferous), gray silty mudstone, and thin streaks of coal associated with dark-gray, carbonaceous shale.

In the section between 3,000 and 4,200 ft (mainly Aptian), marginally developed middle to outer shelf foraminiferal faunas are found in SWC and cuttings samples. Nannofossil assemblages increase notably as terrestrial palynomorphs decline in SWC samples. The middle to outer shelf depositional environment is also indicated by the lithology which is gray, glauconitic, silty mudstone, with minor arenite, wacke, and limestone.

Only 4 species of foraminifera are represented in the cuttings from 4,200 to 5,300 ft. Foraminifera and nannofossils are totally missing from SWC samples through this section. Marine palynomorphs are less common than terrestrial forms. Lithologically, from 4,200 to 4,500 ft, limestone ranging from bioclastic and oolitic grainstone to argillaceous micrite, interbedded with gray shale and mudstone indicates shallow-water marine environment. A mainly nonmarine to marginal marine conditions are indicated for 4,500-5,300 ft by thick-bedded, coarse-grained sandstone interbedded with coal, lignitic shale, and light-gray mudstone.

Middle to outer shelf conditions prevailed during deposition of the basal Lower Cretaceous and uppermost Jurassic sediments between 5,300 and 6,900 ft. The development of nannofossil floras is fair; marine palynomorphs again increase and the families nodosariidae and ceratobuliminidae are the dominant foraminifera. The lithology at 5,300-5,750 ft is mainly gray, silty, calcareous mudstone; at 5,750-6,900 ft, clayey, micritic to chalky limestone predominates.

Below 6,900 ft foraminiferal faunas decline and are more arenaceous. Marine palynomorphs again decline and nannofossils become sparse. From ±6,900 to 11,350 ft paleontological analysis indicates marginal or nonmarine conditions. From 11,350 ft to total depth, foraminiferal samples are barren; rare occurrences are probably due to caving except for specimens found in thin section from 18,700 to 18,746 ft. Seventy four of 77 nannofossil samples from 6,900 to 20,724 ft are barren. Palynological samples are poor to good from 6,900 to 13,287 ft; terrestrial palynomorphs are somewhat more common than marine forms. Palynological samples from 13,287 to 20,724 ft are barren, with the exception of the 18,412 ft SWC sample. Because micropaleontologic indicators are sparse, environments of deposition below 6,900 ft are estimated mainly from lithofacies.

From 6,900 to 9,600 ft, shallow marine to nonmarine conditions are indicated by interbedded sandstones, gray and red shales, thin beds of oolitic limestone, and in the lower part of the section, streaks of coal. The red shales are concentrated mainly below 7,800 ft.

Straddling the Upper/Middle Jurassic boundary at 11,800 ft, the section from 9,600 to 13,360 ft consists of limestone, in part oolitic, interbedded with sandstone and gray shale. Deposition in shallow marine waters is interpreted. Tuff recovered at 11,812 ft, in the top part of conventional core 3, and scattered in drill cuttings from 11,720 to approximately 12,000 ft indicates nearby volcanic activity at approximately the Middle to Late Jurassic transition.

The deposition of the brown-red sandstone, silty mudstone, and shale between 13,360 and 13,650 ft suggests mainly nonmarine environments.

The thick Middle to Lower Jurassic section from 13,650-21,833 ft is characterized by dolomite, limestone, anhydrite, and anhydritic carbonates. The carbonates range from mudstone facies to oolitic-peloidal packstones and grainstones. Depositional environments are interpreted to range from very shallow restricted marine for the mudstone facies, to higher-energy shallow marine for the oolitic grainstone facies, and to supratidal flats or sabkha for the anhydrite and anhydritic carbonates.

The salt encountered near the bottom of the well (21,833-21,874 ft) is tentatively correlated with the Lower Jurassic Argo Salt on the Scotian Shelf of Canada, and is interpreted to reflect restricted rift valley conditions during the initial rifting stage of the Atlantic.

CORRELATION WITH OTHER WELLS

By Thomas W. Judkins, Edvardas K. Simonis, and Bruce A. Heise

The COST No. G-2 well was correlated with the COST No. G-1 well (pl. 2), and with seven other wells in the Baltimore Canyon area and the Scotian Shelf of Canada (pl. 3). Owing to the great distances between wells, the lithologic correlations must be considered as only tentative.

The Scotian Shelf of Canada is the nearest area to the Georges Bank where formal rock-stratigraphic units have been defined for the Mesozoic and Cenozoic section by McIver (1972), Jansa and Wade (1975), and Given (1977).

An attempt is made here to project the Canadian formations to the Georges Bank Basin and the Baltimore Canyon Trough. Despite the many problems in such long-distance correlations, there is a gross similarity of sedimentary sequences between the Scotian Shelf of Canada and the U.S. Atlantic margin, a similarity which appears to reflect the tectonic events associated with the post-Paleozoic evolution of the North Atlantic Ocean.

Triassic(?): Jansa and Wade (1975) and Ballard and Uchupi (1975) respectively discussed Triassic grabens developed on the western Nova Scotia Shelf and in the Georges Bank area. The grabens resulted from precursor stresses of thermal events in the lithosphere which ultimately led to the separation of North America and Africa. During this "rift-valley" stage, volcanic material and continental clastics derived from doming of the continental crust were deposited within the grabens.

The Triassic age of the sedimentary rocks in the Georges Bank area is inferred by Ballard and Uchupi (1975) from correlations of seismic profiles from the Triassic Newark Group. However, neither COST well drilled on the Georges Bank penetrated rocks of unequivocal Triassic age.

Jurassic: The most distinguishing stratigraphic feature of the Georges Bank wells is the thick Jurassic section (pls. 2 and 3), ranging in thickness from approximately 10,000 feet in the G-1 well to 16,000 feet in the G-2 well. The Jurassic section penetrated in the correlated wells on the Scotian Shelf is thinner, but Jurassic sediment thicknesses in excess of 15,000 feet are reported in the deeper parts of the Scotian Basin (Jansa and Wade, 1975).

Of the selected wells, only the Mohawk and the COST G-1 penetrated the entire sedimentary section reaching basement respectively at 6,930 feet and 15,600 feet. Salt was encountered near total depth in the G-2 and the Mohican wells.

The earliest confident age date based on palynology in the G-2 well is Middle Jurassic (Bebout, this volume). The presence of older rocks in the G-2 well can only be surmised at this time on the basis of stratigraphic position and lithologic correlation. The salt encountered near total depth in the G-2 well is tentatively correlated with the Lower Jurassic Argo Salt in the Scotian Basin.

The Lower(?) to Middle Jurassic section overlying the salt in the G-2 well consists mainly of anhydritic dolomite and limestone (pls. 1 and 2), which are overlain by gray to red sandstones.

The G-1 well, located updip from the G-2, contains considerably more clastics in its Lower(?) to Middle Jurassic section than the G-2 well (pl. 2). However, the lower 3,600 feet of the section in the G-1 well contains thick sequences of dolomite interbedded with anhydrite overlain by sandstone and variegated shale.

The Mohican well on the Scotian Shelf contains a Lower Jurassic sequence of salt and carbonates similar to that found in the G-2, though the carbonate section is much thinner. Here the Lower Jurassic Iroquois Formation overlies the Argo salt. McIver (1972) described the Iroquois Formation as being dominated by a brown, anhydritic dolomite.

Given (1977) described the Mohican Formation as a texturally immature sandstone interbedded with varicolored shale. The Mohican is of Early to Middle Jurassic age and overlies the Iroquois Formation.

In the Scotian Basin, the Mohican is overlain by limestones of the Middle Jurassic to lowest Cretaceous Abenaki Formation or its clastic equivalents: the Mohawk, Mic Mac, and Verrill Canyon Formations. An excellent description and interpretation of the Abenaki Formation were published by Eliuk (1978), who stressed the complex relationships between the Abenaki and its siliciclastic equivalents.

In the G-1 and G-2 wells, the Jurassic section above the Mohican-equivalent clastics appears to be correlative to the Abenaki and Mic Mac or Mohawk Formations (pls. 2 and 3). The relationship between the Mic Mac and Mohawk equivalent rocks is unclear. In the G-2 well the Abenaki Formation, which contains a tongue of Mohawk-Mic Mac clastics is approximately 7,500 feet thick, whereas in the Scotian Basin, the Abenaki section reaches a maximum of only "more than 4,100 feet thick" (Eliuk, 1978, p. 429).

Minor amounts of tuff and/or volcanic clasts within the Jurassic section were reported in the Mohawk well by Bhat and others (1975), in the Oneida well by Shell Canada Ltd. (1970a), and in the G-2 well by Simonis (this volume). In the Mohawk well, position of the volcanic material within the Jurassic section is not specified by Bhat and others (1975), but the volcanic components are probably not older than Middle Jurassic--the oldest Mesozoic rocks encountered in the well; in the Oneida well "volcanic grains (basalt?)" and "numerous glass shards" were reported by Shell Canada Ltd. (1970a) in 3 sidewall cores recovered between 12,767 and 13,283 feet (Middle Jurassic Abenaki and Mohican Formations); in the COST G-2 well, a tuff occurs in the Abenaki Formation near the Middle/Upper Jurassic boundary (pl. 1).

Cretaceous-Cenozoic: The Lower Cretaceous rocks are of somewhat similar thickness in the Georges Bank Basin, the Baltimore Canyon Trough, and the Scotian Basin except for the relatively thin section in the Mohawk well, and the extremely thick deltaic sequence in the Sable Island area (pl. 3). The Upper Cretaceous section, on the other hand, is generally thinner in the Georges Bank Basin than in the adjoining basins.

In the Scotian Basin, the Lower Cretaceous is typified by a thick sandstone and shale sequence characterized by abundant sandstone (McIver, 1972). The age-equivalent section in the Georges Bank Basin and Baltimore Canyon Trough consists of similar rocks. However, in the Sable Island area the main deltaic sandstones are in the Mississauga Formation (mainly Neocomian), whereas in the Baltimore Canyon Trough the thickest-bedded sandstones occur in the Logan Canyon equivalent section (Aptian to lower Cenomanian).

Siliciclastic sediments continue to dominate the Upper Cretaceous through Cenozoic in the Georges Bank Basin and Baltimore Canyon Trough, but, except for the G-1 well, shale dominates over sandstone. Limestone, including chalk, is also present in the G-2, B-2, and B-3 wells. The Upper Cretaceous to Tertiary sediments in the Scotian Basin consist of mudstone, shale, argillaceous siltstone and fine-grained sandstone, and chalk or marl (McIver, 1972). The Cenozoic sediments in the Georges Bank wells are much thinner than in the other correlated wells.

No regional correlations were attempted for the Cretaceous Dawson Canyon and younger formations in this preliminary correlation summary; however, tentative correlations of these younger rock units between the G-1 and G-2 wells are shown in plate 2.

SEISMIC VELOCITY AND REFLECTION CORRELATION

By Hans H. Waetjen

The COST No. G-1 and G-2 wells, drilled 42 statute miles apart, can be correlated seismically using USGS lines 1, 12, 77-1, and 77-2. Figure 6 shows the location of both COST wells and seismic lines. Schlee and others (1975) interpreted the seismic section for USGS line 1 across Georges Bank and noted five continuous seismic events (horizons) across the section. The upper four horizons also correlate with lithologic boundaries in both the G-1 and G-2 wells, as shown in plate 4. Geologic ages given in this report to the horizons differ from those of Schlee because paleontologic age dates are now available from the wells. The following discussion describes these seismic horizons and their inferred correlation with the COST No. G-2 and compares the seismic velocities from well surveys to those from line 77-2. In this chapter, depths are given in feet below sea level.

Horizon 1 occurs in the G-2 well at 770 milliseconds (ms) or 2,310 feet depth near the Turonian-Cenomanian (lower part of the Upper Cretaceous). The horizon is represented in the well by a change downwell from calcareous claystone and siltstone to shelly limestone with interbedded sandstone. The same reflector ties near the boundary between conglomeratic sandstone and a thick shale at 2,157 feet (690 ms) in the G-1 well.

Horizon 2 is Late Jurassic (Tithonian) in age and occurs at 1,630 ms (6,440 feet depth) in the G-2. It approximates the break between thin beds of sandstone and shale and massive chalky limestone. In the G-1, horizon 2 occurs near the interface between shaly sandstone and a 200-foot-thick shale.

Horizon 3 correlates with the Middle Jurassic section in the G-2 at 2,570 ms or 13,135 feet depth. It probably represents the change downwell from a series of massive limestones to sandstone and shale a little deeper, at 13,350 feet. This same lithologic change occurs where horizon 3 intersects the G-1 at 2,360 ms or 11,404 feet. Although the seismic reflector

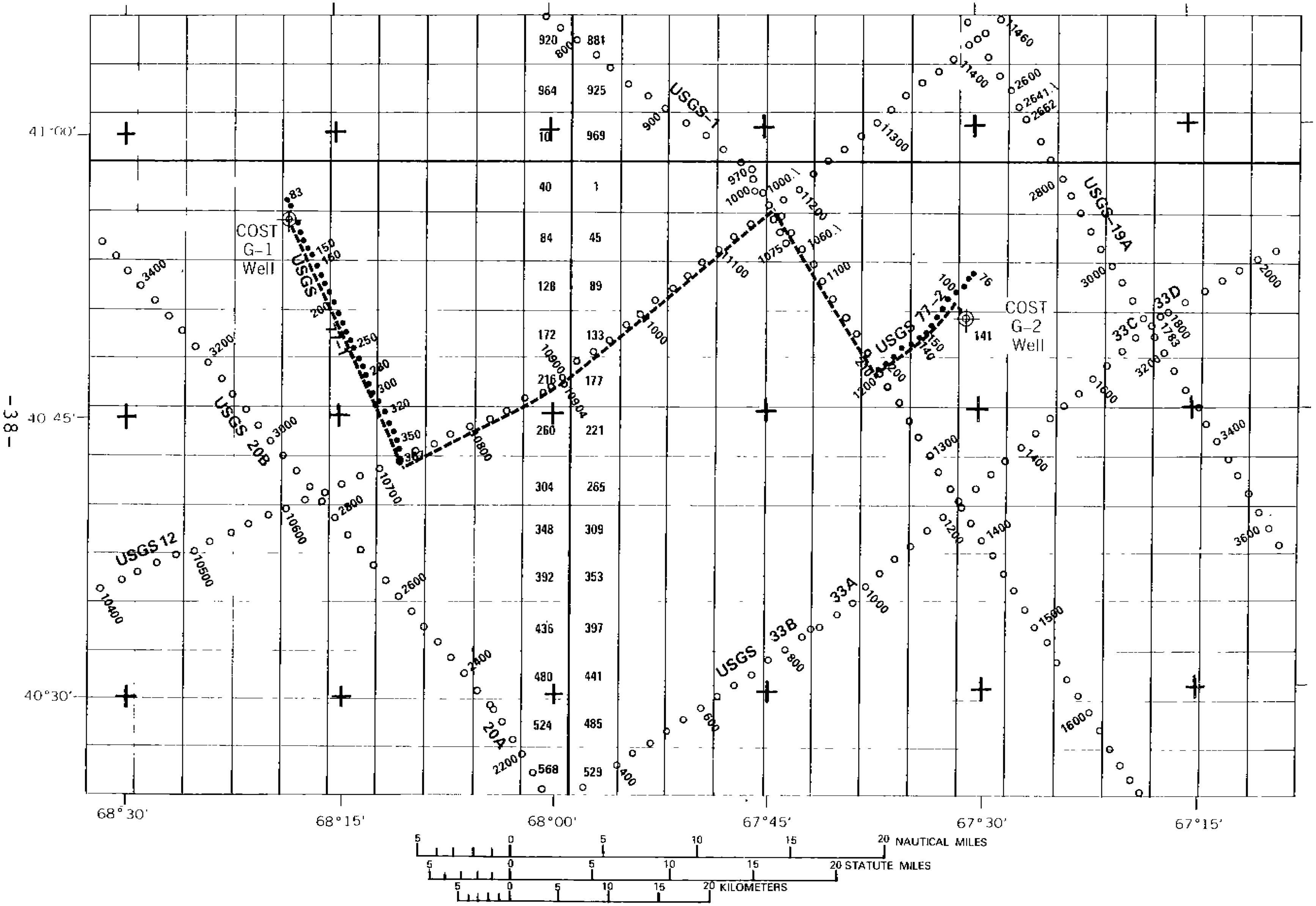


Figure 6.--Location map of USGS seismic lines in the vicinity of the COST No. G-1 and G-2 wells. Dashed line shows segmments of seismic lines used for correlation of the two wells.

represents similar lithologic changes in both wells, the amplitude of the waves forming the reflector is somewhat higher in the G-2 well.

Horizon 4 occurs at 3,150 ms (18,890 feet) in the G-2 and represents a change from dense limestone and dolomite to a 450-foot-thick zone of dolomitic sandstone and siltstone. The same horizon occurs in the G-1 at 2,670 ms or 14,104 feet and represents a change from dolomite to a thick bed (300 feet) of sandstone and siltstone. The reflector for this horizon changes amplitude and wave character considerably between the two wells. The reflector is generally of very low amplitude except on segments of USGS lines 1 and 12 where it is strong. Near the G-2 location, the amplitude is so low as to be barely discernible.

Analysis of seismic sections between the two wells (pl. 4) indicated no major stratigraphic breaks except for two faults on line 77-1. The four horizons thus appear continuous, except where noted, and no correlation problems were encountered. Even though slightly incorrect velocity values could cause errors in depth values used for the lithological correlation, the apparent changes in reflector character between the wells are assumed to indicate changing lithology, not possible miscorrelations.

USGS line 77-2, which ties the COST No. G-2 well near Shot Point 104, was used for a comparison of velocity data between the line and the well. The seismic velocity analysis on line 77-2 has been interpreted and converted to time-depth. In figure 7, resulting curve is compared to the time-depth curve derived from the uphole velocity survey of the G-2 well made by Seismic Reference Service, Inc. The two curves are nearly identical.

Interval velocities are compared in figure 8. Considering that only 10 interval velocity values could be calculated from the velocity function on line 77-2, the two functions are in fair agreement. The much higher interval velocity when first penetrating the limestone section near 12,000 feet stands out on both surveys.

Figure 9 shows time-depth curves and figure 10 interval velocities derived from the uphole velocity surveys of the G-1 and G-2 wells. The

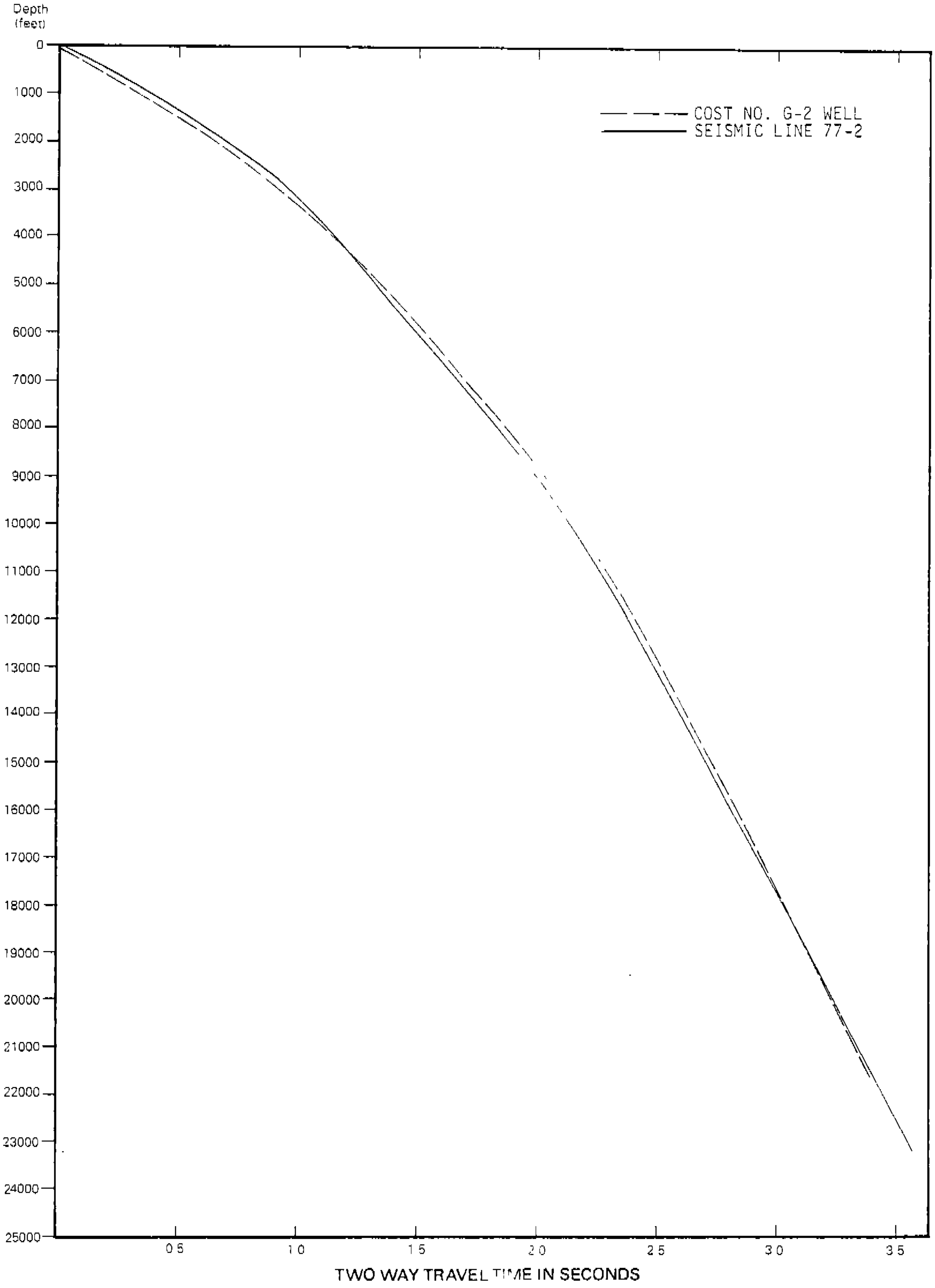


Figure 7.--Comparison of time-depth curves from velocity survey of the COST No. G-2 well, and from seismic data of USGS line 77-2 near shot point 104.

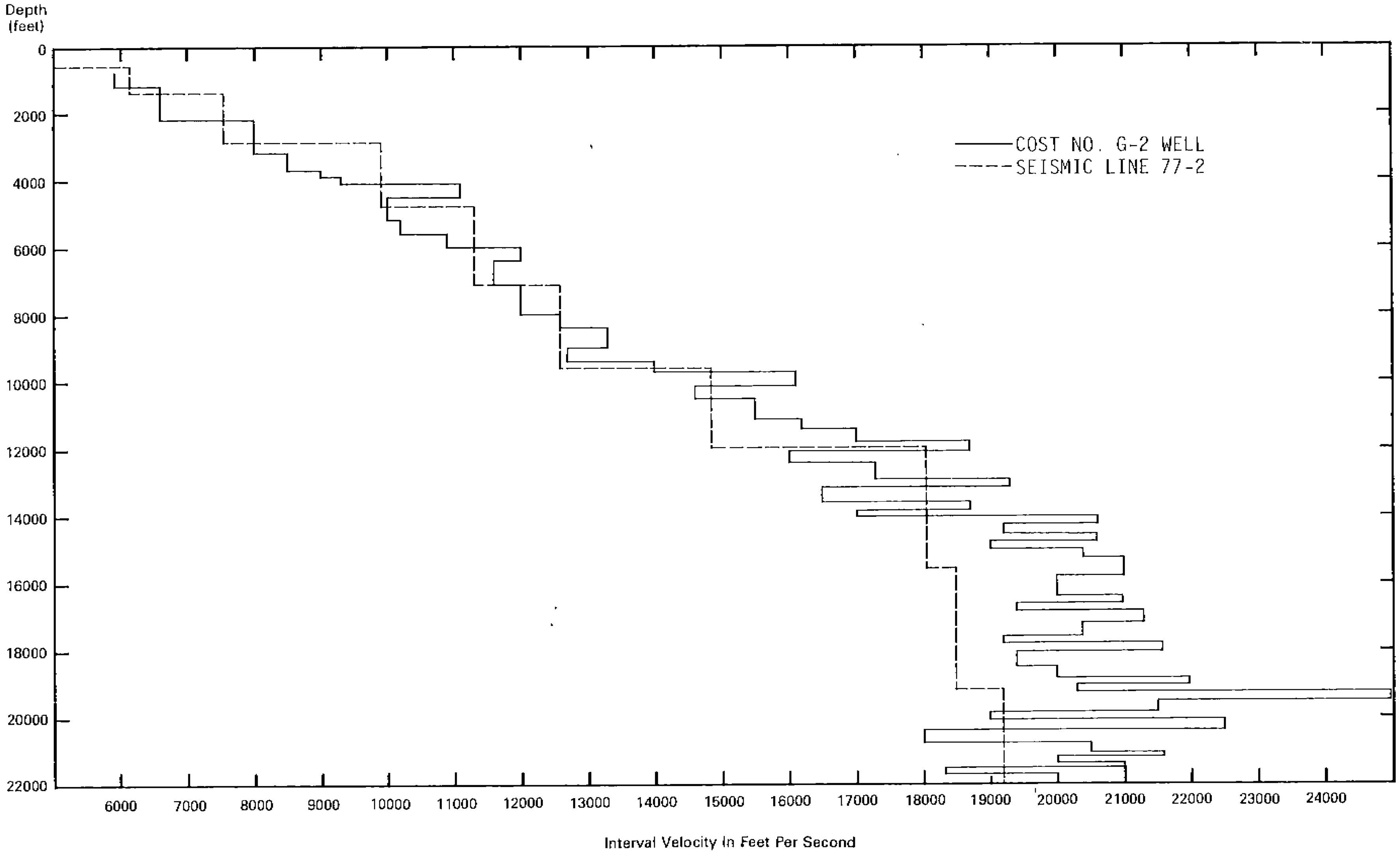


Figure 8.--Comparison of interval velocities from COST No. G-2 well and USGS seismic Line 77-2 near shot point 104.

time-depth curves (fig. 9) indicate slightly lower average velocities in the G-2 than in the G-1 well, due in part to deeper water at the G-2 location. However, most interval velocities (fig. 10) are higher in the G-2 well, reflecting the higher carbonate content there.

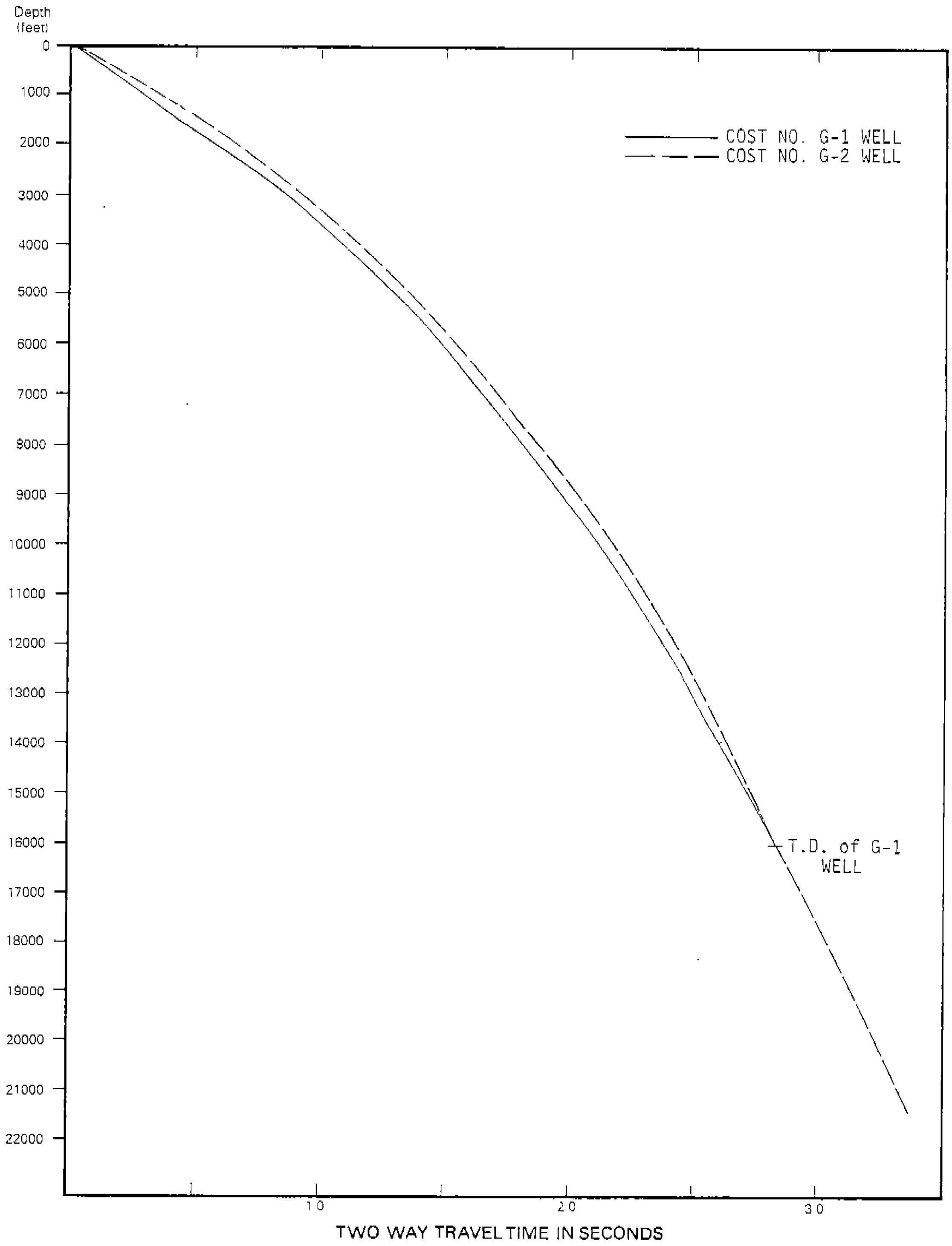


Figure 9.--Comparison of time-depth curves from velocity surveys of COST No. G-1 and G-2 wells.

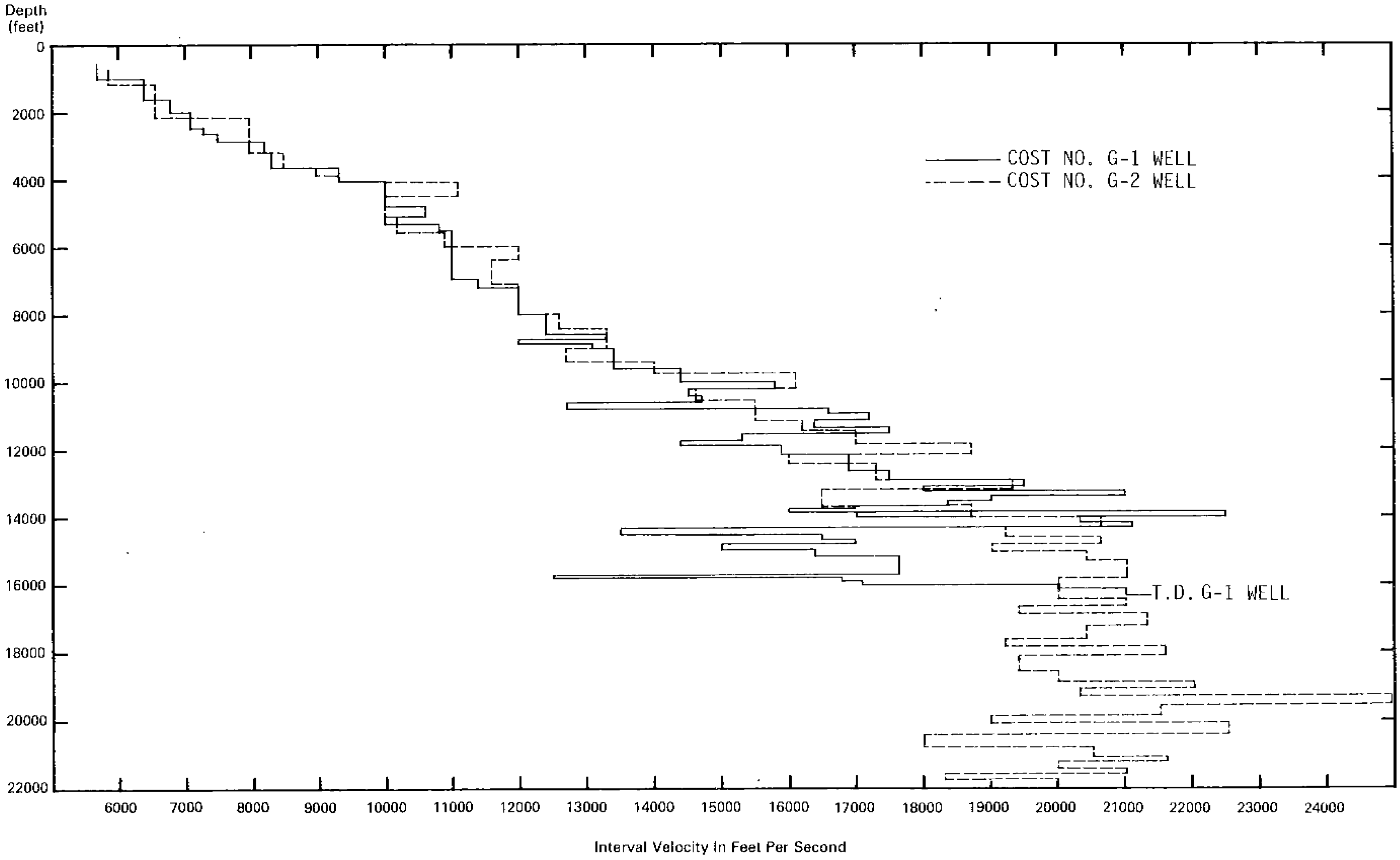


Figure 10.--Comparison of interval velocities for the COST No. G-1 and G-2 wells.

INTERPRETATION OF GEOPHYSICAL LOGS

By Stephen E. Prensky

Schlumberger Ltd. ran the following geophysical ("electric") logs in the COST No. G-2 well for the purposes of petrophysical analysis.

Log	Depth interval (feet)
Dual Induction-Laterolog (DIL)	1,057-21,798
Dual Laterolog (DLL)	12,396-21,796
Compensated Neutron-Formation Density (CNL-FDC)	1,057-21,794
Borehole Compensated Sonic (BHC)	1,057-21,781
Long Spaced Sonic (LSS)	1,057-21,781
Proximity-Microlog (PML)	4,120-18,829
High Resolution Dipmeter (HDT)	4,120-21,791
Thermal Neutron Decay Time (TDT)	4,000-10,000
Temperature	0-21,800
Velocity Survey	1,057-21,800

These data (except for the Temperature and Velocity Survey) were prepared both in analog format (diazo prints) and in digital format (magnetic tapes). A lithology (mud) log, a drilling pressure log, and a pressure analysis log were prepared by Exploration Services Inc.

Log quality is generally good except for run 5, 18,811-21,798 ft of the DIL gamma-ray, which apparently failed locally possibly due to the high temperatures encountered. Hole conditions, indicated by the caliper on the CNL-FDC log, were intermittently poor. Severe washout occurs throughout the length of the well, hampering accurate log analysis and in one case, 19,315-19,430 ft, no analysis was made. Hole washout above 5,500 ft occurs primarily in the unconsolidated sands, whereas below 5,500 ft hole washout occurs in shaly zones. Observation of tool response indicates that large fluctuations occur at depths where hole size exceeds bit size by 2.5 inches, and data from the porosity tools (BHC and in particular the FDC-CNL) are unreliable for these depths.

Schlumberger notes that on run 2 of FDC-CNL the gamma-ray trace is 4 ft shallow of the other curves. On the final digital data, depth adjustment was made and all log traces are tied in to the DIL log.

Although water saturations were not computed for this study, mention is made of a discrepancy in determination of water resistivity (Rw) of formation fluids. Rw is generally calculated using the spontaneous potential (SP) curve and for the interval 8,700-8,800 ft was calculated at 0.085 ohm at an equivalent temperature of 75°F. Laboratory analysis of fluid recovery made during a drill-stem test of the interval 8,724-8,770 ft gave an Rw at 75°F of 0.15 ohm. The difference between the two Rw values for this interval may be due to problems with multivalent ions.

Analysis

Porosity values were computed at 1-foot increments for: (a) all input data; and (b) data considered more reliable, i.e., where hole size is less than the sum of bit size + 2.5 inches. For purposes of analysis, the well was divided into intervals, according to: (1) dominant lithology--sandstone-shale, limestone or dolomite (indicated on the lithology log); and (2) drilling conditions (mud weight and bit size).

The value for interval matrix density used in calculating porosity from FDC bulk density data was selected after examining data from core analysis. Table 1 summarizes rock properties determined for both sidewall cores and conventional cores by Core Laboratories, Inc. (1977a). For purposes of this study it is assumed that the porosities obtained from the conventional core material are close approximations to the in situ effective porosity. Both the core descriptions and the X-ray diffraction analyses (made by Core Laboratories on selected samples) indicate that the carbonate intervals are lithologically complex: one lithology grades into another and cements are varied and gradational. The interval matrix density values (table 2) were

Table 1. Grain density and porosity data for cores from the COST NO. G-2 well.

Cored depth (ft) below KB	Lithology (core description)	Core type	Core No.	Cut (ft)	Recovered (ft)	Grain density (gm/cc)	Average porosity (percent)	Number of samples
1,117 - 2,050	Uncon ss, clayst	SWC	-	-	-	2.58	22.0	1
2,371 - 2,508	Ls, ss	SWC	-	-	-	2.53	34.7	2
2,584 - 4,069	Ss, mudst, calc	SWC	-	-	-	2.55	30.6	18
4,178 - 4,446	Ls, sh	SWC	-	-	-	2.65	23.6	4
4,510 - 5,229	Uncon ss, sh, calc	SWC	-	-	-	2.64	25.6	20
5,312 - 5,554	Mudst w/ls	SWC	-	-	-	2.67	19.8	4
6,235 - 7,236	Ls, calc sh	SWC	-	-	-	2.62	27.6	5
7,376 - 9,576	Ss, sh, calc	SWC	-	-	-	2.64	24.4	38
8,736 - 8,787.5	Ss, sh	CON	1	51.3	51.3	2.68	11.1	41
9,636 -13,170	Ls, sh	SWC	-	-	-	2.66	16.2	17
10,960 -11,007	Ls, w/ss	CON	2	47	47	2.71	0.8	8
11,812 -11,864	Ls, w/ss	CON	3	52	52	2.70	0.9	21
13,235 -13,289.5	Ls, silty	CON	4	54.5	54.5	2.71	0.6	8
13,531	Ss, sh	SWC	-	-	-	2.60	12.5	1
14,548 -14,598	Ls, dol, anhy	CON	5	50	48.1	2.82	1.1	8
14,248 -18,507	Ls, dol, anhy	SWC	-	-	-	2.70	10.9	7
18,700 -18,750	Ls, dol, sandy	CON	6	50	47.1	2.73	0.7	14
20,540 -20,575	Dol, anhy	CON	7	35	34.3	2.80	0.8	6
21,240 -21,300	Dol, anhy, sandy	CON	8	60	59	2.83	1.1	16
21,771	Dol, anhy, sandy	SWC	-	-	-	2.65	9.5	1
21,800 -21,822	Dol, anhy	CON	9	22	19.5	2.78	3.9	8

Key

ss - sandstone
sh - shale
clayst - claystone
mudst - mudstone
ls - limestone

calc - calcareous
dol - dolomite
anhy - anhydrite
SWC - sidewall core
CON - conventional (diamond) core

w/ - with
uncon - unconsolidated

Table 2. Interval porosity averages (percent) calculated from geophysical logs.
[Lithology abbreviations explained in table 1. All,-- average for all values within interval; 2.5,-- average of values only at depths where hole size less than sum of bit diameter and 2.5 inches]

Depth (ft) below KB	Lithology	Density														Neutron		Sonic		Sonic matrix (micro sec/ft)
		2.65		2.66		2.68		2.71		2.75		2.80		2.87						
		All	2.5	All	2.5	All	2.5	All	2.5	All	2.5	All	2.5	All	2.5	All	2.5	All	2.5	
1,059- 2,300	Uncon ss, sh, calc	37.5	18.6	-	-	38.6	19.3	-	-	-	-	-	-	-	-	53.4	30.2	42.1	22.4	55.5
2,331- 2,510	Ls, ss	28.4	28.4	-	-	29.7	29.7	30.9	30.9	-	-	-	-	-	-	40.8	40.8	40.8	40.8	47.6
2,511- 3,950	Uncon ss, sh, calc	29.9	27.7	-	-	31.1	28.9	-	-	-	-	-	-	-	-	46.3	43.5	35.5	33.1	55.5
3,951- 4,500	Ls, sh	21.6	21.8	-	-	23.0	23.2	24.3	24.6	-	-	-	-	-	-	38.0	37.0	30.6	30.2	47.6
4,501- 5,750	Uncon ss, sh, mudst calc	16,5	20.4	-	-	18.0	21.8	-	-	-	-	-	-	-	-	37.7	38.4	29.1	30.9	55.5
5,751- 7,120	Ls, ss, calc sh	5.2	6.1	-	-	6.9	7.8	8.6	9.4	-	-	-	-	-	-	30.0	24.0	21.8	17.3	47.6
7,121- 9,580	Ss, sh, calc	18.7	-0.8	17.8	1.4	-	-	-	-	-	-	-	-	-	-	33.0	7.7	16.8	-0.3	55.5
9,581-13,350	Ls, sh	-	-	-	-	5.8	0.6	7.5	2.4	-	-	12.1	7.2	-	-	12.6	9.5	9.4	8.2	47.6
13,351-13,630	Ss, sh	-0.1	-3.4	-	-	3.3	0.1	-	-	-	-	-	-	-	-	12.7	8.8	6.6	3.5	52.5
13,361-18,720	Ls, w/ dol, anhy	-	-	-	-	-	-	-6.9	-9.3	-	-	-1.5	-3.8	2.3	0.1	0.9	0.9	1.9	2.1	47.6
18,721-18,910	Dol, ss	-	-	-	-	-	-	-0.7	-0.7	-	-	4.4	4.4	7.9	7.9	4.0	4.0	4.6	4.6	43.5
*18,911-20,115	Ls w/dol, anhy	-	-	-	-	-	-	-8.7	-9.1	-	-	-3.3	-3.6	0.6	0.2	2.8	2.8	2.9	3.0	43.5
20,116-20,460	Ls w/dol, anhy	-	-	-	-	-	-	-	-	-2.9	-3.1	0	-0.2	3.7	3.5	3.2	3.6	3.3	2.1	47.6
20,461-21,792	Dol, ss w/anhy	-	-	-	-	-	-	-9.1	-9.8	-	-	-3.6	-4.3	0.2	-0.4	5.3	4.8	4.9	4.5	43.5
21,793-21,830	Halite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

*no calculations made for 19,136-19,430 ft, due to hole washout.

chosen after simulation work using the core porosities and the well log data for the same interval. Matrix travel times chosen for calculating sonic porosities are the standard values for "clean" (that is, pure) lithologies in microseconds/ft: unconsolidated sands 55.5; consolidated sands with silica or calcite cement 52.5; limestone 47.5; dolomite 43.5. Sonic porosities have been corrected for undercompaction using a compaction factor determined from the travel time in "clean" shale intervals. Average porosities determined from each tool (FDC, CNL and BHC) for each interval examined are summarized in table 2. The very low value for Neutron porosity for the interval 13,361-18,720 ft reflects the fact that most Neutron porosity readings from 13,650 to 18,250 ft are in the range of 0 to -1.5 porosity percent. A negative value for neutron porosity indicates that the matrix used by Schlumberger (limestone for this log) does not accurately reflect the lithology being logged. These negative values imply that the interval is lithologically more like a sandstone, i.e., less carbonate and more silica. Effective porosity for each depth was calculated and the interval averages and matrix density used in the calculations are presented in table 3. Effective porosity was obtained by subtracting the volume of shale (VSH) from a weighted average porosity value obtained from corrected CNL and FDC porosities. This procedure used shale and "clean" matrix values determined from the gamma-ray trace and cross-plots. (The DIL gamma-ray was used except for the interval 18,811-21,799 ft where the FDC-CNL gamma-ray trace was used.) The major sources of error in calculating effective porosity in this study are these shale and matrix values. Both core descriptions and X-ray diffraction analyses indicate complex lithologies, particularly in the carbonate intervals. There are no zones of pure matrix (limestone or dolomite) of sufficient thickness to provide reliable tool response. Similarly, the shale intervals are frequently calcareous or dolomitic, and usually very thin, resulting in approximations of true shale response.

Effective porosity was calculated as a means for estimating reser-

Table 3. Summary of effective porosity and porosity-feet calculated from geophysical logs
[Lithology abbreviations explained in table 1. a,-- average for all samples where volume of shale is less than 50 percent. b,-- average for samples where hole size is less than bit size + 2.5 inches and volume of shale is less than 50 percent]

Depth (ft) below KB	Lithology	Matrix density (gm/cc)	Effective porosity %		Porosity-Feet							
					>15%		>10%		>6%		>3%	
			a	b	a	b	a	b	a	b	a	b
1,059- 2,330	Uncon ss, sh, calc	2.65	21.5	18.3	898	672	1007	750	1029	766	-	-
2,331- 2,510	Ls, ss	2.71	21.2	26.2	-	-	-	-	146	145	146	145
2,511- 3,950	Uncon ss, sh, calc	2.68	21.1	8.0	412	393	458	438	497	477	-	-
3,951- 4,500	Ls, sh	2.71	13.0	19.0	-	-	-	-	358	282	375	294
4,501- 5,750	Uncon ss, sh, mudst, calc	2.65	20.5	7.8	349	335	411	378	501	408	-	-
5,751- 7,120	Ls, ss, calc sh	2.71	4.4	8.6	-	-	-	-	484	125	773	157
7,121- 9,580	Ss, sh, calc	2.66	16.7	18.6	1587	787	1776	946	2026	1128	-	-
9,581-13,350	Ls, sh	2.71	4.2	4.0	-	-	-	-	141	17	257	50
13,351-13,630	Ss, sh	2.68	2.4	1.7	0	0	1	1	34	30	-	-
13,361-18,720	Ls w/dol, anhy	2.71	0.3	4.4	-	-	-	-	80	16	91	22
		2.77	0.6	5.1	-	-	-	-	197	46	242	68
18,721-18,910	Dol, ss	2.87	3.1	4.9	-	-	-	-	11	11	100	100
18,911-20,115	Ls w/dol anhy	2.87	2.3	2.1	-	-	-	-	40	32	150	139
20,116-20,460	Ls w/dol anhy	2.75	0.6	1.6	-	-	-	-	3	3	11	10
20,461-21,792	Dol, ss w/anhy	2.87	1.6	2.6	-	-	-	-	69	47	206	180
21,792-21,830	Halite	-	-	-	-	-	-	-	-	-	-	-

voir potential. The counts of porosity-feet given in table 3 are provided for this same reason. These data are the summation of the number of interval-feet with an effective porosity greater than the indicated porosity limit and a VSH less than 50 percent. Reservoir potential, on a porosity basis, is excellent above 10,000 ft, both in the clastic sections and in the carbonates, and fair to poor below that depth.

Dipmeter

A Schlumberger Arrow Plot computed dipmeter is available for the depth interval 4,120-21,791 ft. The plotted dips are most consistent and uniform in the carbonate intervals, whereas dips in the clastic intervals frequently are scattered (variable in amount and direction) probably due to internal sedimentary structures. Regional dip for the well is 1-4° S-SW-W. Dipmeter data are summarized below. (Lithology abbreviations are explained in table 1.)

Depth (ft)	Lithology	Dip (degrees)	Direction	Comments
4,120- 5,250	Ss, sh	1-3	S-SW	Scatter in the clastics.
5,250- 7,300	Ls, ss, sh	1-2	SW-SE	Do.
7,300- 9,500	Ss, sh	1-4	SE-SW	Do. Possible fault at 7,460 ft.
9,500-11,650	Ls, sh	1-3	S-SW	
11,650-11,720				Structural change, possible fault or unconformity.
11,720-15,100	Ls, sh w/dol, anhy	1-4	SW	
15,100-16,000	Ls, w/dol, anhy	3-4	W-SW	
16,000-18,600	Ls, w/dol, anhy	2-4	W-SW	
18,600-18,700	Ls, w/dol, anhy			No dips recorded. Dips above and below are similar.
18,700-19,800	Ls w/dol, anhy	2(?)	SW	Scattered.
19,800-21,800	Ls, dol, anhy	1-3	W-SW	

GEOTHERMAL GRADIENT

By Bruce A. Heise and Dana S. Jackson

The geothermal gradient for the COST No. G-2 well was calculated by two methods: bottom hole temperatures recorded during the various log runs, and temperatures recorded on the temperature log (fig. 11).

Thermometers were run at four logging depths. At the shallowest logging depth (4,200 feet), temperatures did not reach 100 °F--the minimum temperatures the thermometers were designed to record. At each of the remaining logging depths, temperatures recorded on the various log runs were increasing as the time since termination of mud circulation (TTC) was increasing. In order to obtain comparable temperatures, the writers used logarithmic regression to extrapolate the bottom hole temperatures at each logging depth to a common TTC of 25 hours. The following "corrected" temperatures were obtained:

Average logging depth (feet)	"Corrected" temperature (°F)
4,200	100 (estimated)
12,500	212
18,800	306
21,790	360

By applying linear regression to these data a geothermal gradient was calculated to be 1.46 °F/100 feet (26.6 °C/km) of depth. The value is relatively high in comparison to the gradient of 1.34 °F/100 feet (24.4 °C/km) computed using 42 temperatures taken from the temperature log which was run from total depth to surface (fig. 11).

A comparison of the G-2 well with other COST wells on the U.S. Atlantic continental margin is given in the following table.

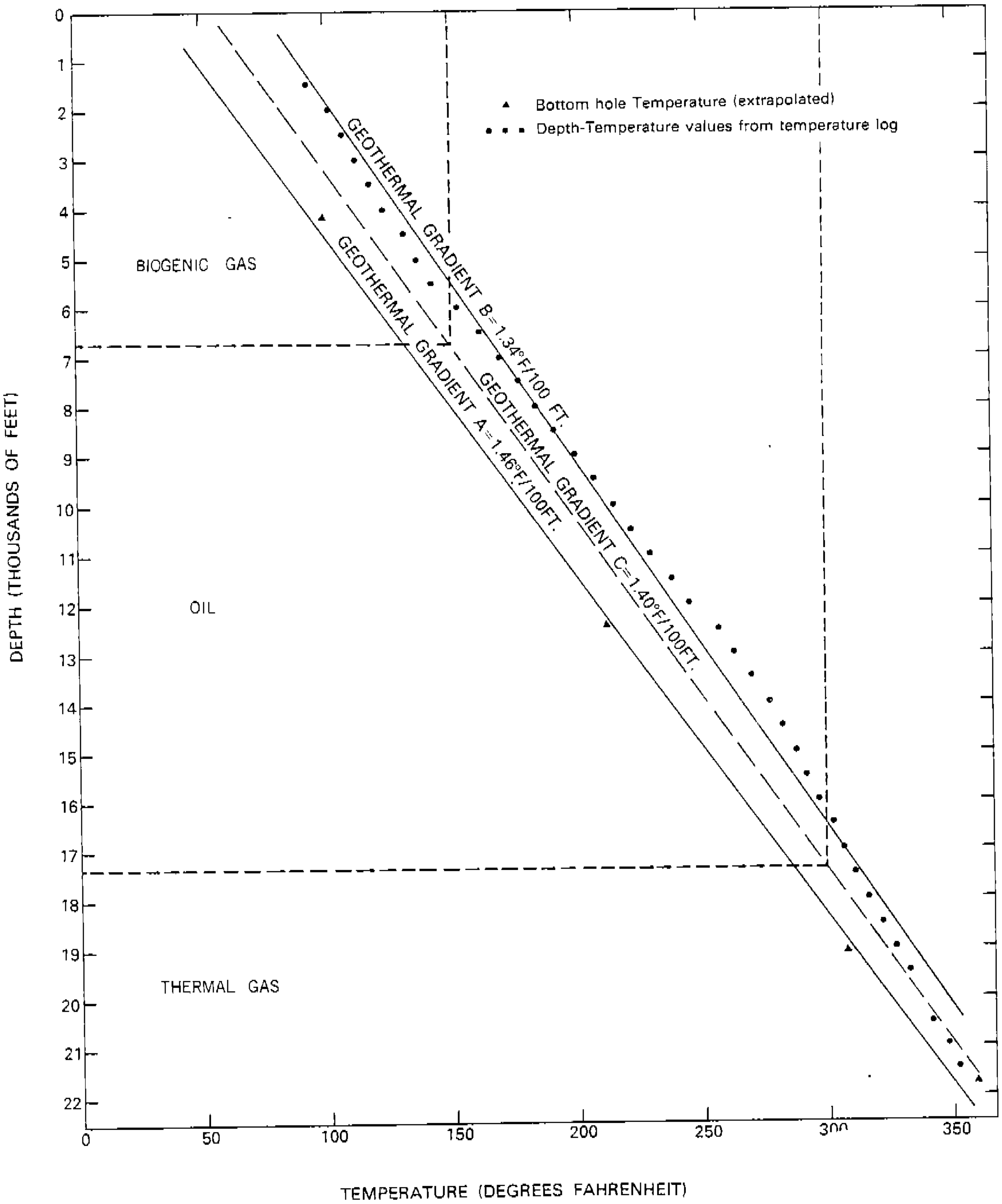


Figure 11.--Geothermal gradient estimates for the COST No. G-2 well. Gradient A is derived from extrapolated bottom-hole temperatures; gradient B is defined by temperature values from the temperature log; gradient C is an average of A and B.

Well	Geothermal gradient	
	°F/100 ft	°C/km
Georges Bank G-2	1.5 (1.3)	27 (24)
Georges Bank G-1	1.2 (1.3)	22 (24)
Baltimore Canyon B-2	1.3 (1.3)	24 (24)
Baltimore Canyon B-3	1.2	22
Southeast Georgia Embayment GE-1	0.9 (0.9)	16 (16)

In this table, geothermal gradient values computed from bottom hole temperatures are given first, followed in parentheses by values obtained from the temperature logs. Gradient values are rounded off because it is not certain how closely the temperature readings reflect the true formation temperatures.

Pusey (1973) has shown that most of the world's oil is found in reservoirs having temperatures between 150 and 300 degrees F. Assuming the true geothermal gradient for the G-2 well lies midway between the gradients derived from the bottom hole temperatures and the temperature log (fig. 11) this concept can be used to estimate hydrocarbon occurrence. Thus the 150° to 300° F "oil window" in the G-2 well is estimated to be between 6,700 feet and 17,300 feet. This contrasts significantly with the geochemical data interpreted by Smith (this volume) to indicate oil generation conditions occuring only between approximately 14,000 feet and total depth (21,874 feet).

DRILL-STEM TESTS

By Orrin W. Gilbert

Three drill-stem tests (DST) were conducted in the G-2 well after drilling was completed.

A drill-stem test was attempted from the shoe of the 7 5/8-inch casing at 18,829-21,872 feet but failed because of mechanical problems. The lower portion of the hole was not retested. The second DST tested perforations from 12,050 to 12,140 feet in the 9 5/8-inch casing. This test also failed, owing to a leak in the drill string. This interval was not retested and was plugged.

The third drill stem-test was made through perforations in the 9 5/8-inch casing from 8,724 to 8,770 feet. The tester was open for 2 hours and a light blow of air was recorded; no gas was recovered. The tester was closed for an 1-hour final shut-in period. The fluid rise was reversed out. A 15-gallon sample from a sample chamber above the test tool recovered salt water which was analyzed to be 32,000 ppm chlorides with no show of hydrocarbons. The test tool pressure charts indicated that the tool was open with the following pressures recorded: initial hydrostatic mud pressure, 4,752 psi; initial flow pressure, 2,274 psi; final flowing pressure, 3,404 psi; final shut-in pressure, 3,665 psi; final hydrostatic mud pressure, 4,708 psi.

CORE DESCRIPTIONS AND ANALYSES

By Marion J. Malinowski

Nine conventional diamond cores and 126 sidewall cores were recovered from the COST No. G-2 well and analyzed by Core Laboratories, Inc. (1977a). Table 4 lists the conventional cores including their dominant lithologies and ranges of porosity and permeability. Table 5 lists the porosities and permeabilities of analyzed sidewall cores. Figures 12 and 13 show the range of porosity and permeability values of the conventional cores and sidewall cores in the COST No. G-2 well. Figure 14 shows core porosities plotted against core permeabilities. In general, porosity decreases gradually with depth; however, there is an abrupt decrease in porosity at 10,000 feet. There are few sandstone intervals below 10,000 feet. Most of the porosity values given for the conventional cores from 10,000 to 21,822 feet are below 5 percent. Values greater than 5 percent porosity for conventional and sidewall cores in this interval may reflect development of secondary porosity in carbonates or vuggy porosity created during drilling by salt being washed out from salt-plugged vugs. Figure 13 shows that permeability also decreases dramatically at 10,000 feet. Most permeability values are 0.1 md. or less from 10,000 to 22,822 feet. Values greater than 0.1 md. reflect fracturing or salt wash-out. Figure 14 shows that when core porosities are plotted against core permeabilities, the majority of samples having porosity values less than 18 percent have permeability values less than 0.2 md.

The lithologic summaries of the nine conventional cores are based on lithologic and thin section description provided by Core Laboratories, Inc. (1977a). Positions of the cores in the stratigraphic column are shown in plate 1.

Core 1 (fig. 15) is predominantly sandstone alternating with silt and conglomerate. The sandstone is light gray to gray, medium to fine grained, well-indurated, slightly calcareous, and fossiliferous in places. It contains some black interlaminations of shale, and streaks of dark silt along wavy bedding planes. Minor amounts of pyrite, hornblende and hematite are

Table 4.--Record of conventional cores, their dominant lithologies and ranges of porosity and permeability, COST No. G-2 well.

Core No.	Cored interval (feet)			Core recovery (feet)	Porosity (percent)			Permeability (md)			Dominant lithology
	Top	Bottom	Feet Cut		High	Low	Mean	High	Low	Mean	
1	8,736	8,787.3	51.3	51.3	21.2	1.8	11.1	211.0	0.01	23.6	Sandstone and shale
2	10,960	11,007	47	47	1.7	0.2	0.8	0.15	0.01	0.05	Limestone and shale
3	11,812	11,864	52	52	9.3	0.3	1.3	1.4	0.01	0.09	Limestone with interbedded shale and siltstone
4	13,235	13,289.5	54.5	54.5	1.1	0.02	0.6	0.01	0.01	0.01	Limestone and anhydrite
5	14,548	14,598	50	48.1	2.8	0.3	1.1	0.03	0.01	0.01	Anhydrite with some limestone and dolomite
6	18,700	18,750	50	47.1	1.2	0.4	0.7	0.04	0.01	0.01	Limestone and siltstone
7	20,540	20,575	35	34.3	1.4	0.2	0.8	0.01	0.01	0.01	Anhydrite and dolomite
8	21,240	21,300	60	59	4.8	0.1	1.1	0.26	0.01	0.03	Dolomite
9	21,800	21,822	22	19.5	11.0	0.6	3.9	67	0.01	11.2	Gypsum, anhydrite, limestone, salt

Table 5.--Porosities, permeabilities, and dominant lithologies of sidewall cores from COST No. G-2 well. [Permeability values determined empirically. Data from Core Laboratories, Inc., 1977a].

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Dominant lithology
1,305	22.	1.7	Sand
2,371	37.	125.	Sand
2,508	32.4	6000.	Sand
2,584	31.2	3800.	Sand
2,621	36.2	2500.	Sand
2,662	30.9	2700.	Sand
2,664	32.6	2750.	Sand
2,842	22.7	43.	Sand
2,856	31.2	210.	Sand
2,920	23.3	6900.	Sand
2,923	31.2	7100.	Sand
3,192	21.9	3.5	Sand
3,280	39.0	44.	Sand
3,303	34.2	2400.	Sand
3,378	32.9	3500.	Sand
3,395	30.	4500.	Sand
3,516	30.5	42.	Sand
3,650	29.4	1.0	Siltstone
3,702	33.8	2.1	Siltstone
3,862	30.3	240.	Sandstone
4,069	30.4	6900.	Sandstone
4,178	21.5	1.3	Sandstone
4,345	13.0	0.1	Limestone
4,403	30.6	330.	Sandstone
4,446	29.1	51.	Sandstone
4,510	26.2	100.	Sandstone
4,556	31.7	320.	Sandstone
4,588	25.9	86.	Sandstone
4,618	19.4	0.9	Sandstone
4,630	28.2	42.	Sandstone
4,660	29.2	510.	Sandstone
4,716	30.1	225.	Sandstone
4,776	25.0	1250.	Sandstone
4,856	15.8	0.1	Siltstone
4,917	23.3	0.4	Sandstone
5,002	28.7	73.	Sandstone
5,018	31.3	37.	Sandstone
5,053	21.6	27.	Sandstone
5,089	26.6	265.	Sandstone
5,102	29.6	20.	Sandstone

Table 5.--Porosities, permeabilities, and dominant lithologies of sidewall cores from COST No. G-2 well.-- continued

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Dominant lithology
5,136	25.2	8.5	Sandstone
5,145	23.5	105.	Sandstone
5,172	28.4	40.	Sandstone
5,195	23.0	86.	Sandstone
5,229	19.2	0.2	Sandstone
5,312	23.2	6.2	Sandstone
5,404	18.7	0.1	Sandstone
5,507	21.7	0.4	Sandstone
5,554	15.7	0.1	Sandstone
6,235	29.4	20.	Sandstone
6,965	25.7	25.	Sandstone
7,025	10.8	0.1	Sandstone
7,192	28.8	150.	Sandstone
7,206	26.8	185.	Sandstone
7,236	27.2	6.5	Sandstone
7,376	30.3	86.	Sandstone
7,423	26.7	130.	Sandstone
7,620	28.5	86.	Sandstone
7,653	25.3	22.	Sandstone
7,702	19.3	0.2	Sandstone
7,713	28.7	13.	Sandstone
7,714	26.4	47.	Sandstone
7,731	27.4	55.	Sandstone
7,740	29.5	530.	Sandstone
7,762	21.7	5.1	Sandstone
7,763	23.0	8.5	Sandstone
7,793	24.0	26.	Sandstone
7,896	24.2	16.	Sandstone
7,939	25.8	155.	Sandstone
7,984	27.3	50.	Sandstone
8,075	23.8	14.	Sandstone
8,149	25.8	38.	Sandstone
8,215	26.5	49.	Sandstone
8,236	27.5	7.6	Sandstone
8,246	25.4	115.	Sandstone
8,364	19.8	0.4	Sandstone
8,374	19.2	0.3	Sandstone
8,541	16.7	0.1	Sandstone
8,654	22.1	1.5	Sandstone
8,728	22.0	47.	Sandstone

Table 5.--Porosities, permeabilities, and dominant lithologies of sidewall cores from COST No. G-2 well.-- continued

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Dominant lithology
8,752	25.0	35.	Sandstone
8,753	23.7	19.	Sandstone
8,758	25.0	30.	Sandstone
8,759	25.2	44.	Sandstone
8,760	22.1	18.	Sandstone
8,761	24.6	7.0	Sandstone
8,762	20.0	6.4	Sandstone
8,891	21.9	2.9	Sandstone
8,999	15.0	0.1	Sandstone
9,386	29.8	47.	Sandstone
9,424	27.1	18.	Sandstone
9,505	21.8	0.9	Sandstone
9,576	23.3	3.8	Sandstone
9,636	19.1	0.7	Sandstone
9,712	17.6	0.1	Sandstone
9,836	27.4	90.	Sandstone
9,841	20.6	2.1	Sandstone
10,004	15.7	0.1	Sandstone
10,337	17.5	0.1	Sandstone
10,854	14.3	0.1	Limestone
11,047	17.7	0.1	Sandstone
11,204	16.4	0.1	Sandstone
11,337	8.8	0.1	Limestone
11,481	16.2	0.1	Sandstone
11,538	17.0	0.1	Sandstone
11,643	10.7	0.1	Limestone
11,945	12.9	0.1	Limestone
12,160	14.3	0.1	Limestone
12,790	12.2	0.1	Siltstone
12,911	13.3	0.1	Siltstone
13,170	12.5	0.1	Limestone
13,531	12.5	0.1	Sandstone
14,248	14.1	0.1	Limestone
14,974	10.7	0.1	Limestone
16,529	2.2	0.1	Limestone
17,289	10.3	0.1	Limestone
17,354	9.1	0.1	Limestone
17,665	7.0	0.1	Limestone
17,691	10.4	0.1	Limestone
18,507	11.7	0.1	Limestone
21,771	9.5	0.1	Sandstone

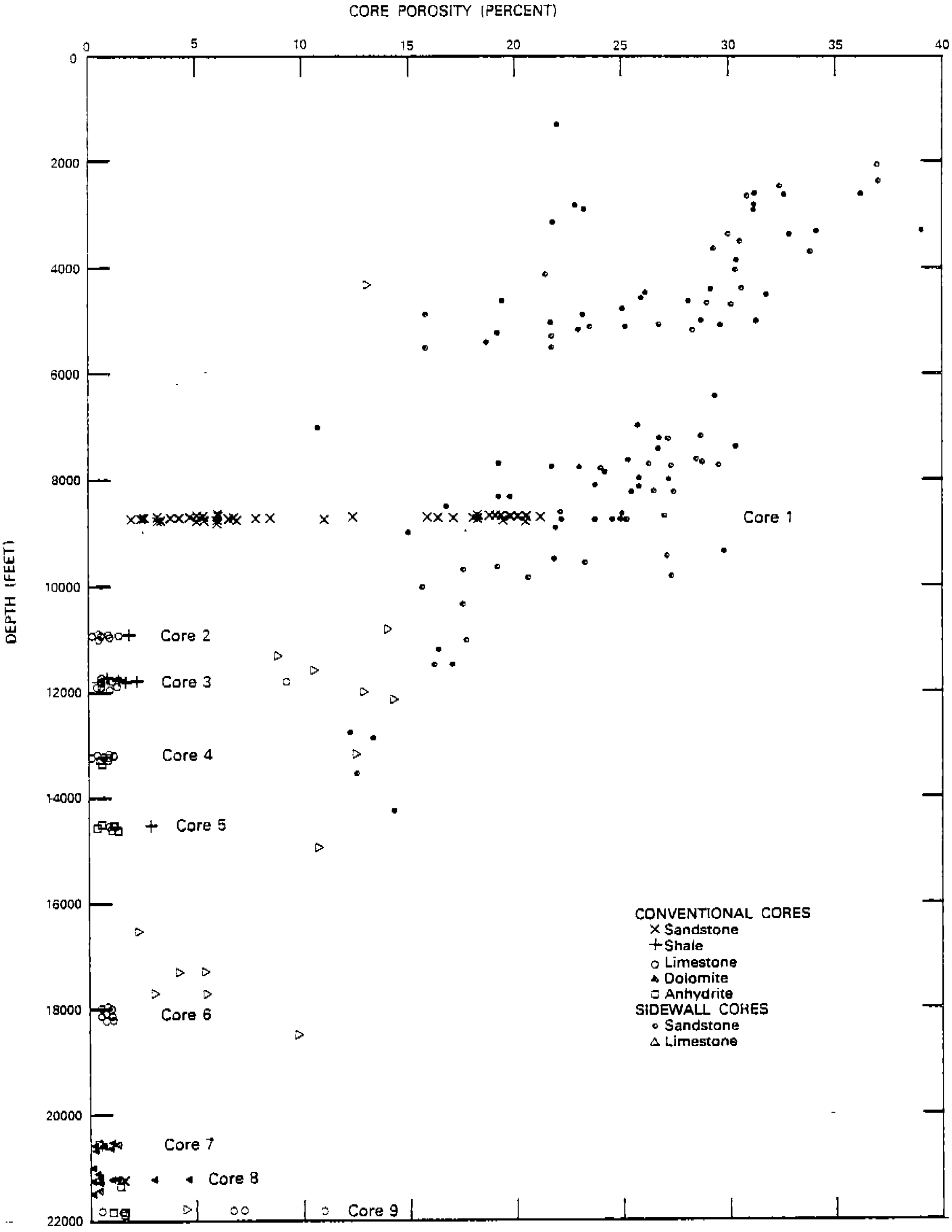


Figure 12.--Porosity of conventional and sidewall cores, COST No. G-2 well.

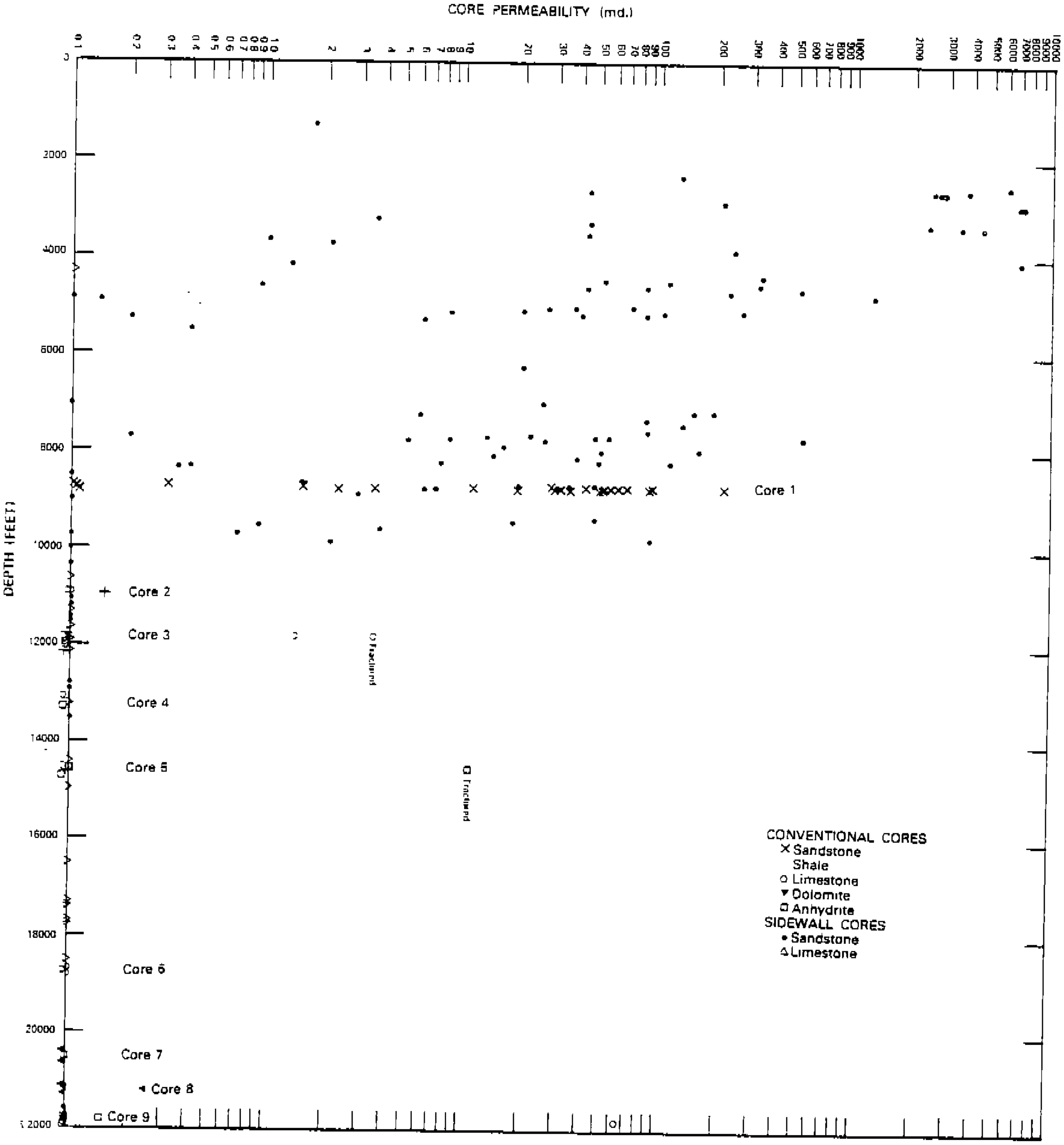


Figure 13.—Permeability of conventional and sidewall cores, COST No. G-2 well.

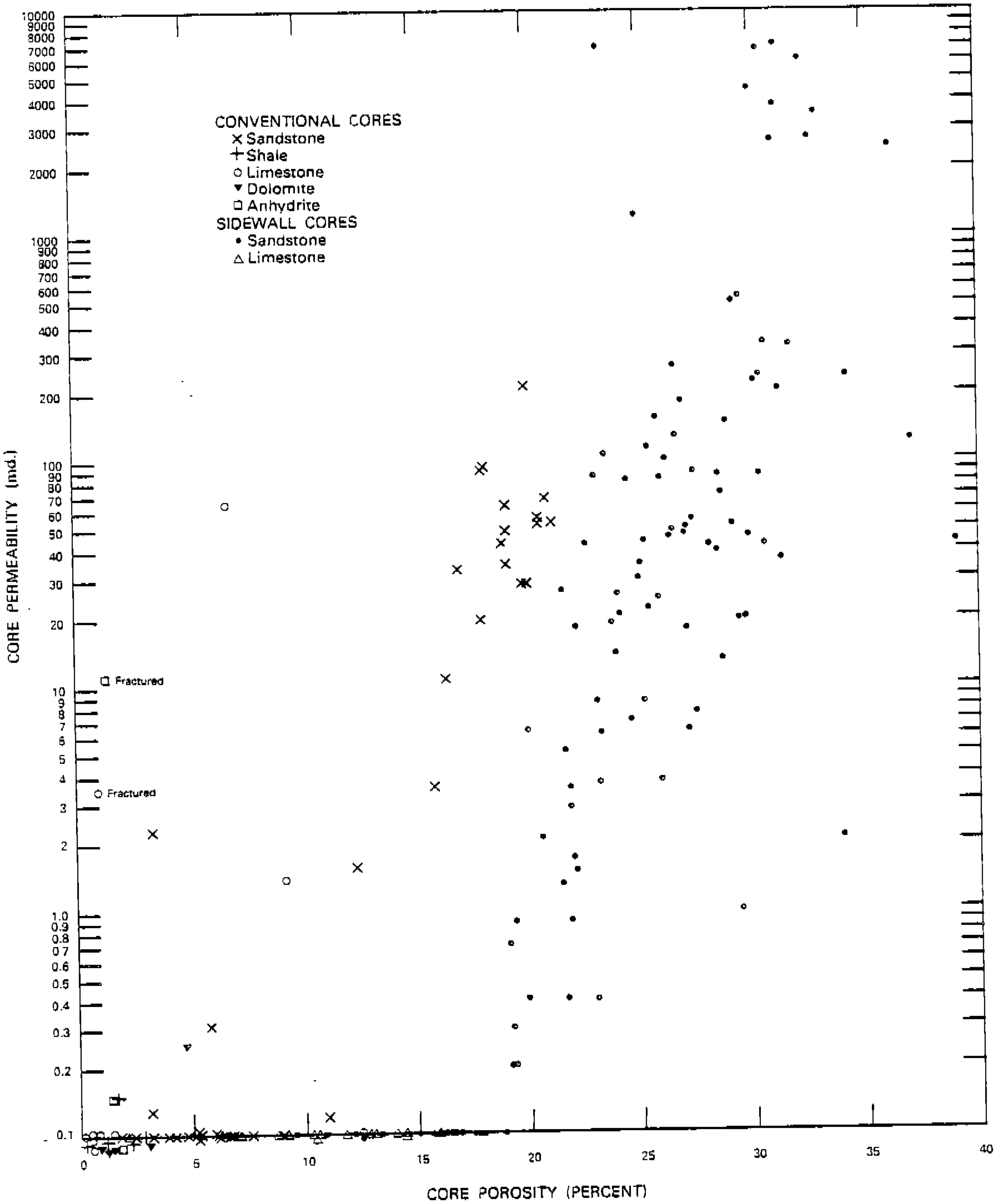


Figure 14.--Core porosity plotted against core permeability, COST No. G-2 well.

also present. Porosity in the sandstone averages from 12 to 20 percent; permeability ranges from 0.1 to 211 md.

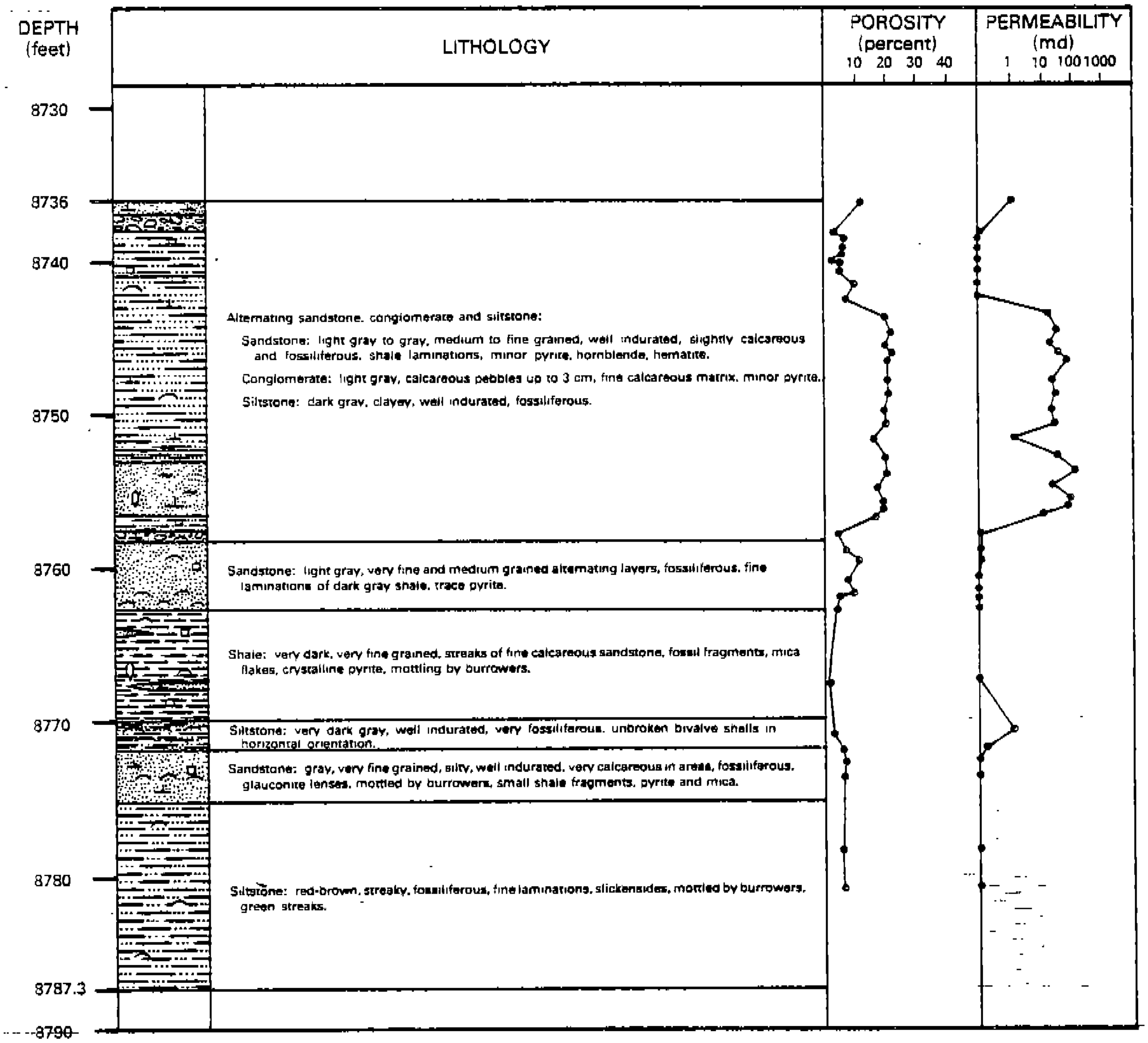
The siltstone is dark gray, clayey and well-indurated, with poorly defined, discontinuous bedding planes, and is fossiliferous in places. The silt unit at the bottom of the core is red-brown with calcareous interclasts, slickensides, and floating pebbles in a fine grained matrix.

The conglomerate is light gray and contains calcareous pebbles up to 3 cm in size in a very fine calcareous matrix. Pyrite is present in minor amounts. A very dark, very fine grained shale with streaks of fine sandstone is present from 8,762.6 to 8,769.8 feet. The shale contains fossil fragments, fine mica flakes, crystalline pyrite, and hairline cracks filled with swelling clays.

<u>Core 2</u> (fig. 16) consists of alternating gray to dark gray fossiliferous limestone, shaly limestone, and calcareous shale. In thin section, the limestone contains algal biomicrite and algal boundstone. Fossil debris includes ostracode and mollusk remains. Traces of anhydrite, mica, tourmaline, and pyrite are associated with organic material. The largest fragments of fossil hash are less than or equal to 25 mm. Bedding is wavy and slightly bioturbated. Porosity averages 1 percent and permeability averages 0.05 md. Layers of medium and fine sand are identified in thin section at 10,970 and 10,980.6 feet; they contain algal laminae, calcite cement and minor amounts of mica, anhydrite and pyrite.

<u>Core 3</u> (fig. 17) consists of interbedded limestone, shale and siltstone. The limestone is dark gray to dark brown and microcrystalline to indistinctly granular, and contains shale stringers and laminations. Some layers are fossiliferous, and contain molluscan, echinoid, and ostracodal biomicrite. Bioturbation is evident at some intervals. Porosity averages 0.4 percent permeability averages less than 0.01 md.

The shale is dark to very dark gray, fine to coarse in texture, platy but not fissile, and slightly to very calcareous; some layers grade to limestone as described above. Laminations are slightly wavy and subparallel,



Alternating sandstone, conglomerate and siltstone:

Sandstone: light gray to gray, medium to fine grained, well indurated, slightly calcareous and fossiliferous, shale laminations, minor pyrite, hornblende, hematite.

Conglomerate: light gray, calcareous pebbles up to 3 cm, fine calcareous matrix, minor pyrite.

Siltstone: dark gray, clayey, well indurated, fossiliferous.

Sandstone: light gray, very fine and medium grained alternating layers, fossiliferous, fine laminations of dark gray shale, trace pyrite.

Shale: very dark, very fine grained, streaks of fine calcareous sandstone, fossil fragments, mica flakes, crystalline pyrite, mottling by burrowers.

Siltstone: very dark gray, well indurated, very fossiliferous, unbroken bivalve shells in horizontal orientation.

Sandstone: gray, very fine grained, silty, well indurated, very calcareous in areas, fossiliferous, glauconite lenses, mottled by burrowers, small shale fragments, pyrite and mica.

Siltstone: red-brown, streaky, fossiliferous, fine laminations, slickensides, mottled by burrowers, green streaks.

Figure 15.--Lithology, porosity, and permeability of conventional core 1, 8,736-8,787.3 feet, COST No. G-2 well.

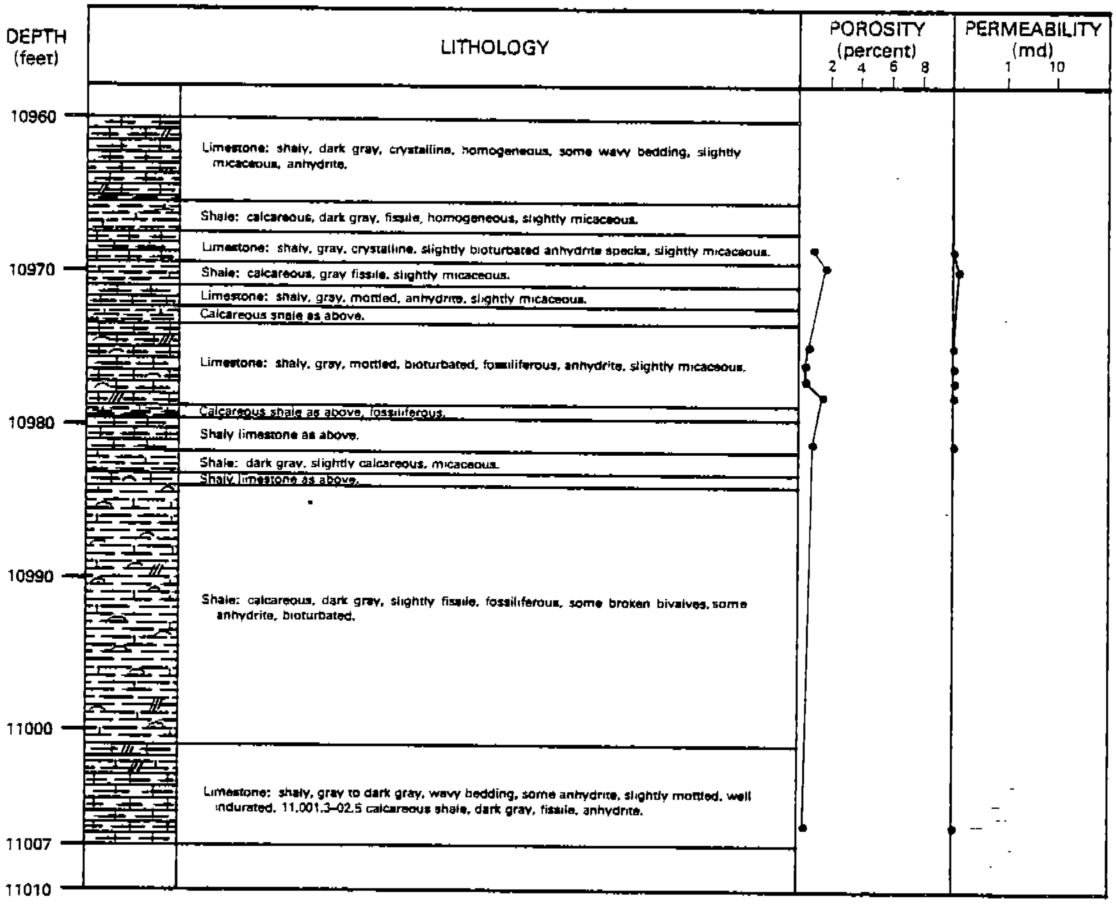
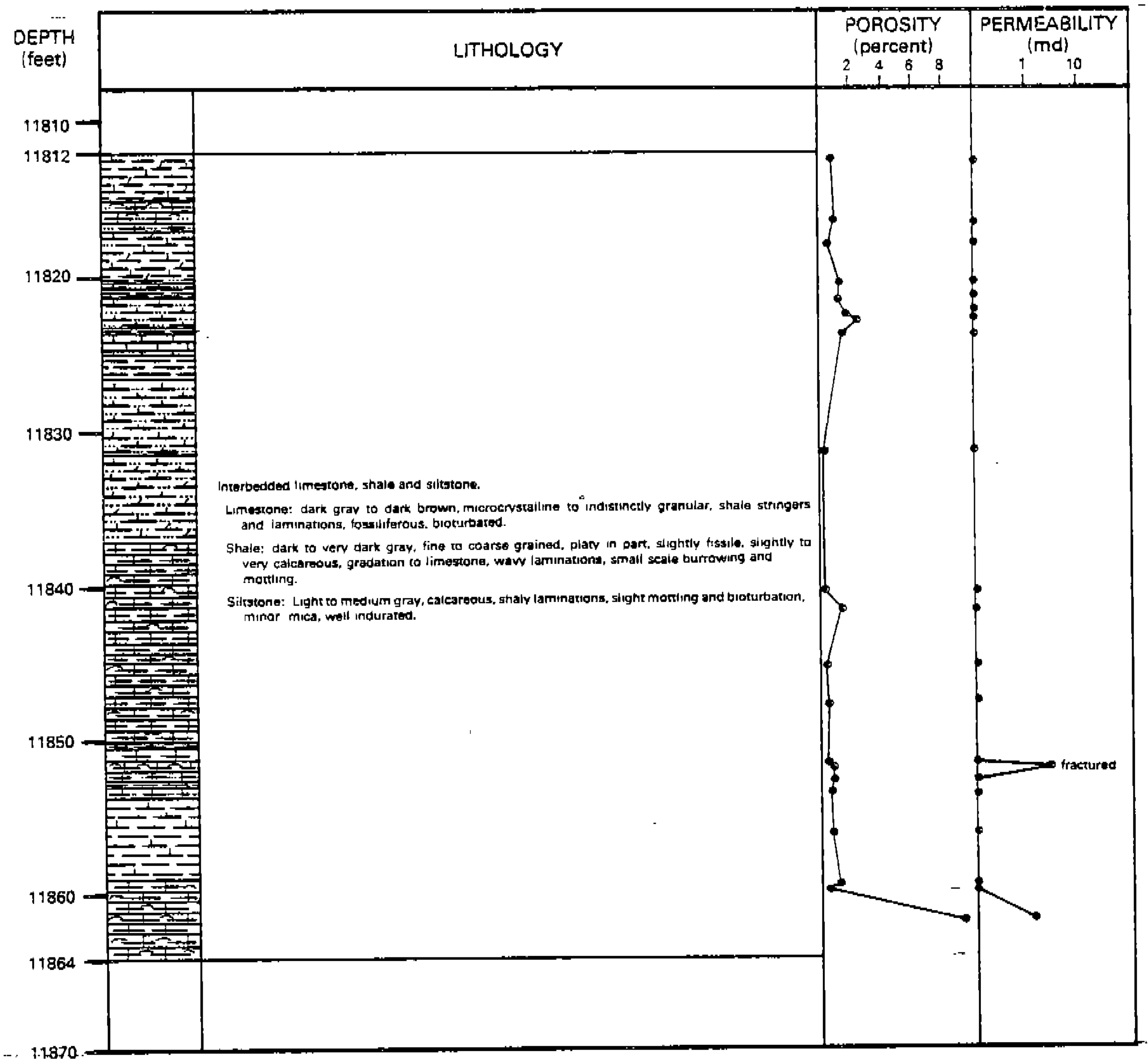


Figure 16.--Lithology, porosity, and permeability of conventional core 2, 10,960-11,007 feet, COST No. G-2 well.



Interbedded limestone, shale and siltstone.

Limestone: dark gray to dark brown, microcrystalline to indistinctly granular, shale stringers and laminations, fossiliferous, bioturbated.

Shale: dark to very dark gray, fine to coarse grained, platy in part, slightly fissile, slightly to very calcareous, gradation to limestone, wavy laminations, small scale burrowing and mottling.

Siltstone: Light to medium gray, calcareous, shaly laminations, slight mottling and bioturbation, minor mica, well indurated.

Figure 17.--Lithology, porosity, and permeability of conventional core 3, 11,812-11,864 feet, COST No. G-2 well.

and small scale burrowing and mottling are apparent.

The light- to medium-gray calcareous siltstone is well-indurated and contains laminated, organic-rich algal boundstone, some lenticular clasts, and minor amounts of mica. Slight mottling and bioturbation are present. Porosity averages 1.2 percent; permeability is less than 0.01 md.

Core 4 (fig. 18) is dominantly limestone with an average porosity of 0.7 percent and permeability less than 0.01 md. It is dark-gray, microcrystalline and clayey, with abundant dark-gray shale and calcareous silt laminae, fossiliferous micrite and algal boundstone. Irregular vertical fractures are healed and filled with calcite. At 13,235.9-13,239.5 feet, the limestone contains abundant gastropod and bivalve fragments. Interval 13,278-13,288.3 feet is oolitic. Interval 13,272.2-13,275.9 feet is very light gray, nodular anhydrite with some massive portions. Irregular and deformed gray, very fine grained, calcareous partings are present. The partings also contain fine crystalline pyrite.

Core 5 (fig. 19) consists of anhydrite and limestone. The anhydrite is white to light gray to blue gray, medium crystalline, has "chicken wire texture," and is well-indurated. Parts are nodular with wavy laminations and shaly streaks and stringers. The limestone is gray to dark gray, well-indurated and finely crystalline, with disseminated anhydrite crystals and clasts, and some shaly streaks. Small-scale stylolites and fine wavy laminations are present. Average porosity is 0.7 percent, and permeability throughout is near 0.01 md. A well-indurated layer of dark organic asphaltic material occurs at 14,571.9 feet.

Core 6 (fig. 20) is primarily dense, fossiliferous limestone containing traces of shale and anhydrite. The fossil fragments include molluscs, brachiopods, pelecypods and echinoderms, with some shell fragments filled with anhydrite. Fossil fragments are also present in a fine micrite matrix. The limestone appears bioturbated and contains dark streaks. Anhydrite is included as lenses, streaks and nodules. Thin section analyses indicate the presence of dolomitic micrite matrix and dolomite, and traces of pyrite and clay minerals. Porosity averages 0.7 percent; permeability is less than 0.01 md.

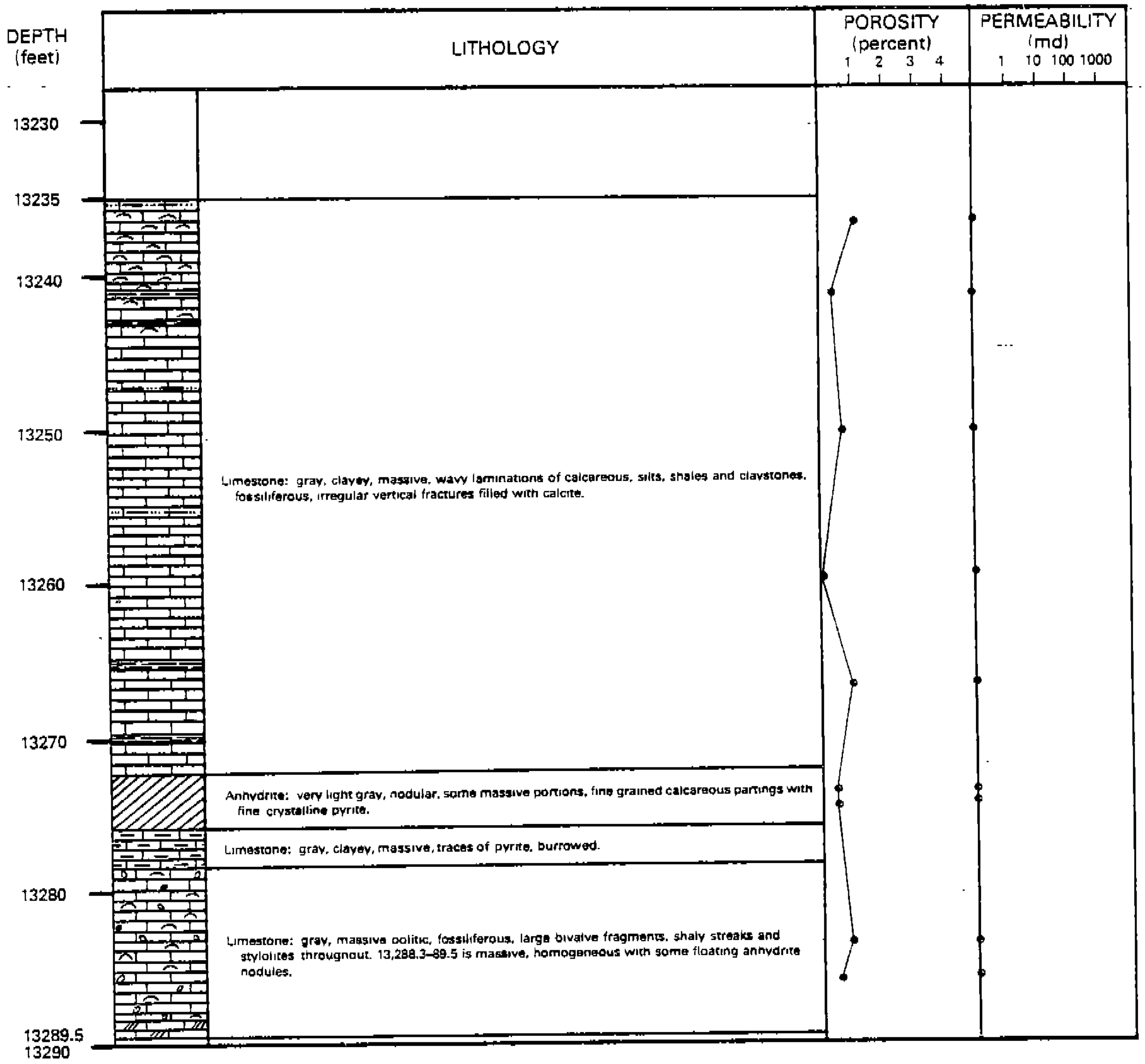


Figure 18.--Lithology, porosity, and permeability of conventional core 4, 13,235-13,289.5 feet, COST No. G-2 well.

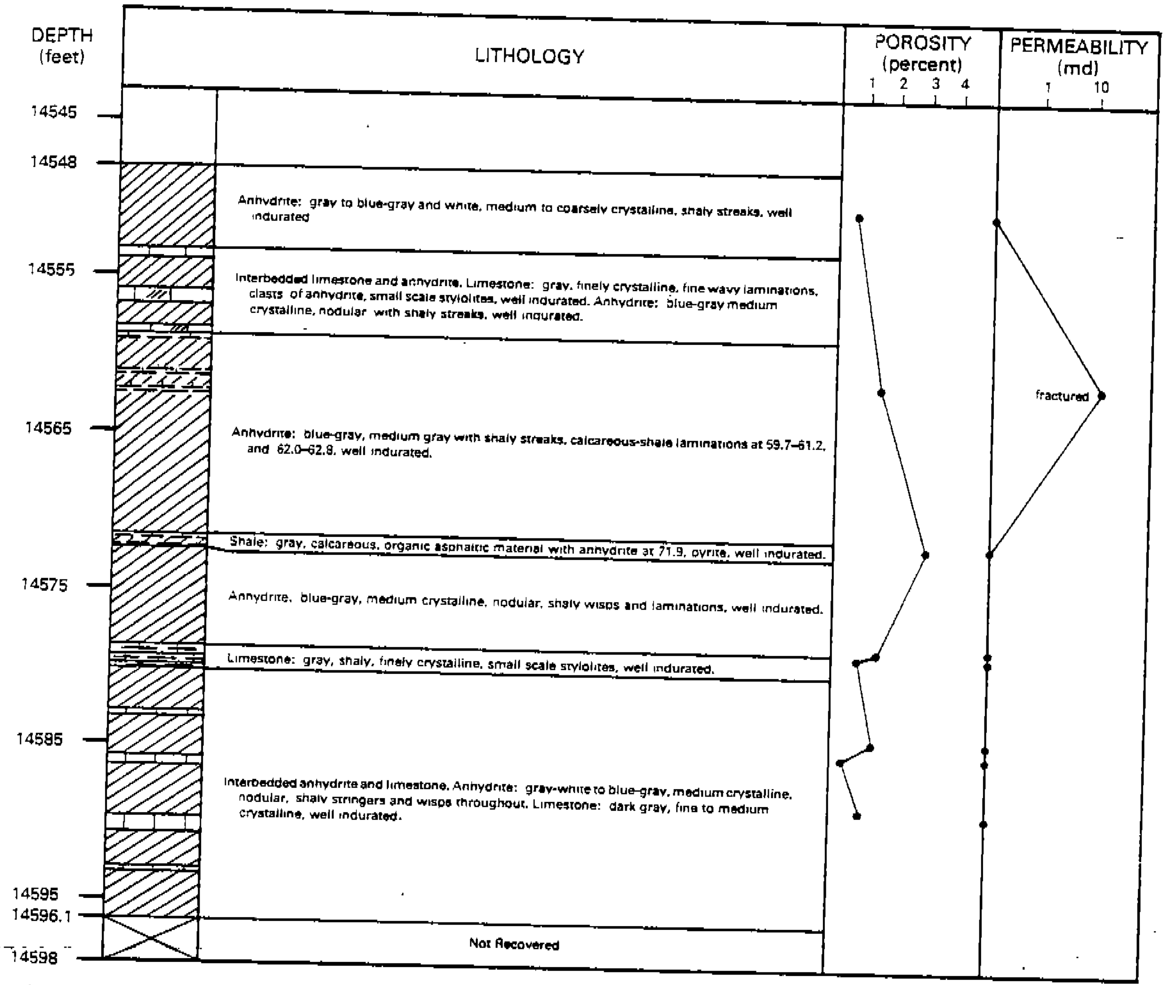


Figure 19.--Lithology, porosity, and permeability of conventional core 5, 14,548-14,596.1 feet, COST No. G-2 well.

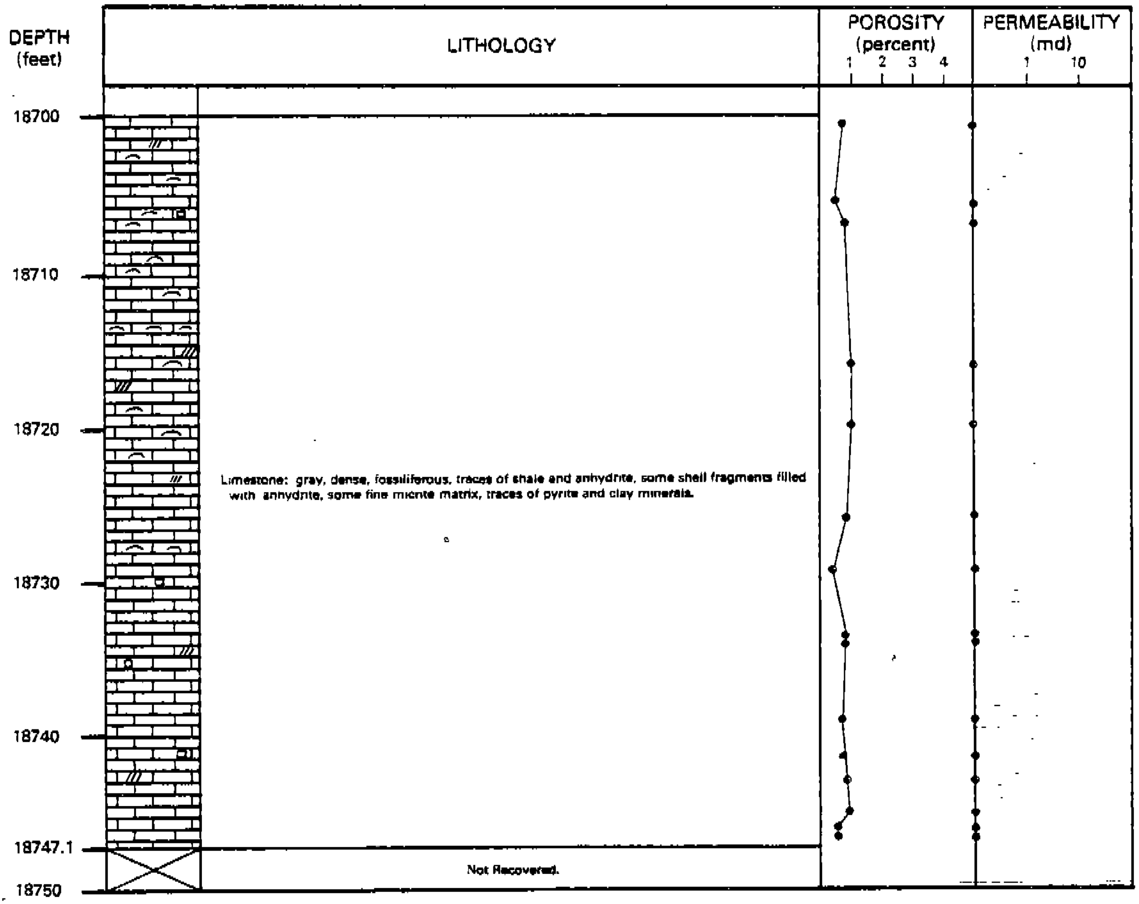


Figure 20.—Lithology, porosity, and permeability of conventional core 6, 18,700-18,747.1 feet, COST No. G-2 well.

Core 7 (fig. 21) is dominantly anhydrite mixed with dolomitic shale, dolomicrite, and shaly dolomitic siltstone. The anhydrite is gray and contains very clayey dolomicrite in wavy, subhorizontal laminations. Anhydrite also occurs in nodular pockets with a horizontal orientation. The dolomitic shale is dark gray, well-indurated and has wavy subhorizontal laminations of silty shale. Micrite and laminated algal boundstone are present in a gray shaly dolomitic siltstone with wisps of dolomitic shale. The dolomite is gray and contains finely laminated micrite, clayey dolomite, and small pockets of anhydrite. Pelecypod molds are calcite-filled.

Core 8 (fig. 22) is gray, homogeneous, finely crystalline dolomite with argillaceous laminations and small patches, pockets, and infilled fractures of anhydrite. Porosity averages 1 percent; permeability is less than 0.01 md. A layer of white to light-gray, medium crystalline anhydrite occurs from 21,271.9-21,272.7 feet, below a thin layer of dark-gray, fine-grained, well-indurated sandstone containing anhydrite, mica and pyrite, and having an uneven laminated appearance. From 21,272.7-21,273.7 feet, the dolomite is oolitic and has dark-gray algal laminations and minor mica and pyrite. The lower section of the core contains more anhydrite, alternating with dolomite.

Core 9 (fig. 23) consists of anhydrite and limestone. The anhydrite is white, medium crystalline, slightly silty and contains wisps and streaks of clay in a generally horizontal orientation. Pyrite is present in trace amounts. There are salt disseminations and partially leached, salt-filled vertical fractures. The light-gray to buff limestone has a finely crystalline, granular-sucrosic texture. It contains clay, some salt, anhydrite, and dolomite rhombs. Its general appearance is streaky. The average porosity of the limestone is 8 percent; permeability (the lower part of the unit is fractured) is 67 md.

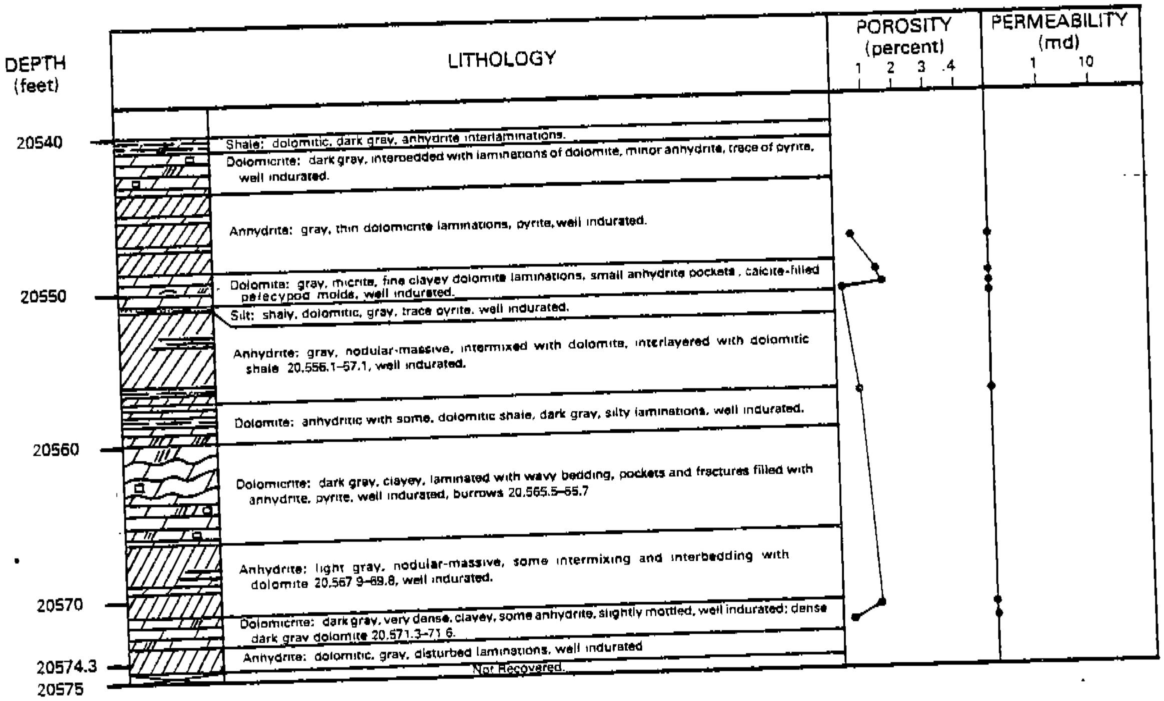


Figure 21.--Lithology, porosity, and permeability of conventional core 7, 20,540-20,574.3 feet, COST No. G-2 well.

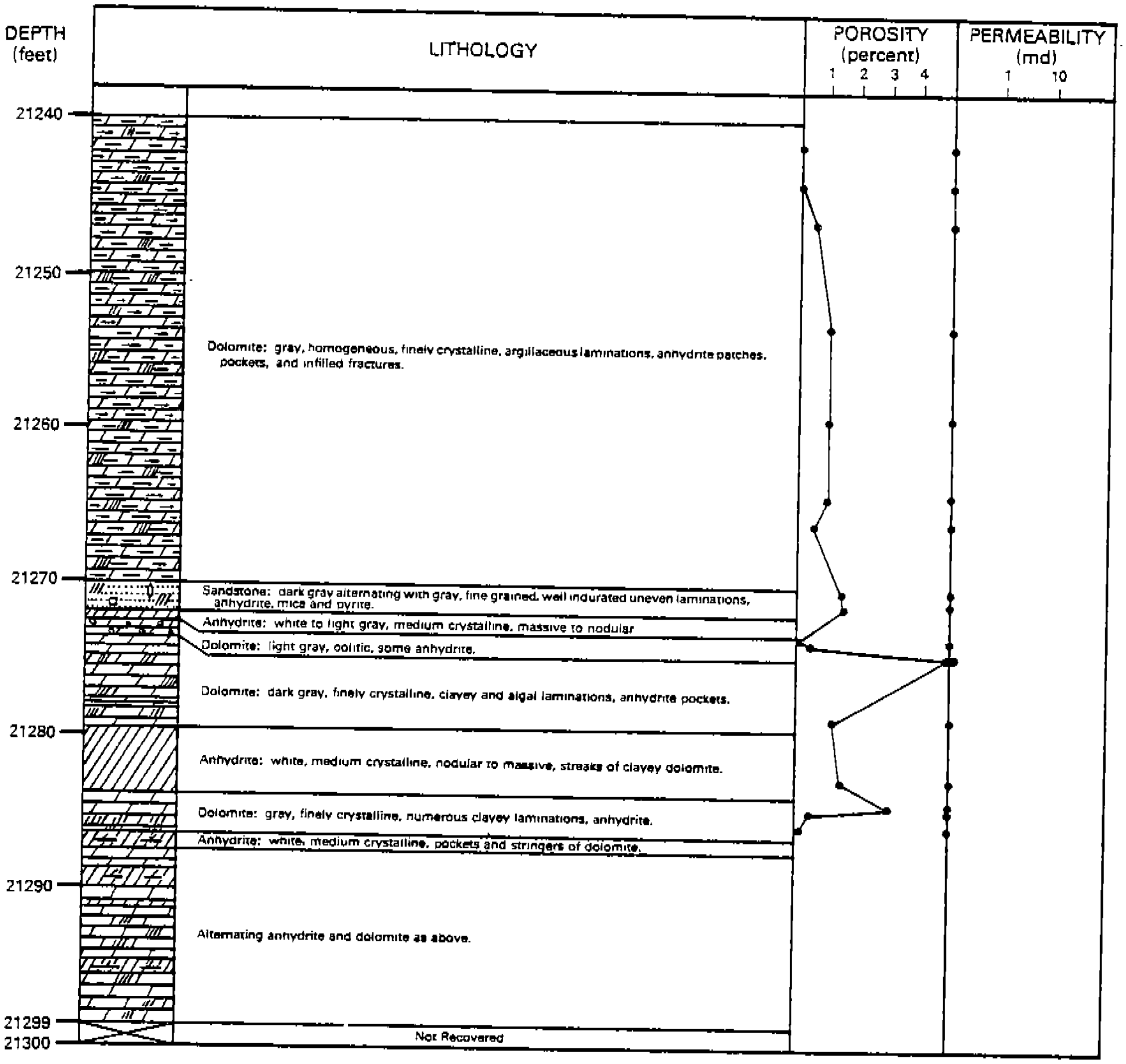


Figure 22.--Lithology, porosity, and permeability of conventional core 8, 21,240-21,299 feet, COST No. G-2 well.

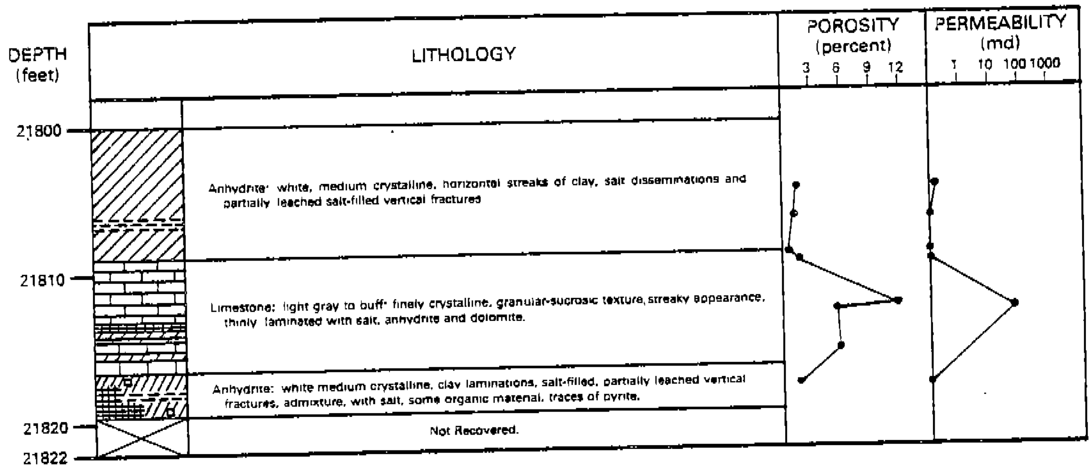


Figure 23.--Lithology, porosity, and permeability of conventional core 9, 21,800-21,819 feet, COST No. G-2 well.

GEOCHEMICAL ANALYSIS

By Michael A. Smith

Source-Rock Potential

The organic geochemistry program for the COST No. G-2 well was designed to evaluate the potential of strata in this area for petroleum generation based on detailed analysis of core samples and well cuttings collected at regular intervals. GeoChem Laboratories, Inc. (1977) analyzed canned cuttings samples, generally selected at 150-foot intervals, for their light and gasoline-range hydrocarbon content and total organic carbon. More than half of these samples, mostly collected at 300-foot intervals, were then evaluated for detailed gasoline-range and high-molecular-weight hydrocarbon composition and for the type of kerogen and its degree of thermal alteration. Aliquots of these samples and processed material were sent to Phillips Petroleum Company (written communication, 1978) for carbon isotope measurements. Core Lab (Core Laboratories, Inc., 1977b) also received cuttings samples at approximately 300-foot intervals which were analyzed for total organic carbon, high-molecular-weight hydrocarbons, vitrinite reflectance, and the type, thermal alteration index, and elemental analysis of kerogen. Most of the same analyses were made on 20 sidewall core samples by GeoChem and on 8 conventional cores by Core Lab.

The total organic carbon (TOC) in the G-2 cuttings samples is listed in table 6 and shown, with other indicators of organic richness, in figure 24. Measurements from the two geochemical service companies are plotted separately; significant differences are evident, even though cuttings samples above 18,700 feet were analyzed from the same 30-foot intervals. Core Lab detected 2.4 times the TOC in samples above 7,000 feet and 39 percent more TOC in the underlying interval to 13,500 feet than GeoChem; however, GeoChem's analyses below 17,000 feet showed 81 percent more TOC than Core Lab's. The COST G-2 Geochemistry Subcommittee was unable to explain these discrepancies (G. D. Roe, Atlantic Richfield Company, written com-

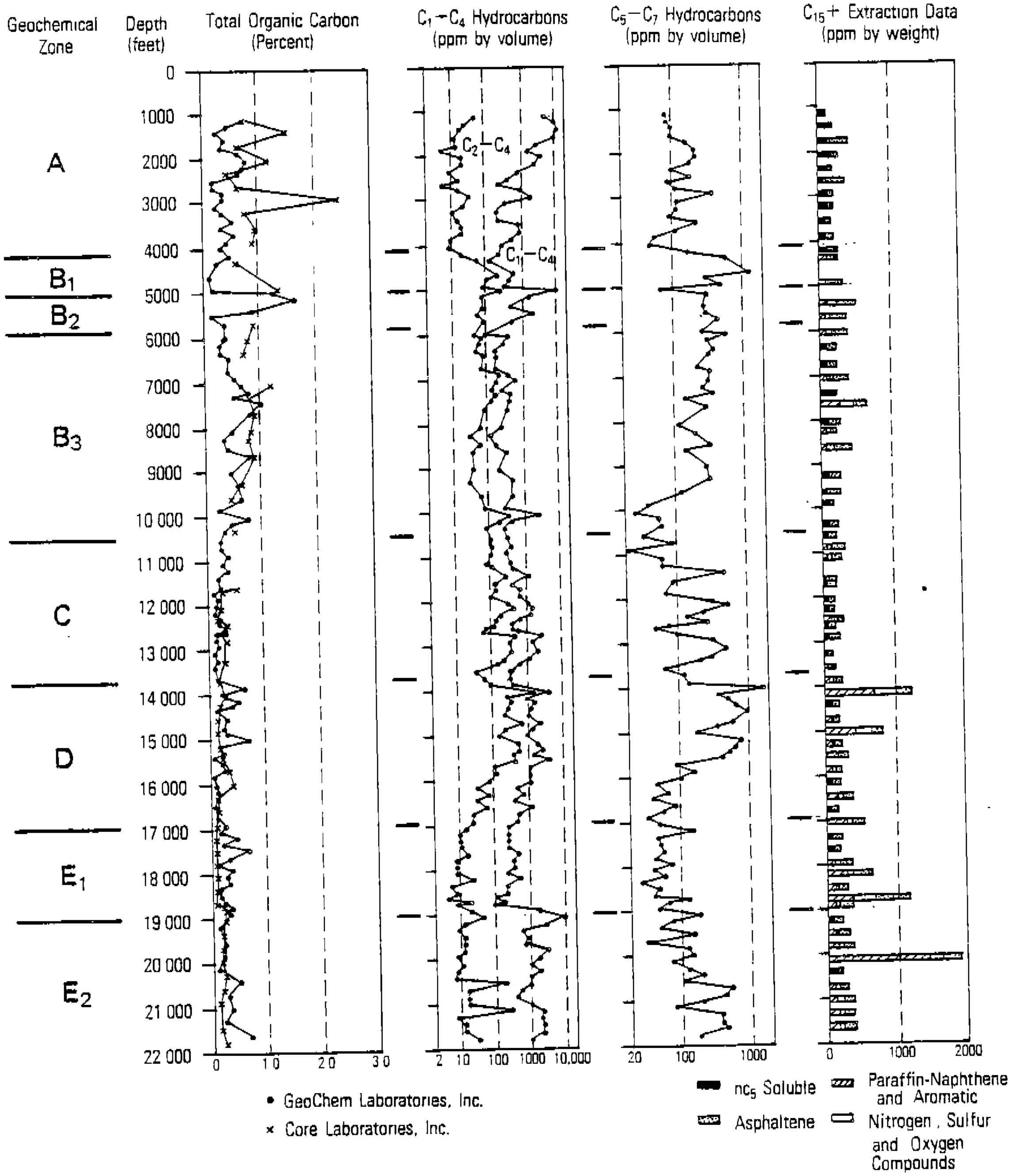


Figure 24.--Measurements of organic richness of sedimentary rocks in the COST No. G-2 well.

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings.
[Depths represent 30-ft sampling intervals from stated depth downward; --, no data available. g, analysis by GeoChem Laboratories, Inc.; c, analysis by Core Laboratories, Inc.; a, average of analyses by both laboratories]

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (R₀ percent)	H/C in kerogen
					Geochemical	Zone A		
1,160	0.72 (a)	5,625	0.9	83	100	1.33	0.33	1.05
1,280	.45 (g)	11,392	.2	85				
1,430	.90 (a)	11,535	.2	97	191	1.42	.33	.74
1,610	.40 (g)	9,257	.1	97				
1,760	.50 (a)	2,972	.5	159	410	1.42	.31	.90
1,910	.66 (g)	1,784	.3	220				
2,060	.98 (a)	3,521	.6	219	251	1.42	.32	.67
2,210	.74 (g)	2,678	.8	180				
2,360	.58 (a)	846	1.2	98	182	1.42	.36	--
2,540	.21 (g)	464	3.3	184				
2,660	.42 (a)	256	2.5	90	366	1.42	.34	.80
2,780	.37 (g)	931	1.6	110				
2,930	1.40 (a)	1,931	1.8	404	211	1.42	.34	.76
3,110	.23 (g)	383	6.7	125				
3,230	.55 (a)	192	6.6	118	213	1.42	.39	.70
3,440	.53 (g)	223	6.7	98				
3,560	.65 (a)	836	2.2	212	163	1.42	.41	.71
3,710	.55 (g)	884	2.2	113				
3,860	.68 (a)	557	1.7	55	213	1.42	.42	.78
4,010	.33 (g)	288	2.7	49				

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (R₀ percent)	H/C in kerogen
					Geochemical Zone B_1			
4,190	0.44 (g)	220	8.7	162	275	1.42	0.42	0.84
4,330	.40 (a)	118	44.3	618	275	1.50	.45	.92
4,660	.12 (g)	632	30.6	1,157				
4,780		472	21.3	293				
4,930	.74 (a)	343	24.2	453	312	1.50	.43	.63
					Geochemical Zone B_2			
5,020	1.23 (g)	9,140	2.8	69				
5,140	1.59 (g)	1,639	4.4	308				
5,380	.86 (g)	461	17.2	266	486	1.50	0.44	0.83
5,530	.14 (g)	2,068	2.6	289				
5,680	.64 (a)	470	16.6	410	378	1.50	.45	.78
					Geochemical Zone B_3			
5,980	0.41 (g)	90	49.9	267				
6,040	.58 (a)	382	17.3	599	376	1.50	0.45	0.86
6,190	.30 (g)	244	21.9	305				
6,340	.51 (a)	158	29.3	351	205	1.50	.46	.67
6,460	.44 (g)	169	44.9	332				
6,760	.44 (g)	153	44.8	227	221	1.50	.47	.66
6,880	.51 (g)	343	62.9	337				
7,060	.90 (a)	556	31.6	325	383	1.50	.47	.61
7,240	.78 (g)	238	54.5	277				
7,330	.66 (a)	410	37.2	349	224	1.50	.48	.59
7,480	1.01 (g)	401	30.8	149				
					644	1.58	.49	.73

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (Ro percent)	H/C in kerogen
					Geochemical Zone B_3 (Continued)			
8,070	0.66 (a)	225	26.2	113	253	1.75	0.49	0.65
8,260	.57 (a)	110	29.8	202	294	1.67	.51	.66
8,490	.40 (g)	167	33.0	336				
8,630	.82 (a)	301	12.0	138	434	1.67		
9,020	.47 (g)	206	19.4	289				
9,290	.60 (a)	485	6.0	318	246	1.75	1.06	.72
9,620	.56 (a)	469	12.1	128	240	1.75	1.05	.55
9,890	.25 (g)	290	27.2	42	155	1.92	1.06	.64
10,070	.74 (g)	2,304	15.4	26				
10,190	.43 (g)	425	44.2	60				
10,340	.42 (a)	235	34.7	65	205	1.92	1.06	.76
					Geochemical Zone C			
10,580	0.27 (g)	311	32.5	37	167	1.83	1.22	0.67
10,730	.27 (g)	397	30.1	86				
10,880	.39 (g)	270	40.3	21	320	1.83	1.33	.55
11,090	.31 (g)	316	26.0	64	261	1.83	1.25	.60
11,240	.37 (g)	409	25.5	64				
11,390	.21 (g)	1,099	24.0	466				
11,600	.38 (a)	421	31.5	86	166	1.83	1.35	.55
11,720	.20 (a)	680	19.8	78	164			
11,870	.21 (g)	598	17.5	70		1.92		
12,050	.22 (a)	1,045	31.1	318	149	1.92	1.38	.64

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (R_o percent)	H/C in kerogen
					Geochemical Zone C (Continued)			
12,290	0.21 (a)	1,229	15.8	244	148	1.92	1.09	0.74
12,380	.26 (a)	672	23.0	142				
12,530	.32 (g)	406	30.2	270	246	1.75		
12,590	.28 (a)	412	14.6	78			1.15	.70
12,650	.16 (g)	530	10.9	42	157	1.75		
12,770	.26 (a)	2,632	16.8	96			1.43	.76
12,920	.20 (g)	1,633	21.5	336	201	1.83		
13,100	.14 (g)	1,887	20.4	474				
13,280	.24 (a)	1,140	21.5	292	101	1.92	1.30	.65
13,370	.13 (g)	575	27.4	209				
13,550	.18 (g)	341	10.9	64	134	2.00		
					Geochemical Zone D			
13,700	0.23 (a)	332	17.0	126			1.39	0.77
13,850	.61 (g)	414	20.9	142	241	1.83		
14,000	.26 (a)	3,605	41.6	1,560			1.38	.70
14,150	.50 (g)	921	26.5	365	1,212	1.83		
14,210	.32 (a)	1,508	21.8	488			1.48	.63
14,360	.17 (g)	1,197	25.2	651	177	2.08		
14,510	.26 (a)	980	25.0	858			1.54	.66
14,720	.27 (g)	2,055	32.2	601	187	2.00		
14,840	.24 (a)	1,184	19.4	350			1.51	.64
14,990	.69 (g)	988	17.1	181	799	1.83		
15,140	.19 (a)	1,865	28.8	731			1.61	.61
15,290	.23 (g)	2,428	22.9	645	229	1.92		

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (Ro percent)	H/C in kerogen
Geochemical Zone D (Continued)								
15,380	0.18 (a)	1,571	25.8	536			1.46	0.61
15,530	.24 (g)	3,085	13.7	410	317	1.92		
15,680	.32 (a)	1,008	10.7	86			1.63	.60
15,830	.04 (g)	1,314	8.9	159	226	2.08		
15,980	.27 (a)	1,120	7.0	99			1.87	.43
16,130	.14 (g)	491	7.5	48	204	2.08		
16,280	.14 (a)	624	9.4	66			1.72	.48
16,430	.12 (g)	377	7.6	41	374	2.08		
16,580	.16 (a)	1,029	6.1	86			2.06	.76
16,730	.15 (g)	516	4.4	60	143	2.00		
16,880	.20 (a)	444	4.8	36			1.90	.73
Geochemical Zone E_1								
17,030	0.20 (g)	255	5.7	52	512	1.92		
17,180	.27 (a)	254	4.3	145			1.92	0.70
17,330	.23 (g)	268	4.1	47	192	1.92		
17,480	.38 (a)	269	4.3	52			2.09	.60
17,630	.35 (g)	480	3.1	58	182	1.67		
17,780	.12 (a)	292	2.8	45			1.92	.63
17,930	.38 (g)	302	2.7	73	337	1.58		
18,050	.20 (a)	218	3.9	43			2.07	.56
18,200	.33 (g)	521	3.8	58	621	1.58		
18,350	.14 (a)	234	2.9	27			2.11	.67
18,500	.17 (g)	223	3.5	45	283	1.75		
18,650	.16 (a)	118	3.9	42			2.44	.70

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (R₀ percent)	H/C in kerogen
Geochemical Zone E_1 (Continued)								
18,710	.20 (c)						1.86	.75
18,740	.36 (g)	163	12.1	128	1,155	1.75		
18,770	.26 (g)	92	8.8	67				
18,800	.28 (c)						2.32	--
18,920	.28 (g)	1,817	1.1	49	331	1.92		
Geochemical Zone E_2								
19,070	0.25 (c)	9,324	0.4	179			2.53	0.64
19,220	.14 (g)	2,572	.6	74	185	2.08		
19,370	.20 (c)	639	1.4	52			3.23	.73
19,520	.22 (g)	751	1.7	141	282	2.08		
19,670	.18 (c)	668	2.1	32			3.06	.75
19,820	.21 (g)	2,699	.5	128	350	2.17		
19,970	.17 (c)	1,783	.4	145			2.74	.86
20,120	.15 (g)	1,032	.9	75	1,889	2.17		
20,270	.22 (c)	1,658	.4	126			2.86	.76
20,420	.47 (g)	1,063	.6	194	182	2.17		
20,570	.21 (c)	901	19.2	98			2.52	.72
20,720	.30 (g)	503	2.9	517	268	2.17		
20,780							2.63	--
20,870	.14 (c)	366	4.0	418			2.97	.80
21,020	.35 (g)	868	1.9	209	351	2.17		
21,170	.20 (c)	2,125	12.5	83			2.88	.41

Table 6.--Organic geochemical measurements from COST No. G-2 well cuttings--continued

Depth (feet)	Total organic carbon (percent)	C_1-C_4 (ppm)	Gas wetness (percent)	C_5-C_7 (ppm)	C_{15+} total extract (ppm)	Thermal alteration index (TAI)	Vitrinite reflectance (R_o percent)	H/C in kerogen
Geochemical Zone E_2 (Continued)								
21,320	0.23 (g)	1,968	0.4	372	340	2.17		
21,470	.16 (c)	2,160	.5	386				
21,620	.65 (g)	2,064	.6	417	382	2.17	2.91	0.85
21,770	.22 (c)	976	3.3	178			3.08	.81

munication, 1977) but when additional samples were homogenized and analyzed by GeoChem, Core Lab, and two of the participants, consistent results about halfway between the original values were obtained. For this reason, the TOC values listed in table 6 are averaged in most cases where data from both service companies are available. Several of the Core Lab TOC measurements could not have been obtained by combining analyses for the different lithologies in the cuttings, however, and these values were not used for the tabulation. Even though cuttings from the same intervals were analyzed, gross lithological descriptions by the two companies for most samples above 7,000 feet and for some of the deeper samples that had divergent TOC values reveal drastically different compositional makeups; the discrepancy, therefore, reflects sample inhomogeneity or possibly contamination, rather than poor analytical quality.

Although the absolute organic carbon values for individual samples are questionable, conclusions can still be drawn about the organic richness of different well intervals. Five major geochemical zones, with zones B and E divided into subzones, have been designated by GeoChem and are shown in the figures and tables of this chapter as well as on plate 1. Petroleum source rocks must have a minimum organic carbon content (in general, 0.5 or 0.6 weight percent organic carbon for shale and 0.2 weight percent for limestone) to generate significant amounts of oil or gas. With few exceptions, the G-2 sediments have adequate richness to be considered potential source beds with values slightly above the required minimum organic carbon, averaging 0.60 percent TOC for zones A and B in the upper clastic section of the well and 0.25 percent TOC for carbonates in the deeper zones. Zone B_2 has the highest average TOC in the well, 0.89 percent, while zone B_1 average only 0.42 percent TOC. GeoChem's analyses of the deepest sections of the well, zones E_1 and E_2, show a moderate increase in TOC to an average of 0.30 percent.

Measurements of the light (C_1-C_4) and gasoline-range (C_5-C_7) hydrocarbons also indicate source-rock richness while providing information on the degree of thermal alteration and possible contamination of samples. GeoChem, for its C_1-C_7 hydrocarbon content and composition, analyzed the air space gas from the sealed 1-quart sample cans and the gas released by macerating the cuttings in a blender (table 6 and fig. 24). A detailed analysis of the molecular composition of C_4-C_7 hydrocarbons separated from washed, hand-picked cuttings was also made using a gas chromatograph unit equipped with a capillary column. Average methane concentrations are high for zones A (2,809 ppm), B_2 (2,648 ppm), and E_2 (1,760 ppm); average concentrations in the remaining zones range from 267 ppm to 990 ppm. Methane concentrations at shallow depths have a biogenic origin whereas methane deeper in the well has formed from the thermal cracking of more complex organic molecules or from gas-prone source material. The apparent richness and higher methane content of zone B_2 may be partially explained by a greater abundance of of coal in this interval. The C_2-C_4 wet gas hydrocarbon components show a sharp jump from an average of 18 ppm in zone A to about 100 ppm at a depth of 4,500 feet and then increase gradually to an average of 273 ppm for zone D. In zones E_1 and E_2, the wet gas average drops back to 25 ppm because of an increase in the coaly material present and the greater temperatures. The gasoline-range (C_5-C_7) hydrocarbon content varies from 21 ppm to 1,560 ppm and averages 223 ppm for all G-2 cuttings samples. The highest concentrations are found in the 4,300-6,100-foot interval (430 ppm), the 14,000-15,600-foot interval (615 ppm), and below 20,700 feet (323 ppm). Increasing C_5-C_7 concentrations at the base of the well indicate that the potential for liquid hydrocarbon generation still exists at this depth. Although Core Lab reported significant "diesel" and/or "grease" contamination below 18,800 feet and at several other intervals in the well, this problem is not indicated by the n-C_4/n-C_7 ratio calculated from the detailed C_4-C_7 analysis. Values of less than 1.0 for this ratio can indicate contamination by diesel fuel, but n-C_4/n-C_7 averages 3.06 in the well and increases slightly to 3.29 for zones E_1 and E_2.

The high-molecular-weight (C_{15+}) solvent-extractable organic matter is another indicator of source richness and type. GeoChem's measurements are for bitumen that was soxhlet extracted with a benzene-methanol solvent and separated into asphaltene and pentane-soluble fractions. Adsorption chromatography on a silica gel-alumina column separated the pentane-soluble fraction into C_{15+} paraffin-naphthene, C_{15+} aromatic, and C_{15+} nitrogen-sulfur-oxygen containing components. These data appear in figure 24 and the total extract concentrations are given in table 6. Core Lab also provided extractable organic matter and high-molecular-weight hydrocarbon measurements; because of the ball-mill extraction technique used, their average C_{15+} total extract is only 24 percent of that reported by GeoChem and these data are not considered further in this report. Extractable organic matter generally occurs in low concentrations, averaging 282 ppm in the upper clastic section of the well with increasing values in zone C (184 ppm), zone D (374 ppm), and zones E_1 and E_2 (461 ppm). Several samples below 14,000 feet have fair (greater than 500 ppm) or good (greater than 1,000 ppm) organic richness based on their total bitumen content. The C_{15+} paraffin-naphthene and aromatic hydrocarbons also increase with depth, averaging 89 ppm in zones A, B_1, B_2, and B_3, 59 ppm in zone C, 215 ppm in zone D, and 255 ppm in zones E_1 and E_2. C_{15+} hydrocarbon values exceeding 200 ppm are considered to indicate good source richness. The percentage of C_{15+} hydrocarbons in the extractable organic matter increases with depth from 21.2 percent in zones A, B_1, B_2, and B_3 and 22.5 percent in zone C to 41.5 percent in zone D and 38.5 percent in zones E_1 and E_2; such an increase further confirms that deeper sections of the well have the potential for liquid hydrocarbon generation and/or preservation. The G-2 well participants were concerned about the possible effects of mud contamination on any geochemical data interpretation, but the samples were carefully washed, screened, and hand picked, and their gas chromatographic traces do not resemble those of diesel fuel, pipe dope, or gilsonite. On the basis of the geochemical information submitted and additional studies of G-2 samples, the hydrocarbons discussed herein and the amorphous kerogen present throughout the well appear to be indigenous and to represent a Jurassic carbonate section with fair to good petroleum potential.

Thermal Maturity

Two principal methods--the thermal alteration index and vitrinite reflectance--are generally used to determine whether the organic matter in potential source beds has undergone sufficient thermal effects to have been transformed into liquid or gaseous petroleum. Depths can be identified at which the degree of thermal alteration was sufficient for peak oil, wet gas, and dry gas generation, and also the floors below which hydrocarbons will not survive in these forms. Results of the most widely used techniques to measure thermal maturation are shown in figure 25 and listed in table 6. Unfortunately, there is a surprising lack of agreement between the maturity indicators; no single method seems applicable to all lithologies, ages, types and amounts of organic matter and depths of burial in this area. Inconsistencies and other problems encountered with these techniques and two other maturity indicators--pyrolysis and fluorescence analysis--in the COST No. B-3 well are discussed by Smith (1979).

The thermal alteration index (TAI), as defined by Staplin (1969), provides a somewhat subjective maturation scale based on the color changes occurring with increasing temperatures in organic matter that can be observed under a microscope using transmitted light. The visual index ranges from 1 (unaltered) to 5 (metamorphosed) as the color of spores, pollen, plant cuticles, resins, and algal bodies seen in slides prepared from the well samples varies from light yellow to orange, brown, and black. Measurements by GeoChem show a consistent increase in maturity down to about 16,000 feet, and a slight additional increase in the degree of thermal alteration below 20,000 feet. Sidewall cores between 6,500 and 15,000 feet have TAI values similar to those given for the well cuttings. Although a level (2-) was reached near 8,000 feet where immature-type oil could start to be generated, the 2+ to 3- values where peak oil generation is expected were not seen in this well. Figure 25 even indicates a decrease in TAI in zone E_1 from an average of 2 in zone D to values of 2- or less. Caving from higher in the well apparently was not a factor, and

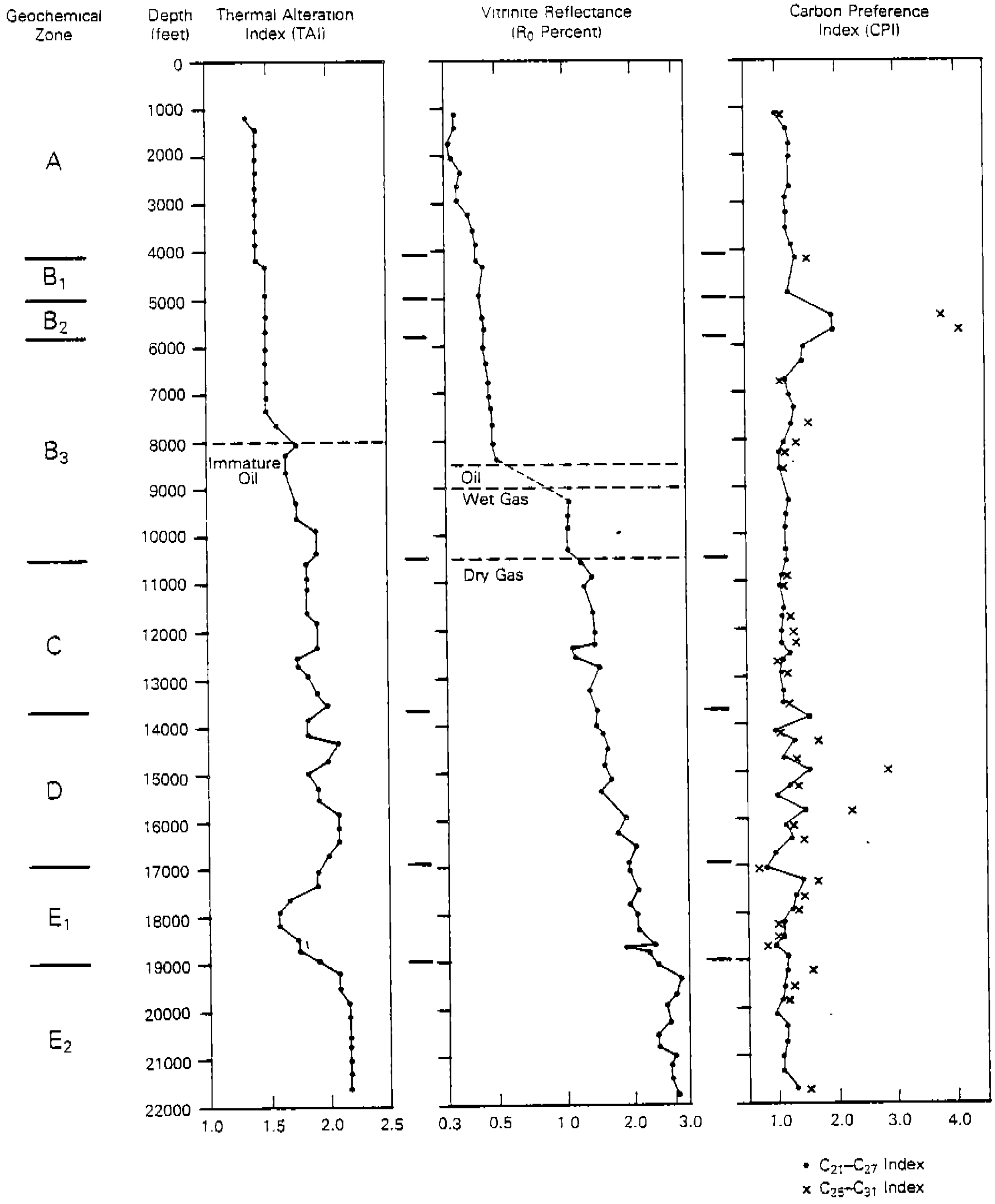


Figure 25.--Indicators of thermal maturity of sedimentary rocks in the COST No. G-2 well.

the preservation of organic matter is better below 17,500 feet than in shallower parts of the carbonate section; however, kerogen from zone E_1 is generally of poor quality with low recoveries and more degraded herbaceous debris than is found in other well intervals.

Core Lab's TAI measurements averaged 1.7 above 8,500 feet compared to 1.5 for GeoChem; for cuttings and conventional cores from the underlying interval to 12,300 feet their TAI averaged 2.9 compared to 1.8 for GeoChem. J. G. Erdman (Phillips Petroleum Company, written communication, 1977) submitted TAI results for 14 core samples supporting these higher maturation values. Organic matter from deeper well cuttings was considered by Core Lab to be largely mud contaminant, so they reported no other TAI values except for measurements of 3.0 for core samples at 13,242 and 14,583 feet. Although two or more maturation populations were recognized in these samples by all investigators, the author's examination of some of the G-2 kerogen slides indicates that the indigenous organic matter has not been strongly altered thermally in any part of the well and that the deeper carbonate section has a gradually increasing TAI with yellow-orange and orange-brown colors predominating. Certainly, the high bottom-hole temperature in the G-2 well (360°F) suggests a degree of thermal alteration, known as metagenesis, that will result in the cracking and conversion of liquid hydrocarbons to gas. However, the hydrocarbon content and composition of G-2 carbonate samples indicate that liquid petroleum can be found in this section of the well and that the TAI should not exceed 3.

A second method of determining thermal maturity is based on the reflectivity (R_o) of polished grains of vitrinite. Vitrinite reflectance increases in samples exposed to higher temperatures or a longer duration of heating as shown by Core Lab's values for the G-2 cuttings samples (fig. 25 and table 6). Dow (1977) has estimated that R_o threshold values of 0.6 percent for oil, 1.0 percent for wet gas, and 1.2 percent for dry gas are required for peak generation to begin. The G-2 vitrinite reflectance data exhibit a large jump in thermal maturation from values of about 0.50 percent at 8,300 feet to 1.04 percent for a core at 8,769 feet; the jump indicates a major unconformity in this interval, with a missing section that includes the most favorable part of the oil-generation window. Maturation levels increase steadily below this point and liquid petroleum would not survive below the oil floor (R_o = 1.35) at approximately 13,000 feet with the wet gas floor (R_o = 2.0) at about 18,000 feet. Vitrinite reflectance measurements for four samples by H. A. Kuehnert (Phillips Petroleum Company, written communication, 1977) were 0.28 percent less on the average than Core Lab's values for these cores, lowering the peak generation ceilings and floors in this well by about 3,000 feet. GeoChem (written communication, 1977) provided an additional R_o determination of 1.03 percent from core 5 (14,548-14,598 feet) compared to the 1.45 percent figure given by Core Lab. Even though GeoChem included supporting results from pyrolysis (thermal extraction) and other types of analyses for this core, W. G. Dow (Getty Oil Company, written communication, 1978) believed that their measured reflectivity was for perhydrous vitrinite, a coalification product formed in highly reducing environments that has a lower reflectance capability than true vitrinite. The analysis of recycled material or strongly oxidized vitrinite will provide values that can be considerably higher than the true maturity level. Limited amounts of indigenous vitrinite in deeper sections of the well and the number of thermal histories represented in individual samples also presented problems. The G-2 vitrinite reflectance results cannot be accepted until there are explanations for incompatibilities with hydrocarbon concentrations in the deeper carbonates and an unconformity between 8,300 and 8,800 feet representing a missing section of about 8,000 feet; these results are not supported by other data.

A direct indication of the maturation stage of strata can be obtained from the molecular composition and concentration of their indigenous hydrocarbons, although these measurements and ratios will not define the exact limits of petroleum generation. One effect of thermal alteration is to reduce the odd-carbon-numbered predominance for normal (straight-chain) paraffins. High-molecular-weight molecules in the C_{24}-C_{33} range derived from waxy plant material will show a strong odd-carbon preference for immature samples. The carbon preference index (CPI)--the ratio of odd-to even-carbon-numbered normal paraffins--was calculated over the C_{21}-C_{27} and C_{25}-C_{31} intervals (fig. 25). These values will approach 1.0 with less spread between the two indices for thermally mature samples. No clear trend appears in GeoChem's CPI data for the G-2 well and some shallow, immature samples have a low CPI, perhaps because hydrocarbons in this molecular weight range are sparse or absent and may be derived from sources other than higher plants such as planktonic algae or bacteria. However, cuttings from zone B_2 are obviously thermally immature (CPI = 1.98 for C_{21}-C_{27}; 3.96 for C_{25}-C_{31}) whereas the averages for zones E_1 and E_2 (CPI = 1.12 for C_{21}-C_{27}; 1.23 for C_{25}-C_{31}) designate mature source beds. Another indicator of source maturity is the total C_{15+} hydrocarbon/total organic carbon ratio. This ratio increases from an average of 0.014 through zone C to 0.109 in zones D, E_1, and E_2; a sharp jump at about 14,000 feet suggests the formation of liquid petroleum below this depth. Similarly, the paraffin-naphthene/aromatic ratio of the high-molecular-weight hydrocarbons goes from 0.74 as an average for zones A, B_1, B_2, and B_3 to 1.42 in zones C, D, E_1, and E_2 with a large increase at about 12,000 feet where more stable types of hydrocarbons become relatively more abundant in thermally mature sediment. Among the gasoline-range hydrocarbons, the straight-chain paraffins are more prevalent in mature samples and the average isoparaffin/normal paraffin ratio drops from 1.73 in zones A, B_1, B_2, and B_3 to 1.20 in zones C, D, E_1, and E_2 with many values less than 1.0 below the top of zone D. The gas wetness or percentage of wet gas components in the total C_1-C_4 hydrocarbons is commonly used as an approximation of maturity levels; higher values signify an addition of thermogenic hydrocarbons to immature samples containing mostly biogenic methane. Values are listed in table 6 and indicated on the C_1-C_4 hydrocarbons part of figure 24. Samples from zones B_1, B_2, and B_3 have 27 percent wetness, the highest average for the well, and the gas wetness below 15,800 feet is generally less than 10 percent, giving the appearance of a dry gas zone. Considering the distribution of all hydrocarbon species seen in the G-2 well, a true maturity profile probably lies between the thermal alteration index and the vitrinite reflectance measurements; maturation is sufficient for the onset of liquid petroleum generation below approximately 14,000 feet.

Hydrocarbon Source Character

The source material for hydrocarbons can be considered oil prone or gas prone depending on the type and composition of kerogen in prospective sections of the well. Aquatic, unstructured, and hydrogen-rich kerogen will generally provide the best oil source whereas terrestrial, structured, and hydrogen-poor organic matter will tend to produce gas. The relative abundance of the major types of kerogen in the G-2 well as determined by GeoChem are plotted in figure 26. All categories are represented fairly consistently throughout the well and the average kerogen composition is 30 percent amorphous, 26 percent coaly, 25 percent woody, and 19 percent herbaceous. Therefore the visual kerogen assessment seems to substantiate the C_{15+} extractable organic matter data which show, when considered in conjunction with total organic carbon measurements, that some gas-prone samples were collected from all sections of the well along with the more numerous oil-prone source rocks. The oil-prone amorphous-sapropelic kerogen was not reported in most samples by Core Lab who may have felt that this material represented nonindigenous mud contamination, but additional analyses by some of the well participants indicated its occurrence in somewhat lesser abundance than reported by GeoChem (G. D. Roe, Atlantic Richfield Company, written communication, 1977).

LaPlante (1974) showed that measurements of the H and C content of kerogen can distinguish between oil-prone and gas-prone sediments. This

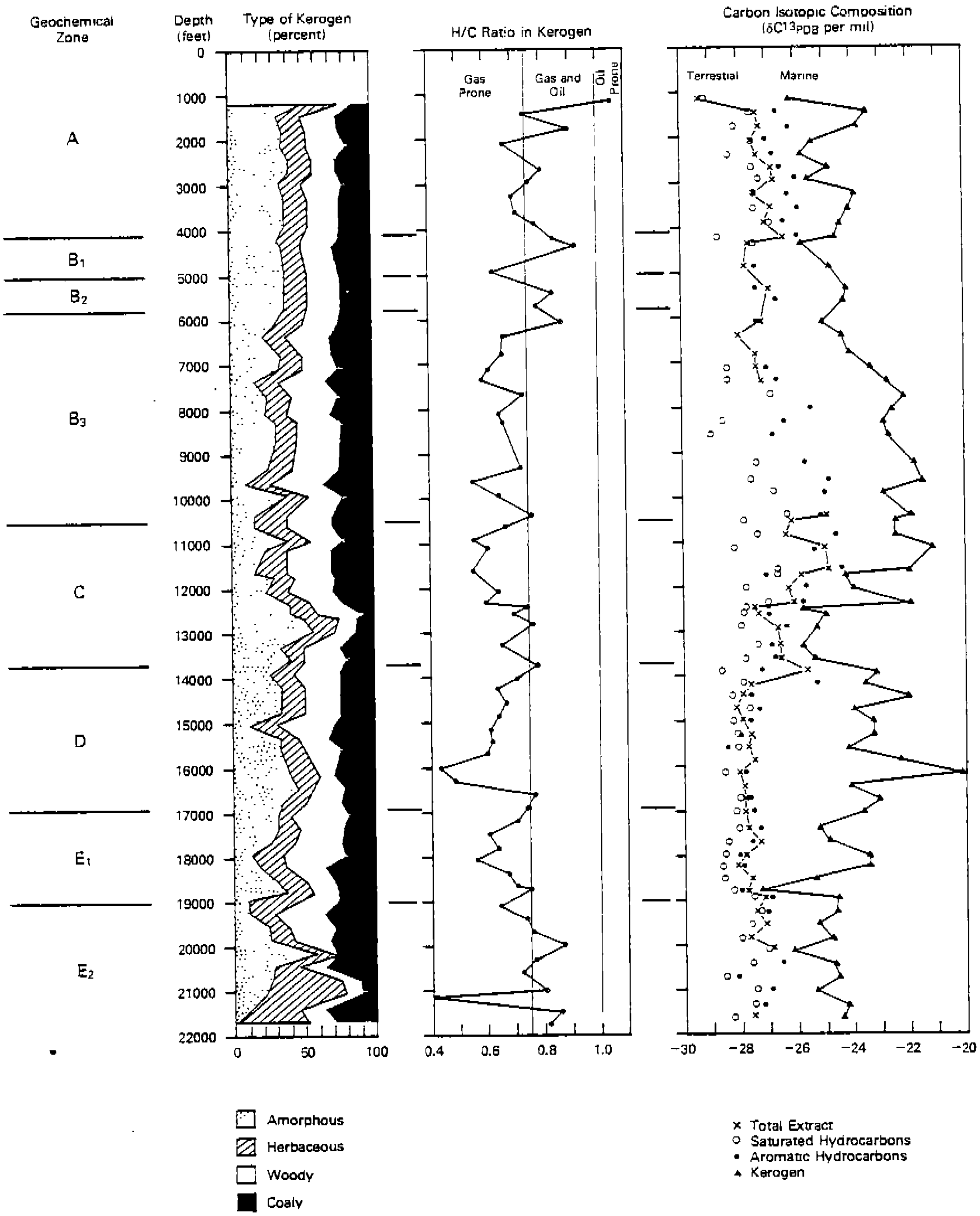


Figure 26.--Measurements showing the type of organic matter in the sedimentary rocks, COST No. G-2 well.

technique demonstrates the hydrogen-rich nature of oil source material and indicates changes in maturity level as the atomic H/C and O/C ratios decrease along well-defined pathways for the major types of organic matter (Tissot and others, 1974). Elemental analysis of kerogen, as shown by the H/C ratio (fig. 26 and table 6), was done by Core Lab on processed organic matter separated from the G-2 samples. Only the shallowest cuttings sample at a depth of 1,160 feet is definitely oil prone with a H/C ratio of 1.05. The overall average for the clastic section of the well above 10,500 feet is 0.74 while the deeper carbonate strata have an average H/C value of 0.67. Although the H/C ratio increases somewhat at the bottom of the well to 0.77 (not counting an anomalously low value of 0.41 for the cuttings from 21,170 feet) for zone E_2, it appears from these measurements that few of the G-2 source beds have the potential to generate liquid hydrocarbons. However, because Core Lab regarded the amorphous-sapropelic oil source material in the well as a mud contaminant, their elemental kerogen analysis is probably not representative of its true source character.

Carbon isotope data (fig. 26) were provided by Phillips Petroleum Company (written communication, 1978) for kerogen, C_{15+} total extract, C_{15+} paraffin-naphthene (saturated) hydrocarbons, and C_{15+} aromatic hydrocarbons separated from 68 cuttings samples. These results contribute information on the type, origin, and depositional environment of organic source material and its petroleum potential. The relative concentration of the two stable carbon isotopes is expressed as a C^{13}/C^{12} ratio compared to the Peedee belemnite standard (PDB--Chicago) according to the formula:

$$\delta\, C^{13} \text{ (per mil)} = [(R_s - R_r)/R_r] \times 1{,}000$$

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

$R_r = C^{13}/C^{12}$ in the reference standard.

The δ values for samples from a marine environment are higher (less negative) because they are enriched in C^{13} and heavier than terrestrial material. Average carbon isotope values for the G-2 well are -27.2 per mil for the total extract and -24.0 per mil for kerogen samples indicating a marine source in most cases. The potential petroleum yield is higher in the deeper section of the well as shown by an abrupt drop in the spread of isotopic values between the C_{15+} saturated and C_{15+} aromatic hydrocarbons from an average of 1.6 per mil above 14,300 feet to 0.5 per mil below this depth.

All geochemical evidence from the G-2 well suggests that hydrogen sulfide and high-sulfur oils should not be widespread in this area. No free sulfur was detected in the C_{15+} total extract and no hydrogen sulfide was noticed in the original samples or measured in a second set of 305 canned cuttings samples that was specifically analyzed for this gas at the request of the Geoscience Committee (G. S. Bayliss, GeoChem Laboratories, Inc., written communication, 1977). Evaporites can serve as a source of hydrogen sulfide through nonmicrobial sulfate reduction at high temperatures but sulfur-rich organic matter or high-sulfur oil, neither of which was present in the G-2 well, may be needed as a catalyst (Orr, 1974).

Summary and Geochemical Significance

Eight geochemical zones and subzones have been defined on the basis of the organic richness, thermal maturity, and organic matter type of sediments in the COST No. G-2 well as shown by results of the geochemical analyses discussed above. Zone-by-zone averages for the most important geochemical parameters are listed in table 7. A reliable interpretation of these data can be given only if the measurements were made for representative and indigenous organic material. The extent of drilling mud contamination is an unresolved question and a more pessimistic picture of this area's petroleum potential is possible.

The upper, predominantly clastic section of this well to a depth of

10,500 feet has adequate organic richness and contains both oil- and gas-prone source material but is thermally immature. The distribution of high-molecular-weight and gasoline-range hydrocarbons suggests that liquid petroleum generation has occurred below 14,000 feet, however. The deeper carbonates in this well also show minimal to good richness with many samples containing an excellent quality amorphous-sapropelic oil source material. There is an increase in the abundance of terrestrial organic matter at the bottom of the well and parts of zone E_2 constitute a potential gas source.

Geochemical correlation with other Atlantic OCS wells is difficult because of facies changes and the large distances involved. Zone B_2 is similar to the coaly interval from 4,600 to 5,300 feet in the COST No. G-1 well, 42 miles to the west, in its high organic carbon and light hydrocarbon content. Upper Jurassic sediments in Baltimore Canyon and Scotian Shelf wells are overlain by a thicker Tertiary and Cretaceous section than the corresponding strata in the G-2 well and have therefore been thermally altered to a greater extent. However, geochemical data on the G-2 carbonate interval appear to show a higher oil-generating potential than has been seen in other Atlantic COST wells. This area of Georges Bank, particularly deeply buried reefs or other facies where amorphous-sapropelic source material should be more abundant, will be a promising area for petroleum exploration.

Table 7.--Summary of geochemical parameters by zone

[Leaders (--) indicate no data available]

Geochemical zone------	A	B_1	B_2	B_3	C	D	E_1	E_2
top (feet)---------	1,160	4,100	5,000	5,800	10,500	13,700	16,900	19,000
bottom (feet)------	4,100	5,000	5,800	10,500	13,700	16,900	19,000	21,872
Organic richness								
Total organic carbon (weight percent)	0.59	0.42	0.89	0.58	0.24	0.26	0.25	0.25
Methane (ppm)	2,809.	267.	2,648.	281.	656.	990.	355.	1,760.
C_2-C_4 (ppm)	18.	90.	107.	98.	187.	273.	12.	36.
C_5-C_7 (ppm)	140.	537.	269.	240.	183.	362.	62.	201.
Extractable organic matter (ppm)	230.	287.	432.	298.	184.	374.	452.	470.
C_{15+} hydrocarbons (ppm)	--	62.	77.	105.	99.	215.	204.	299.
Thermal maturity								
Thermal alteration index	1.41	1.47	1.50	1.65	1.86	1.97	1.76	2.15
Vitrinite reflectance (R_o percent)	.36	.43	.44	.67	1.28	1.63	2.09	2.86
Carbon preference index (C_{21}-C_{27})	1.21	1.30	1.98	1.23	1.11	1.22	1.13	1.11
Carbon preference index (C_{25}-C_{31})	1.10	1.58	3.96	1.26	1.19	1.66	1.13	1.39
C_{15+} hydrocarbons/ total organic carbon	--	.013	.010	.014	.018	.082	.074	.170
Gas wetness (percent)	2.1	25.8	8.7	30.8	23.6	17.6	4.5	2.9
Organic matter type								
Kerogen type (percent)								
amorphous	39.	36.	39.	26.	34.	32.	24.	22.
herbaceous	17.	15.	15.	17.	17.	16.	20.	31.
woody	22.	23.	23.	29.	26.	25.	30.	19.
coaly	22.	26.	23.	28.	23.	27.	26.	28.
H/C in kerogen	.79	.80	.80	.68	.65	.64	.66	.73
Carbon isotopic values-- total extract (per mil)	-27.3	-27.3	-26.9	-27.0	-26.3	-27.7	-27.7	-27.4
Carbon isotopic values-- kerogen (per mil)	-24.7	-25.1	-24.2	-22.9	-23.8	-23.0	-24.8	-24.9

PETROLEUM POTENTIAL

By Edvardas K. Simonis

The four essential requirements for an oil and/or gas accumulation are trap, seal, reservoir, and source. In the Georges Bank Basin, the most favorable combination of these factors is interpreted to occur in the Jurassic and lowermost Cretaceous rocks. The Jurassic section, which ranges in thickness from 10,000 feet in the COST No. G-1 well to at least 16,000 feet in the G-2 well, represents the main phase of basin subsidence. Cretaceous rocks on Georges Bank are widespread but relatively thin (less than 5,000 feet), and are covered by an even thinner (less than 1,000 feet) Cenozoic section. Triassic nonmarine clastics and evaporites appear to be confined to the deepest, down-faulted parts of the basin.

Traps. Regional USGS seismic reflection data indicate that the most common type of trap in the Georges Bank Basin appears to be draping sediments over basement highs (Schlee and others, 1977). Structural closure in most of these drape features tends to be restricted to Jurassic and lowest Cretaceous beds, because structural relief decreases up-section and gradually vanishes in the younger strata.

Possibly the largest drape traps in the Georges Bank Basin occur relatively near the COST No. G-2 well. Schlee and others (1977) described an arched feature seen on USGS seismic line 1 approximately 10 miles south of the G-2 well. The arch is about 5 miles wide and at a depth of 13,000 feet the structural relief is nearly 1,000 feet. This feature differs from most of the draping structures in Georges Bank Basin in that the arching extends higher in the sedimentary section so that even the upper Lower Cretaceous beds appear slightly arched. The arch lies along a northeast-southwest structural trend. Most of the leased blocks in Lease Sale 42 are located along this trend.

Farther seaward, a Jurassic to lowest Cretaceous carbonate bank or reef trend is interpreted to be buried under the present continental slope (Grow and others, 1979; Schlee and others, 1979). Even where no vertical closure can be demonstrated, porosity development along this paleo shelf edge may create stratigraphic traps. Patch reefs and oolite banks may create additional traps landward of the Jurassic shelf edge.

Seals. Shales, tight carbonates, and, in the Iroquois-equivalent section, anhydrites are expected to provide adequate seals in most of the Georges Bank Basin. However, at the eastern part of the Georges Bank, along the continental slope, Ryan and others (1978) dredged Berriasian (earliest Cretaceous) carbonate platform deposits near Corsair Canyon; and Schlee and others (1979, p. 99) interpreted USGS seismic line 7 as showing that the Upper Jurassic reef platform complex crops out on the slope. Apparently, on the slope of the eastern part of the Georges Bank the Upper Jurassic-Lower Cretaceous "reef"-trend carbonates have been breached by erosion and the seaward flank of the trend is not sealed. Sufficient seals for the Upper Jurassic and younger reservoirs may not exist along other parts of the slope, but on the shelf adequate sealing beds are probably present throughout the section.

Reservoirs. In the COST No. G-1 well, the best reservoir characteristics are restricted to the sandstones above 10,000 feet, where commonly core porosity exceeds 20 percent and permeability exceeds 100 millidarcies. Reservoir characteristics deteriorate drastically below 10,000 feet where limestone, dolomite, and anhydrite are the prominent lithologies. Similar reduction of porosity and permeability below 10,000 feet occurs in the COST No. G-2 well. Although carbonates in both wells (which were purposely drilled off-structure) appear to be poor reservoir rocks, enhanced porosity development is anticipated on old structurally positive features such as in carbonates overlying basement highs and in reefal carbonate build-ups. On the Scotian Shelf of Canada, in the Middle Jurassic to Lower Cretaceous Abenaki Formation, significant dolomitization and associated leached limestone porosity appear to be restricted to shelf-edge reefal paleo-highs (Eliuk, 1978).

Source. The amount and type of hydrocarbon generated from a source rock depends mainly on three factors: organic richness of the beds, type of organic matter, and stage of thermal maturation of the organic matter. Geochemical data from the COST No. G-1 well (Smith and Shaw, 1980) indicate that organically richest rocks in the well occur between 4,600 and 6,200 feet (Lower Cretaceous and Upper Jurassic), but they are thermally immature, whereas the deeper thermally mature Jurassic rocks are lean in organic matter. However, oil- and gas-prone thermally mature source beds are interpreted by Smith (this report) to be present in the COST No. G-2 well, below approximately 14,000 feet, in anhydritic carbonates equivalent to the Middle and Lower Jurassic Iroquois Formation of the Canadian Atlantic Shelf. These source beds could provide hydrocarbons not only to traps in vicinity of the G-2 well but possibly also, by lateral migration, to traps in the shallower parts of the basin.

Conclusions. In the Georges Bank Basin, the best petroleum potential appears to be in the Jurassic rocks, because the most favorable traps and sufficient thermal maturation for hydrocarbon generation occur within these beds. Lack of organic-rich beds in the thermally mature zone in the COST No. G-1 well, and presence of oil- and gas-prone source beds in the Middle and Lower Jurassic section in the G-2 well indicate that the deeper part of the basin south of the G-1 well is the more prospective one.

In the COST No. G-2 well, thermally mature source beds appear to be confined mainly to the Iroquois-equivalent anhydritic carbonate section (pl. 1). This section does not contain good reservoir rocks in the G-2 well, but reservoir quality in sandstones and carbonates may improve landward from the well; seaward, near the Jurassic shelf-edge sedimentary and diagenetic conditions are interpreted to have been favorable for porosity development in carbonates.

In the Abenaki-equivalent section, sandstone and carbonate reservoir rocks are expected; dolomite and leached limestone appear to be the most likely reservoirs along the paleo-shelf edge. No mature, organic-rich beds in this section were penetrated in either the G-1 or the G-2 wells, but adequate source beds may exist in other areas, such as the slope seaward of the paleo-shelf-edge.

Petroleum potential of the Jurassic rocks in the Georges Bank Basin appears to depend mainly on the answers to two questions: (1) are there adequate reservoir rocks in the Iroquois-equivalent section, which contains good source beds?; and (2) was it possible for hydrocarbons to accumulate in the apparently adequate reservoir rocks of the Abenaki-equivalent section either by vertical migration from the Iroquois source beds or by improved Abenaki source beds in yet undrilled areas? Only additional drilling will answer these questions.

ENVIRONMENTAL CONSIDERATIONS

By Sara S. Jacobson

The COST No. G-2 well was drilled in the Georges Bank area, east of Nantucket Island, Mass. Before drilling commenced, an environmental analysis of the proposed well site was released by the USGS in December 1976. This report included descriptions of the environmental considerations and a review of comments and suggestions from other concerned Federal and State agencies and officials. As with earlier stratigraphic test wells in the COST program, it was determined that the proposed drilling did not constitute a major Federal action significantly affecting the quality of the human environment, as defined in the National Environmental Policy Act, Section 102(2)(c); therefore no Environmental Impact Statement was required.

The COST No. G-2 well was located approximately 132 statute miles east-southeast of Nantucket Island. The site was selected using available seismic data. The well location is near the center of the area included in the U.S. North Atlantic OCS Lease Sale 42 held Dec. 18, 1979; it is approximately 2.4 statute miles west of the nearest proposed sale tract. The well was purposely drilled offstructure to minimize the chances of penetrating hydrocarbon-bearing sediments. The site is approximately 42 statute miles east-southeast of the COST No. G-1 well.

The above-mentioned environmental analysis for the well considered the geological and other natural hazards as well as manmade hazards. A high-resolution marine geophysical survey of the proposed drill site, done during November 1976 indicated that there were no potential shallow/drilling or construction hazards such as faulting or shallow gas in the prospective drill area. The water depth at this location is 272 feet. The sea floor is smooth, sloping 6.6 ft/mile (1.25 m/km) to the southeast. The shallow structure is characterized by undeformed strata gently dipping to the southeast.

The sea-floor soils are moderately to poorly sorted, medium-grained sands composed of quartz, and considerable amounts of shell hash. Although Georges Bank has been dangerous to shipping because of shifting dune fields, the nearest area of major sand wave development is 18 statute miles northwest of the well site. Bottom sediment transport is also more active in shallower water (150-ft water depth) than at the G-2 location (272-ft water depth). Scour did not prove to be a problem during drilling.

The northeastern region of the U.S. is regarded as an area of relatively high seismic frequency (U.S. Department of Commerce, 1973). This was not considered a major hazard because the drilling project was to be completed within a rather short time period, and most earthquakes in the region are of low intensity. Also, the general engineering design criteria for anchored semisubmersible drilling units included structural safety factors which should have been adequate to withstand severe sea conditions and other adverse conditions resulting from an earthquake. No earthquake occurred in the vicinity of the well during the 8-month drilling operation.

Abnormally high fluid pressures (geopressures), caused by a variety of factors (i.e., rapid sedimentation, compaction, shale and salt diapirs, faulting) could lead to blowouts. Seismic surveys did not detect any potential shallow gas problems at the drill site. Precautions were taken in the event that geopressures were encountered. The mud system in the drilling operation was continuously monitored to check for geopressures and was capable of controlling unusually high geopressures. Blowout prevention devices were available to back up this system. No geopressures were encountered during the course of drilling.

Hydrogen sulfide (H_2S) could also be a drilling problem; however, no problems with H_2S have been reported in drilling on the Scotian Shelf north of the Georges Bank area.

As expected, weather conditions did not present a serious hazard to the drilling of the G-2 well. Parts of only 13 days out of a total of 239 days, or 3.2 percent of the total operational time, were lost to severe weather conditions. Wind speeds of 2-70 knots were recorded; however, wind speed was typically less than 30 knots, winds above 30 knots were recorded on only 57 days. The winds usually blew from a westerly direction. Waves up to 25 feet and swells up to 22 feet were reported, but 90 percent of the swells and 93 percent of the waves were below 10 feet. Most of the maximum weather conditions occurred during January through March.

No manmade hazards are found in the area. No recorded shipwrecks are in the area and there are no identifiable cultural resource features. The well site is approximately 88 statute miles southeast of the nearest cable line, 72 statute miles west of the Boston shipping lanes and 14 statute miles north of the westbound New York City shipping lanes. The proximity of the drill site to the shipping lanes made it necessary to keep other ships informed of the drilling activity. This did not present a greater than normal risk for drilling.

The most detrimental effects on the environment from drilling would have been caused by a major oil spill. Damage would have been incurred by fish, other wildlife and coastal tidelands. This damage could have been quite severe economically in the North Atlantic area considering the large commercial fishing industry in Georges Bank and the popularity of the New England shore as a recreation area. A report issued by the Council on Environmental Quality (1974) showed that a spill in the G-2 area would have a 20-percent chance of reaching shore in spring and less than a 10-percent chance of reaching shore in winter and summer; drilling spanned all three seasons. Even though the percentages of an oil spill reaching shore are low, the processes evaluated in this prediction are poorly understood and some of the data are taken from areas closer to shore than the G-2 well site.

Regardless of the low probability of an oil spill reaching shore, several precautions were taken to prevent and control any oil spills. As mentioned above, the drill site was purposely located off structure to avoid penetrating a hydrocarbon-rich zone. USGS regulation permit stipulations and OCS orders prescribe stringent control over the drilling operation; the drilling operation was continuously monitored by USGS inspectors. Mud pressures were monitored to check for geopressures which could cause blowouts. An oil-spill contingency plan was prepared which included the leasing of four fast-response open sea and bay skimmer systems of the type now being used in the Gulf of Mexico. Additional spill containment and cleanup equipment was also available to the operator. Fortunately, no oil spillage occurred during the drilling.

Normal drilling procedures did not seriously disturb the marine life, fishing industry activity, or recreational use of the area. During the first day of drilling, before the initial string of conductor pipe could be cemented in the hole and the marine riser installed to allow circulation to the drill ship, salt water was used as the drilling fluid to a depth of 502 feet. Some sediments were probably dislodged and cement debris was probably dispersed on the sea floor in the vicinity of the drill hole in the initial phases of drilling before the marine riser was installed. Drilling fluid, containing no oil or toxic material, was disposed of in the ocean. In the Environmental Analysis, it was estimated that a total of 700 cubic yards (535 cubic meters) of small rock chips and 515 cubic yards (395 cubic meters) of drilling mud would be discharged along the sea floor near the drill hole. The drilling mud was normally recirculated, with the mud weight adjusted for pressure control to prevent fluids from flowing between formations and zones or from leaking out at the surface.

The well was plugged and abandoned in accordance with OCS orders to prevent any future pollution at the drill hole location from migration and surface leakage of fluids. The sea floor was cleared of all obstructions and checked by an observation dive.

In conclusion, no serious hazards were encountered during the drilling operation. No long-term environmental effects resulted from the drilling procedure; all short-term effects incurred during the 8 months of drilling were minor and ended when the well site was abandoned. This COST well, along with the G-1 COST well, provided valuable and essential information and experience for conducting future drilling operations in the Georges Bank area.

SUMMARY AND CONCLUSIONS

The COST No. G-2 well was drilled to a total depth of 21,874 feet in the Georges Bank Basin about 132 statute miles east-southeast of Nantucket Island, Mass., and 42 miles east of the G-1 well. The G-2 well was drilled by a semisubmersible rig, the Ocean Victory in 272 feet of water for a total cost of $13.9 million. The well was begun on January 6, 1977, and drilling was completed 213 days later on August 7. Five strings of casing were set during drilling: 30-inch @ 545 feet, 20-inch @ 1,100 feet, 13 3/8-inch @ 4,216 feet, 9 5/8-inch @ 12,475 feet, and 7 5/8-inch @ 18,829 feet. Eight different types of geophysical ("electric") logs, three types of mud logs, and a seismic velocity log were run to evaluate the well. Drill-stem tests, sidewall cores, nine conventional cores, and ditch cutting samples were obtained and analyzed.

From 1,100 feet (in Miocene) where sampling started, to 1,620 feet (in Santonian) the G-2 well penetrated unconsolidated coarse sand and fossiliferous clayey siltstone. The Upper Cretaceous sequence between 1,620 and 2,340 feet is composed of gray calcareous, fossiliferous claystone and clayey siltstone. The Cenomanian to Lower Cretaceous section from 2,340 to 3,950 feet ranges from very coarse unconsolidated sand, fine sandstone and coquina in the upper part to glauconitic silty claystone in the lower part. Limestone between 3,950 and 4,500 feet ranges from bioclastic and oolitic grainstone to clayey micrite and calcareous claystone. Massive, weakly cemented, glauconitic sandstones between 4,500 and 5,320 feet are interbedded with minor gray shale. The Lower Cretaceous lithologic unit from 5,320 to 5,760 feet consists of gray calcareous shale interbedded with coarse to fine sandstone.

The basal Cretaceous to uppermost Jurassic section from 5,760 to 7,000 feet is composed of gray to brown micrite and minor oolitic zones interbedded with gray shale and minor sandstone. From 7,000 to 9,580 feet Upper Jurassic fine-grained sandstone is interbedded with gray and red-brown shale and minor limestone. Oxfordian oolitic limestone from 9,580 to 10,350 feet contains very coarse to fine oolites cemented by micrite. Still in Oxfordian, from 10,350 to 11,200 feet, the well penetrated argillaceous micrite along with brown and gray shales.

Straddling the Upper Jurassic-Middle Jurassic boundary at 11,800 feet, the section from 11,200 to 13,350 feet consists of brown to gray micritic limestone with some anhydritic and oolitic zones interbedded with anhydrite, fine dolomite and minor thin dark-gray shale. Below 11,800 feet the age of the section ranges from Middle Jurassic to Early Jurassic or Triassic, but the time subdivisions have not been resolved yet. Between 18,500 and 19,150 feet fine-grained sandstone ranges to calcareous siltstone and silty limestone. From 19,150 to 21,800 feet light- and dark-gray limestone occurs interbedded with dolomite and anhydrite. Salt occurs from 21,800 to total depth of 21,874.

The COST G-2 well can be divided into five geochemical zones with additional subzones. The upper two zones, down to 10,500 feet, have high organic content but are thermally immature. A subzone between 5,000 and 5,800 feet yielded high amounts of methane and could represent a prospective gas source. Maturation increases in the deeper, predominantly carbonate section so that the two deepest zones, below approximately 14,000 feet, are in the initial stages of oil generation and represent a potentially favorable oil source sequence. In fact, excellent oil-like C_{15+} hydrocarbons have been detected in most samples from these zones. The kerogen type in the lowest subzone, 19,000 to 21,800 feet, is more terrestrial and thus more gas prone. Numerous minor gas shows were detected in sidewall cores taken in the well between 4,000 and 10,000 feet.

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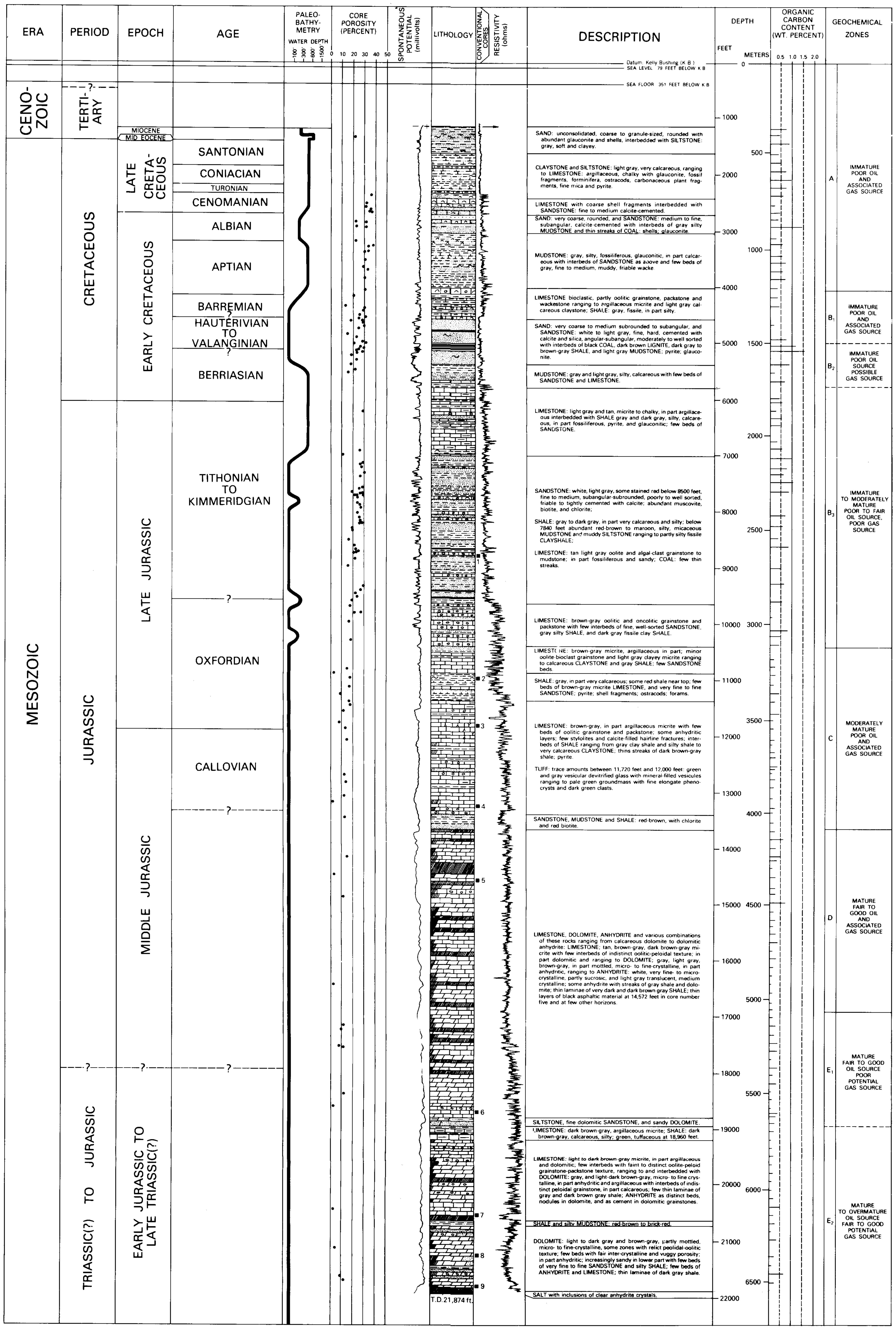
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-269
PLATE 1



SAND: unconsolidated, coarse to granule-sized, rounded with abundant glauconite and shells, interbedded with SILTSTONE: gray, soft and clayey.

CLAYSTONE and SILTSTONE: light gray, very calcareous, ranging to LIMESTONE: argillaceous, chalky with glauconite, fossil fragments, forminifera, ostracods, carbonaceous plant fragments, fine mica and pyrite.

LIMESTONE with coarse shell fragments interbedded with SANDSTONE: fine to medium calcite-cemented.

SAND: very coarse, rounded, and SANDSTONE: medium to fine, subangular, calcite-cemented with interbeds of gray silty MUDSTONE and thin streaks of COAL: shells; glauconite.

MUDSTONE: gray, silty, fossiliferous, glauconitic, in part calcareous with interbeds of SANDSTONE as above and few beds of gray, fine to medium, muddy, friable wacke.

LIMESTONE bioclastic, partly oolitic grainstone, packstone and wackestone ranging to argillaceous micrite and light gray calcareous claystone; SHALE: gray, fissile, in part silty.

SAND: very coarse to medium subrounded to subangular, and SANDSTONE: white to light gray, fine, hard, cemented with calcite and silica, angular-subangular, moderately to well sorted with interbeds of black COAL, dark brown LIGNITE, dark gray to brown-gray SHALE, and light gray MUDSTONE; pyrite; glauconite.

MUDSTONE: gray and light gray, silty, calcareous with few beds of SANDSTONE and LIMESTONE.

LIMESTONE: light gray and tan, micrite to chalky, in part argillaceous interbedded with SHALE gray and dark gray, silty, calcareous, in part fossiliferous, pyrite, and glauconitic; few beds of SANDSTONE.

SANDSTONE: white, light gray, some stained red below 8500 feet, fine to medium, subangular-subrounded, poorly to well sorted, friable to tightly cemented with calcite; abundant muscovite, biotite, and chlorite;

SHALE: gray to dark gray, in part very calcareous and silty; below 7840 feet abundant red-brown to maroon, silty, micaceous MUDSTONE and muddy SILTSTONE ranging to partly silty fissile CLAYSHALE;

LIMESTONE: tan light gray oolite and algal-clast grainstone to mudstone; in part fossiliferous and sandy; COAL: few thin streaks.

LIMESTONE: brown-gray oolitic and oncolitic grainstone and packstone with few interbeds of fine, well-sorted SANDSTONE, gray silty SHALE, and dark gray fissile clay SHALE.

LIMESTONE: brown-gray micrite, argillaceous in part; minor oolite-bioclast grainstone and light gray clayey micrite ranging to calcareous CLAYSTONE and gray SHALE; few SANDSTONE beds.

SHALE: gray, in part very calcareous; some red shale near top; few beds of brown-gray micrite LIMESTONE, and very fine to fine SANDSTONE; pyrite; shell fragments; ostracods; forams.

LIMESTONE: brown-gray, in part argillaceous micrite with few beds of oolitic grainstone and packstone; some anhydritic layers; few stylolites and calcite-filled hairline fractures; interbeds of SHALE ranging from gray clay shale and silty shale to very calcareous CLAYSTONE; thins streaks of dark brown-gray shale; pyrite.

TUFF: trace amounts between 11,720 feet and 12,000 feet: green and gray vesicular devitrified glass with mineral-filled vesicules ranging to pale green groundmass with fine elongate phenocrysts and dark green clasts.

SANDSTONE, MUDSTONE and SHALE: red-brown, with chlorite and red biotite.

LIMESTONE, DOLOMITE, ANHYDRITE and various combinations of these rocks ranging from calcareous dolomite to dolomitic anhydrite: LIMESTONE; tan, brown-gray, dark brown-gray micrite with few interbeds of indistinct oolitic-peloidal texture; in part dolomitic and ranging to DOLOMITE; gray, light gray, brown-gray, in part mottled, micro- to fine-crystalline, in part anhydritic, ranging to ANHYDRITE: white, very fine- to microcrystalline, partly sucrosic, and light gray translucent, medium crystalline; some anhydrite with streaks of gray shale and dolomite; thin laminae of very dark and dark brown gray SHALE; thin layers of black asphaltic material at 14,572 feet in core number five and at few other horizons.

SILTSTONE, fine dolomitic SANDSTONE, and sandy DOLOMITE.

LIMESTONE: dark brown-gray, argillaceous micrite; SHALE: dark brown-gray, calcareous, silty; green, tuffaceous at 18,960 feet.

LIMESTONE: light to dark brown-gray micrite, in part argillaceous and dolomitic; few interbeds with faint to distinct oolite-peloid grainstone-packstone texture, ranging to and interbedded with DOLOMITE: gray, and light-dark brown-gray, micro- to fine crystalline, in part anhydritic and argillaceous with interbeds of indistinct peloidal grainstone, in part calcareous; few thin laminae of gray and dark brown gray shale; ANHYDRITE as distinct beds, nodules in dolomite, and as cement in dolomitic grainstones.

SHALE and silty MUDSTONE: red-brown to brick-red.

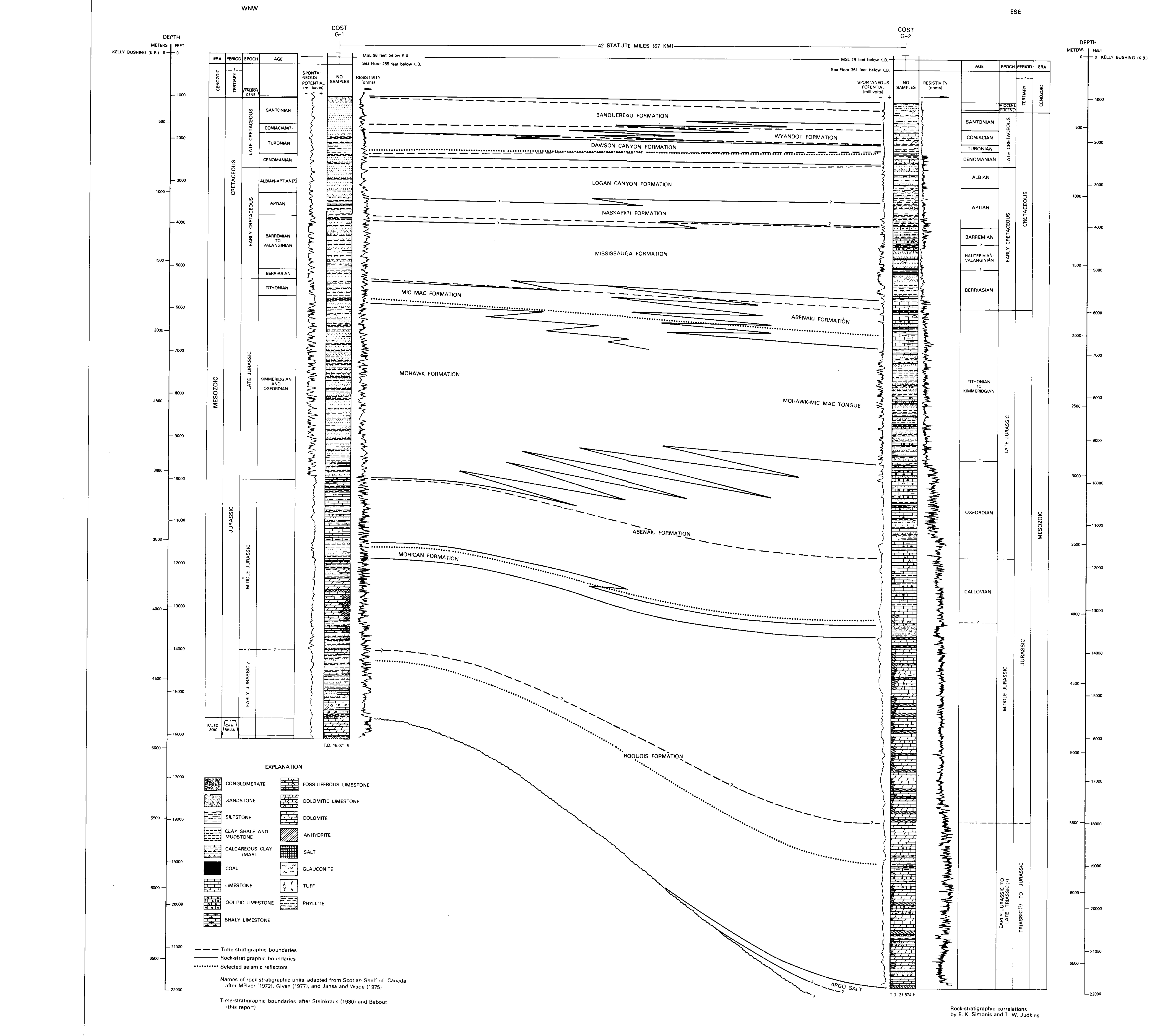
DOLOMITE: light to dark gray and brown-gray, partly mottled, micro- to fine-crystalline, some zones with relict peolidal-oolitic texture; few beds with fair inter-crystalline and vuggy porosity; in part anhydritic; increasingly sandy in lower part with few beds of very fine to fine SANDSTONE and silty SHALE; few beds of ANHYDRITE and LIMESTONE; thin laminae of dark gray shale.

SALT with inclusions of clear anhydrite crystals.

Plate 1. STRATIGRAPHIC COLUMN AND SUMMARY CHART OF GEOLOGIC DATA, COST NO. G–2 WELL, GEORGES BANK, U.S. NORTH ATLANTIC CONTINENTAL MARGIN

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-269
PLATE 2



Names of rock-stratigraphic units adapted from Scotian Shelf of Canada after McIver (1972), Given (1977), and Jansa and Wade (1975)

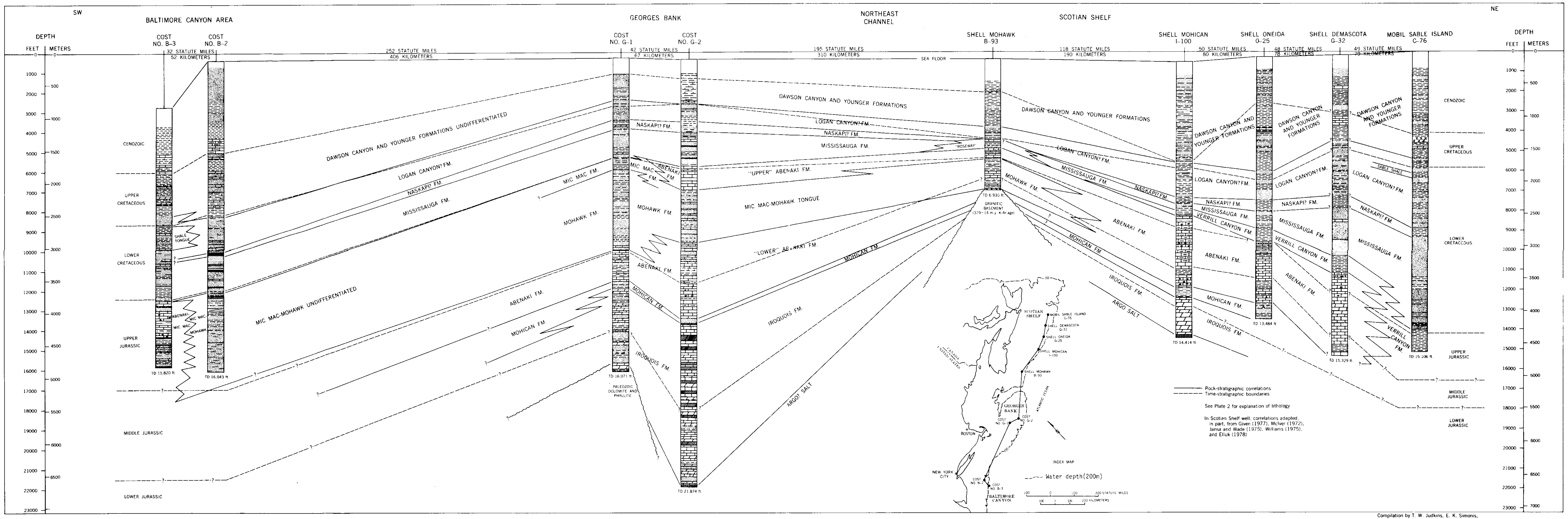
Time-stratigraphic boundaries after Steinkraus (1980) and Bebout (this report)

Rock-stratigraphic correlations by E. K. Simonis and T. W. Judkins

Plate 2. TENTATIVE CORRELATION CHART OF COST WELL G-1 AND G-2, GEORGES BANK, U.S. NORTH ATLANTIC CONTINENTAL MARGIN

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-269
PLATE 3



Rock-stratigraphic correlations
Time-stratigraphic boundaries

See Plate 2 for explanation of lithology

In Scotian Shelf well, correlations adapted, in part, from Given (1977), McIver (1972), Jansa and Wade (1975), Williams (1975), and Eliuk (1978)

Plate 3. TENTATIVE STRATIGRAPHIC CORRELATIONS OF SELECTED WELLS FROM BALTIMORE CANYON AREA TO SCOTIAN SHELF OF CANADA

Compilation by T. W. Judkins, E. K. Simonis,
and B. A. Heise

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

OPEN-FILE REPORT NO. 269
PLATE 4

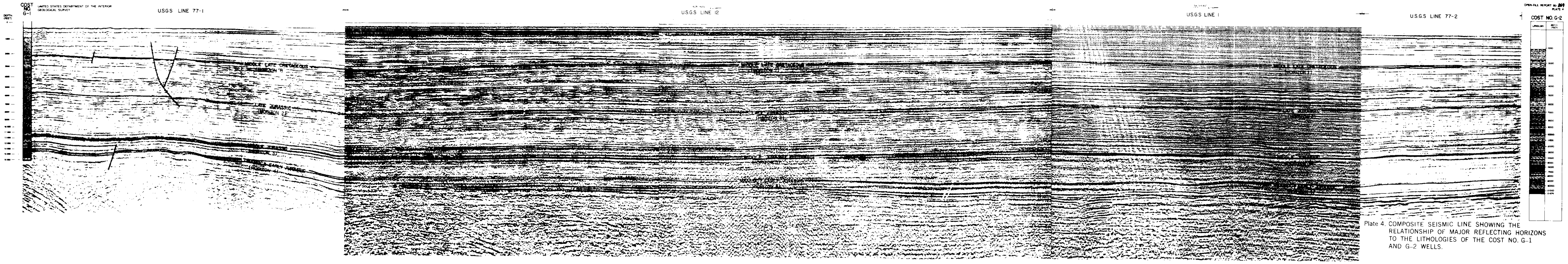


Plate 4. COMPOSITE SEISMIC LINE SHOWING THE RELATIONSHIP OF MAJOR REFLECTING HORIZONS TO THE LITHOLOGIES OF THE COST NO. G-1 AND G-2 WELLS.