Geological and Operational Summary
ST. GEORGE BASIN COST NO. 2 WELL

Bering Sea, Alaska

OCS Report MMS 84-0018

United States Department of the Interior
Minerals Management Service

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Ronald F. Turner (Editor)
Colleen M. McCarthy
C. Drew Comer
John A. Larson
J. G. Bolm
Tabe O. Flett
Allen J. Adams

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March 1984

UNITED STATES DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

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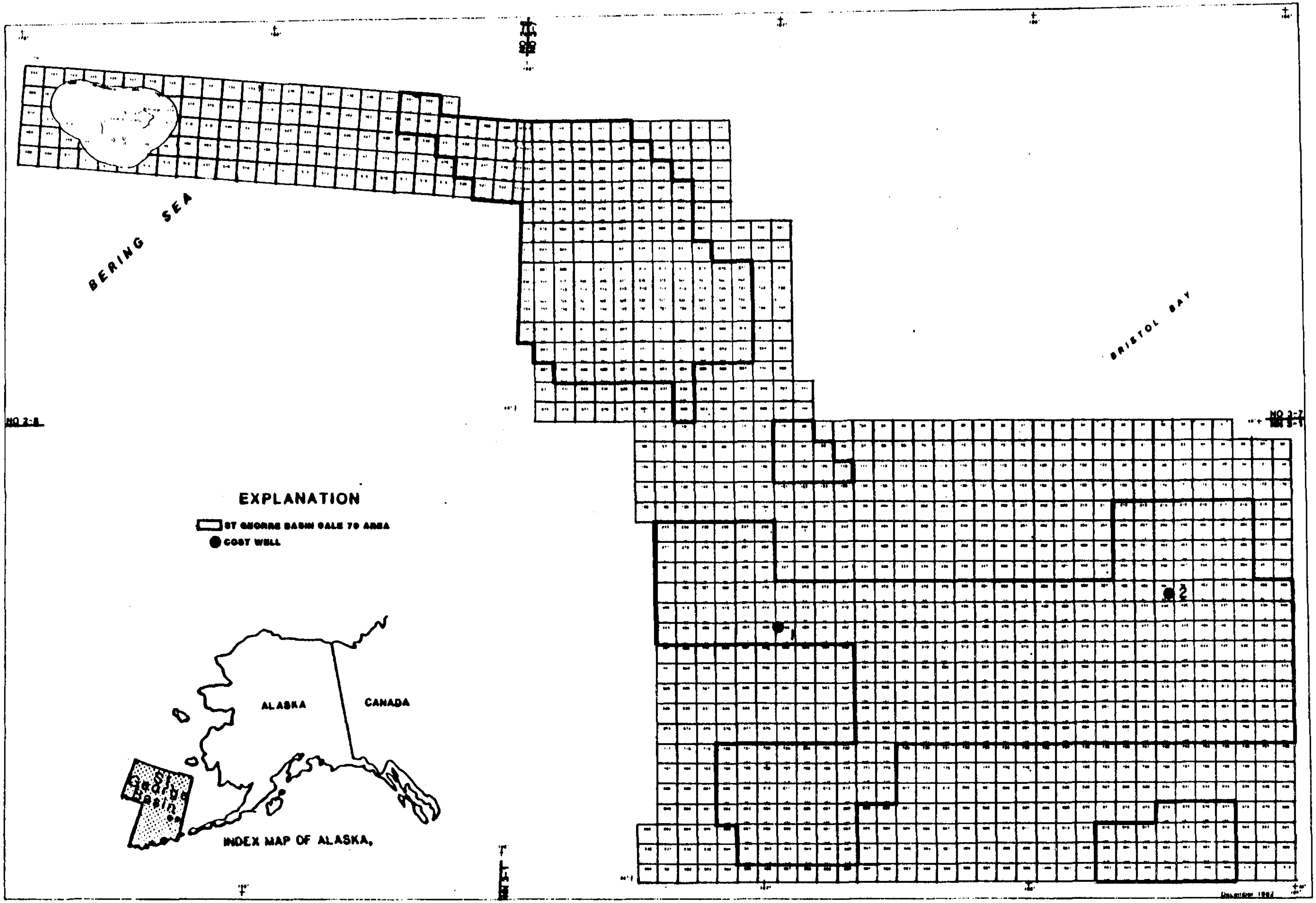

Figure 1. Location map showing St. George Basin Sale 70 area and COST No. 1 and No. 2 Wells.

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Ronald F. Turner, Editor

INTRODUCTION

Title 30, Code of Federal Regulations (CFR), paragraph 251.14 stipulates that geological data and processed geological information obtained from Deep Stratigraphic Test wells drilled on the Outer Continental Shelf (OCS) be made available for public inspection 60 calendar days after the issuance of the first Federal lease within 50 nautical miles of the well site or 10 years after completion of the well if no leases are issued. Tracts within this distance of the second St. George Basin Deep Stratigraphic Test well (designated the ARCO St. George Basin COST No. 2 Well by the operator and hereafter referred to as the well or the No. 2 well) were offered for lease in Sale 70 on April 12, 1983. One hundred and fifty bids on 97 tracts were received with the total high bids amounting to $427,343,829.68. Ninety-six bids were accepted and one was rejected. The effective issuance date of the leases is March 1, 1984.

The ARCO St. George Basin COST No. 2 well was completed on September 2, 1982, in Block 390, located approximately 165 miles southeast of St. George Island, Alaska (fig. 1). The well data listed in the appendix are available for public inspection at the Minerals Management Service Field Operations office, located at 800 "A" Street, Anchorage, Alaska 99501.

All depths are measured in feet from the Kelly Bushing (KB), which was 77 feet above sea level. For the most part, measurements are given in U.S. Customary Units except where scientific convention dictates metric usage. A conversion chart is provided. The interpretations contained herein are chiefly the work of Minerals Management Service (MMS) personnel, although substantial contributions were made by geoscience consulting companies.

EQUIVALENT MEASUREMENT UNITS

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 statute mile = 1.61 kilometers
1 nautical mile = 1.85 kilometers = 1.15 statute miles = 6,080 feet
1 knot = 1 nautical mile/hour
Temperature in degrees Fahrenheit less 32, divided by 1.8 = degrees Celsius

1 pound = 0.45 kilogram
1 pound/gallon = 119.83 kilograms/cubic meter
1 pound/square inch = 0.07 kilogram/square centimeter
1 gallon = 3.78 liters (cubic decimeters)
1 barrel = 42 U.S. gallons = 0.16 cubic meter

OPERATIONAL SUMMARY

by

Colleen M. McCarthy

The St. George Basin COST No. 2 well was drilled by the SEDCO 708, a column-stabilized, self-propelled, semisubmersible drilling rig. The SEDCO 708, owned by SEDCO Maritime, Inc., was built in 1977 by Kaiser Steel Corporation at Oakland, California, and was given a classification of ABS + A-1 (E) (M) AMS. It was designed to withstand 110-foot waves and 100-knot winds while drilling in 600 feet of water. The rig can operate in 1500-foot depths, and the American Bureau of Shipping approved extreme operating temperature is -30° C. The rated drilling depth is 25,000 feet.

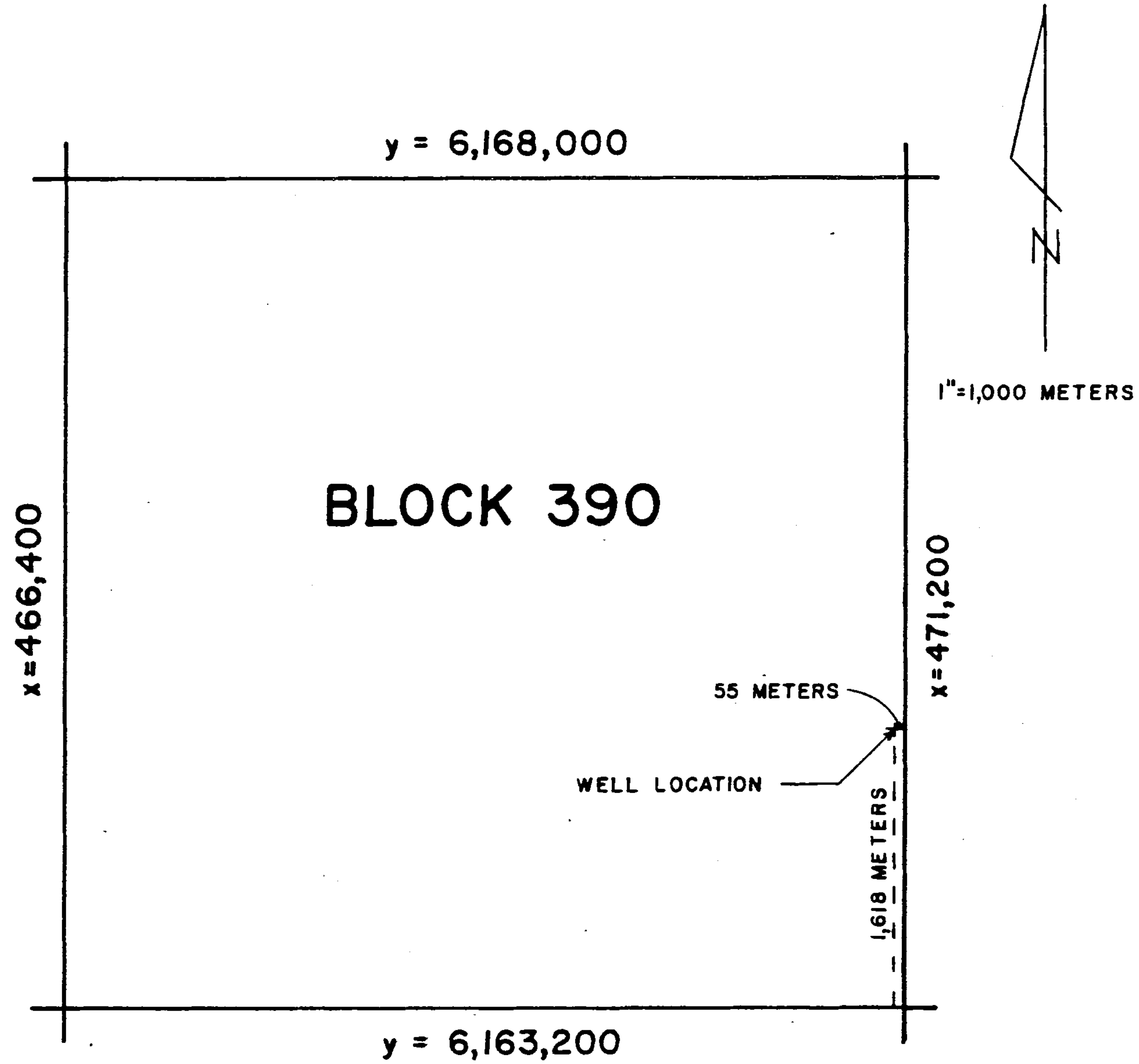
The SEDCO 708 was inspected before drilling began, and operations were observed by Minerals Management Service personnel throughout the drilling period to ensure compliance with Department of Interior regulations and orders.

Cold Bay, Alaska, approximately 110 miles southeast of the well site, was utilized as the primary shore base for personnel transport. Dutch Harbor, Alaska, was used as an equipment and material supply base. Two seagoing supply vessels were used to transport drilling materials and supplies, including fuel, from Dutch Harbor to the rig. Helicopters certified for instrument flight were used to transport personnel, groceries, and lightweight equipment between the rig and Cold Bay. Personnel, equipment, and supplies were transported to and from the shore base and Anchorage by chartered and commercial air carriers.

The well was spudded at 1500 hours Alaska Standard Time, May 19, 1982. The total depth (TD) of 14,626 feet was reached on August 22, 1982, after 95 days of drilling. The well was plugged and abandoned on September 2, 1982, and the rig was released.

ARCO Alaska acted as operator for the following eighteen petroleum companies which shared expenses for the well:

A Ruddy Petina Oil Company, Inc.
American Petrofina Exploration Company
AMOCO Production Company
Chevron, U.S.A., Inc.
Cities Service Company
Conoco, Inc.
Elf Aquitaine Oil and Gas
Exxon Company, U.S.A.
Getty Oil Company
Gulf Oil Company, U.S.A.
Marathon Oil Corporation
Mobil Exploration and Producing Services, Inc.
Murphy Oil Corporation
Pennzoil Company
Phillips Petroleum Company
Shell Oil Company
Texaco, U.S.A.
Union Oil Company of California



GEODETIC POSITION	UNIVERSAL TRANSVERSE MERCATOR COORDINATES, ZONE 3, in METERS.
LAT. 55° 37'49.17" N.	y=6,164,818
LONG. 165° 27'29.81" W.	x= 471,145

Figure 2. Final location plat showing the position of the St. George Basin COST No. 2 Well.

The well location was lat 55°37'49.17" N., long 165°27'29.81" W., or UTM coordinates (zone 3) X = 471,145 meters and Y = 6,164,818 meters. The final well site was located in Block 390 (fig. 2). The water depth was 375 feet. All measurements were made from the Kelly Bushing (KB), which was 77 feet above sea level and 452 feet above the sea floor. The well was drilled with less than 1-degree deviation from normal to a depth of 5000 feet. At 6479 feet, the angle increased to 11 1/2 degrees, but was brought back to 1 1/2 degrees in the next thousand feet. At 13,000 feet, the deviation began increasing again to a final deviation of 9 1/2 degrees at TD.

Drilling stipulations required the operator to provide the Minerals Management Service with all well logs, samples, core slabs, and operational and technical reports at the same time as industry participants.

DRILLING PROGRAM

The No. 2 well was drilled using one 26-inch bit to 578 feet, one 8 1/2-inch pilot hole bit to 1428 feet, two 17 1/2-inch bits to 1385 feet, twenty 12 1/4-inch bits to 12,796 feet, and six 8 1/2-inch bits to 14,626 feet (TD). Additional bits were used for hole opening, to drill through cement, for cleanout trips, and for the conventional coring program. Drilling rates ranged from 2 to 225 feet/hour. The average drilling rate was 100 feet/hour at 5300 feet, decreasing gradually to 50 feet/hour at 8900 feet, and decreasing to a rate of 10 feet/hour at TD. The daily drilling progress for the well is shown in figure 3.

Four strings of casing were set (fig. 4) using Class G cement. The 30-inch casing was set at 570 feet with 675 sacks of cement. The 20-inch casing was set at 1423 feet with 2450 sacks of cement. The 13 3/8-inch casing was set at 4965 feet with 2427 sacks of cement; loss of circulation occurred while cementing this casing string, and although the amount of cement was calculated for surface returns, the cement top is estimated to be at 2600 feet. The 9 5/8-inch casing was set at 10,035 feet with 2000 sacks of cement, and the cement top is estimated to be at 3400 feet. The well was open hole from the 9 5/8-inch casing shoe to TD.

At a drilled depth of 12,796 feet, the pipe became stuck at 7845 feet. After 11 days of conditioning and circulating the mud and utilizing various fishing equipment, the pipe came free with the bit at 5914 feet. The hole was completed with no further problems.

There was one oil spill reported to the Minerals Management Service on July 8, 1982. The spill occurred when a fuel transfer hose ruptured. Approximately 30 gallons of diesel oil spilled into the Bering Sea. A boom was deployed with absorbent pads placed inside and the fuel spill was cleaned up.

The abandonment program is shown in figure 4. A 215-foot cement plug was set at 12,385 feet. At 10,000 feet, a 9 5/8-inch squeeze packer was set with cement above and below. The 9 5/8-inch casing was perforated between 4499 and 4501 feet with 4 shots per foot, and another 9 5/8-inch squeeze packer was set at 4450 feet. The bottom of the cement was calculated to be at 5000 feet and the

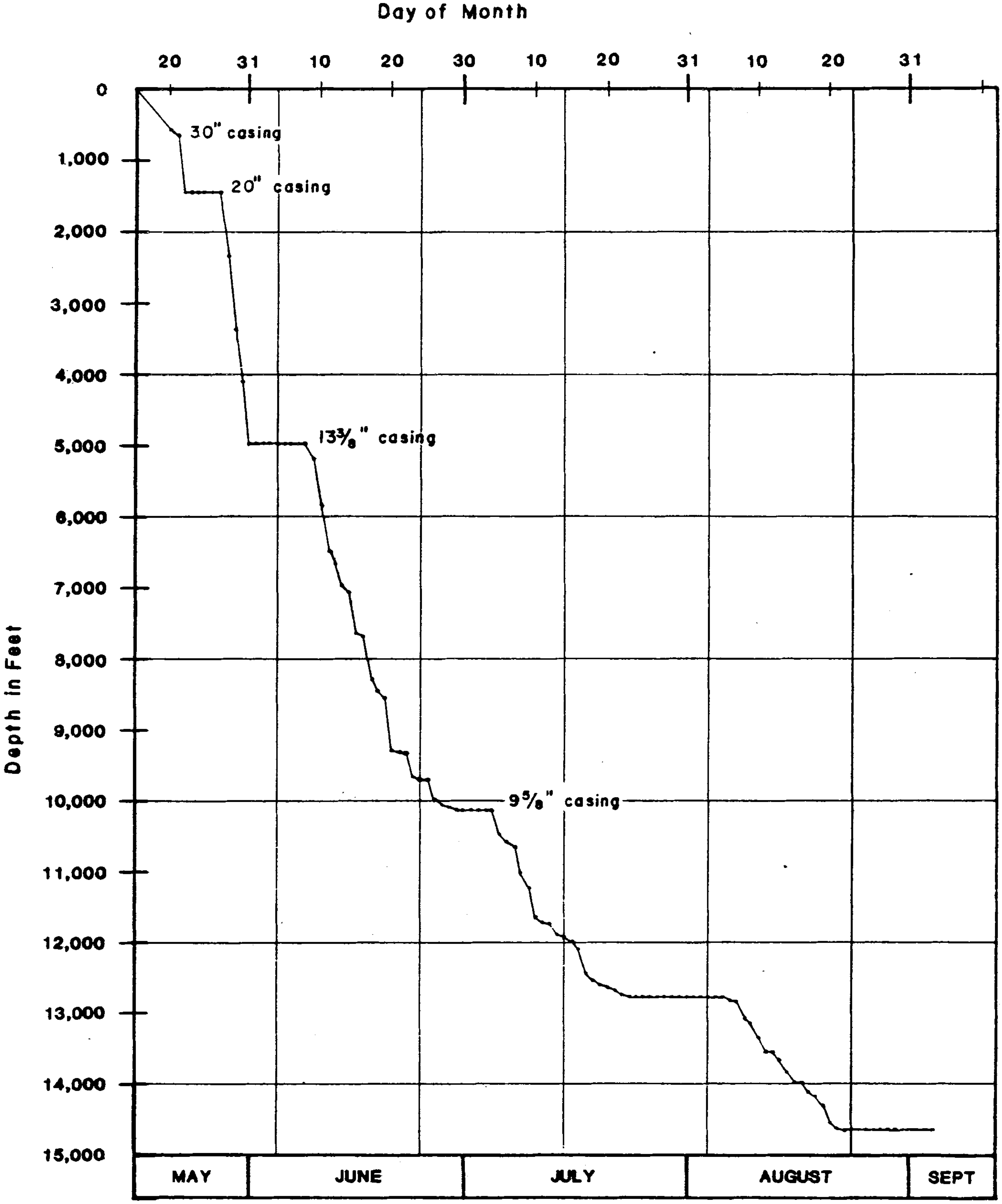


Figure 3. Graph showing daily drilling progress for the St. George Basin COST No. 2 Well.

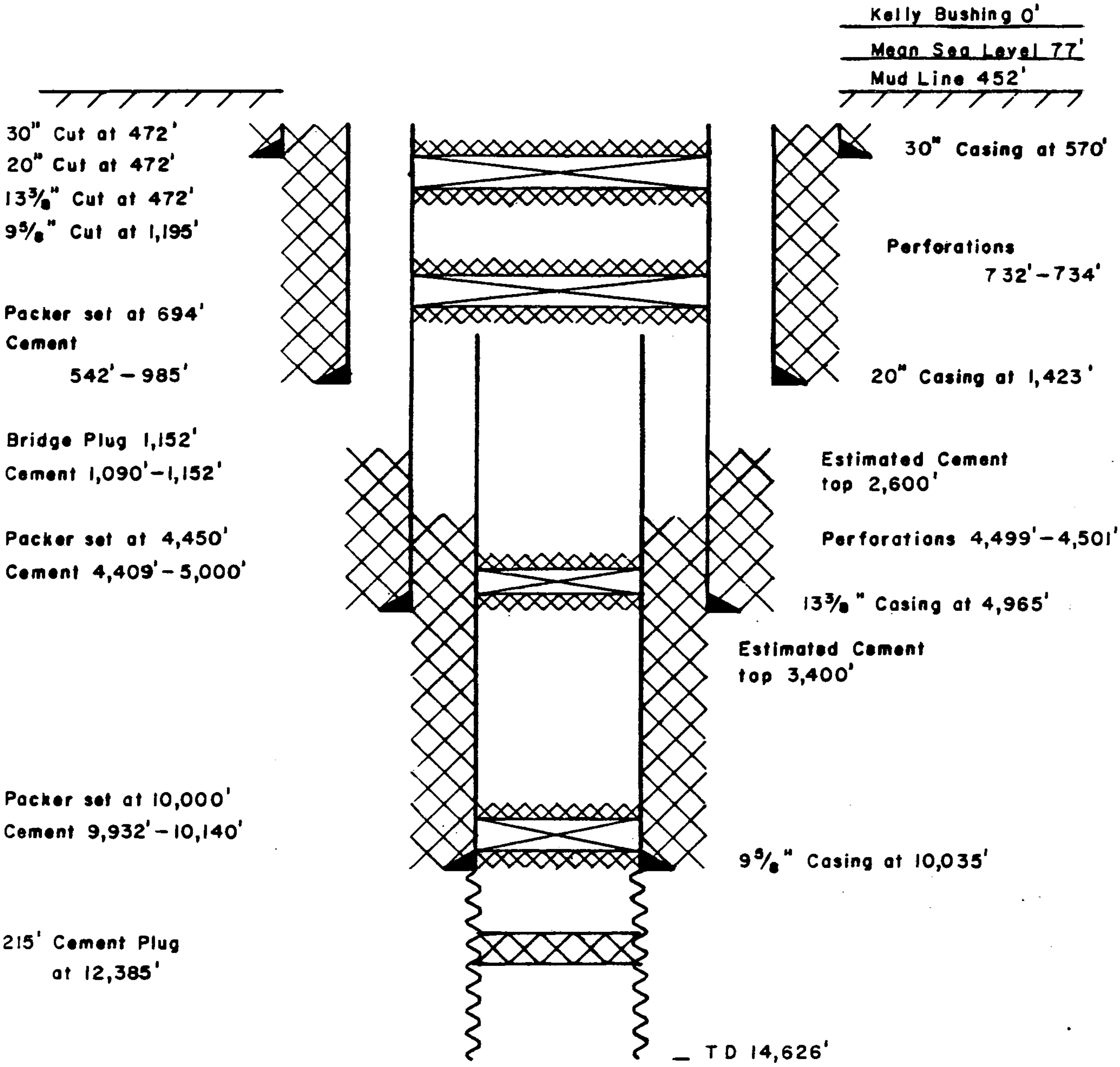


Figure 4. Schematic diagram showing casing strings, plugging and abandonment program, St. George Basin COST No. 2 Well.

top at 4409 feet. The 9 5/8-inch casing was cut at 1195 feet. At 1152 feet, a 13 3/8-inch bridge plug was set. Perforations were made in the 13 3/8-inch casing between 732 and 734 feet, and a squeeze packer was set at 694 feet. The bottom of the cement was calculated to be at 985 feet and the top at 542 feet. The 30-inch, 20-inch, and 13 3/8-inch casing strings were all cut at 472 feet.

DRILLING MUD

Changes in selected drilling mud properties are shown in figure 5. Seawater was used as drilling fluid for the first 1400 feet of hole. A drilling mud with a weight of 9.3 pounds/gallon and a viscosity of 44 was introduced at 1400 feet. Mud weight increased to 9.8 pounds/gallon at 9600 feet and decreased to 9.7 pounds/gallon at TD. Viscosity was as low as 38 seconds at 8000 feet and reached 50 seconds at 13,750 feet. Most viscosity values were between 40 and 43 seconds. The initial drilling mud pH was 9.4. The pH increased to a maximum of 13 at 6600 feet, then decreased to 10.5 at TD. The initial chloride concentration in the mud was 3300 ppm, the highest value for the well. Chloride concentration was as low as 1200 ppm at 9050 feet, and the bottom hole value was 1500 ppm. Mud-logging services were provided by Exploration Logging from 1400 feet to TD.

SAMPLES AND TESTS

Drill cuttings were collected from 1460 to 14,626 feet. These samples were analyzed for organic geochemistry, lithology, and paleontology. Seventeen conventional cores were taken. The cores were analyzed for porosity, permeability, grain density, organic geochemistry, lithology, and paleontology. Table 1 is a summary of the program.

Table 1. Conventional cores

Core No.	Interval (feet)	Recovered (feet)
1	4104-4132	26.9
2	5155-5185	29.5
3	6650-6671	13.8
4	7017-7047	27.2
5	7635-7665	29.4
6	8460-8490	30
7	9262-9298.8	36.8
8	9640-9670	28.91
9	10,058-10,098	40
10	10,596-10,636	32
11	11,702-11,741	1
12	11,988-12,018	26
13	12,420-12,450	27.7
14	12,570-12,600	27
15	13,556-13,576	20
16	14,182-14,203	21
17	14,600-14,626	23.5

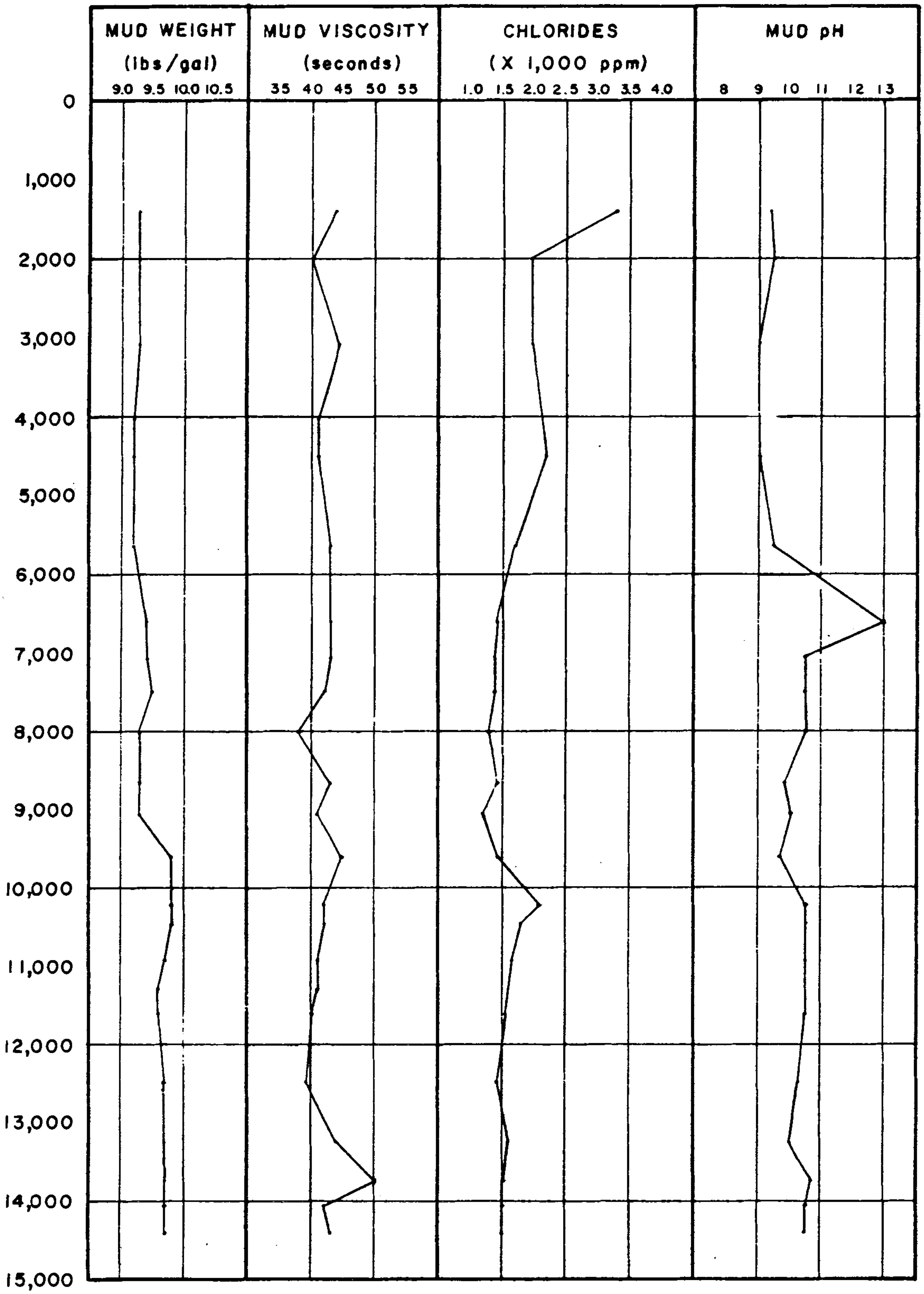


Figure 5. Changes with depth of drilling mud properties, including mud weight, viscosity, total chlorides, and pH, St. George Basin COST No. 2 Well.

Three series of sidewall cores were shot. At 4976 feet, 76 cores were recovered in 90 attempts, with 14 misfired or lost. At 10,135 feet, 153 cores were recovered in 196 attempts, with 36 misfires, 4 lost bullets, and 3 empty bullets. At 14,626 feet, 108 cores were recovered in 179 attempts, with 14 misfires, 50 lost bullets, and 7 empty bullets. Three hundred and thirty-seven successful sidewall cores were obtained.

The types of logs and the intervals logged are as follows:

4976 to 1422 feet

Dual Induction Lateral Log
Borehole Compensated Sonic Log/Gamma Ray/Spontaneous Potential/Caliper Log
Compensated Formation Density/Compensated Neutron Log
Long Spaced Sonic Log
Dipmeter
Proximity Microlog
Repeat Formation Tester

10,135 to 4976 feet

Dual Induction Lateral Log/Spontaneous Potential/Gamma Ray
Bulk Density Log/Neutron Gamma Tool
High Resolution Continuous Dipmeter
Compensated Formation Density/Compensated Neutron Log/Neutron Gamma Tool
Repeat Formation Tester
Proximity Microlog
Long Spaced Sonic Log
Cement Bond Log
Borehole Compensated Sonic Log/Gamma Ray
Velocity Survey
Vertical Seismic Profile

14,622 to 10,135 feet

Dual Induction Lateral Log/Borehole Compensated Sonic Log/Gamma Ray/Spontaneous Potential
Long Spaced Sonic Log/Gamma Ray
Compensated Formation Density Log/Compensated Neutron Log/Neutron Gamma Tool
Dipmeter
Temperature Survey

There were no drill stem tests made on this well.

WEATHER

Weather conditions were monitored from the middle of May until the end of August 1982. Waves of 10 feet or more occurred on 15 days, and a maximum wave height of 17 feet was reached in the latter parts of May and August. In late May and early June, wind speeds greater than 45 knots were recorded on 2 days. The maximum wind speed of 54 knots was recorded in early June. The temperature ranged from 30° F in May to 53° F in August.

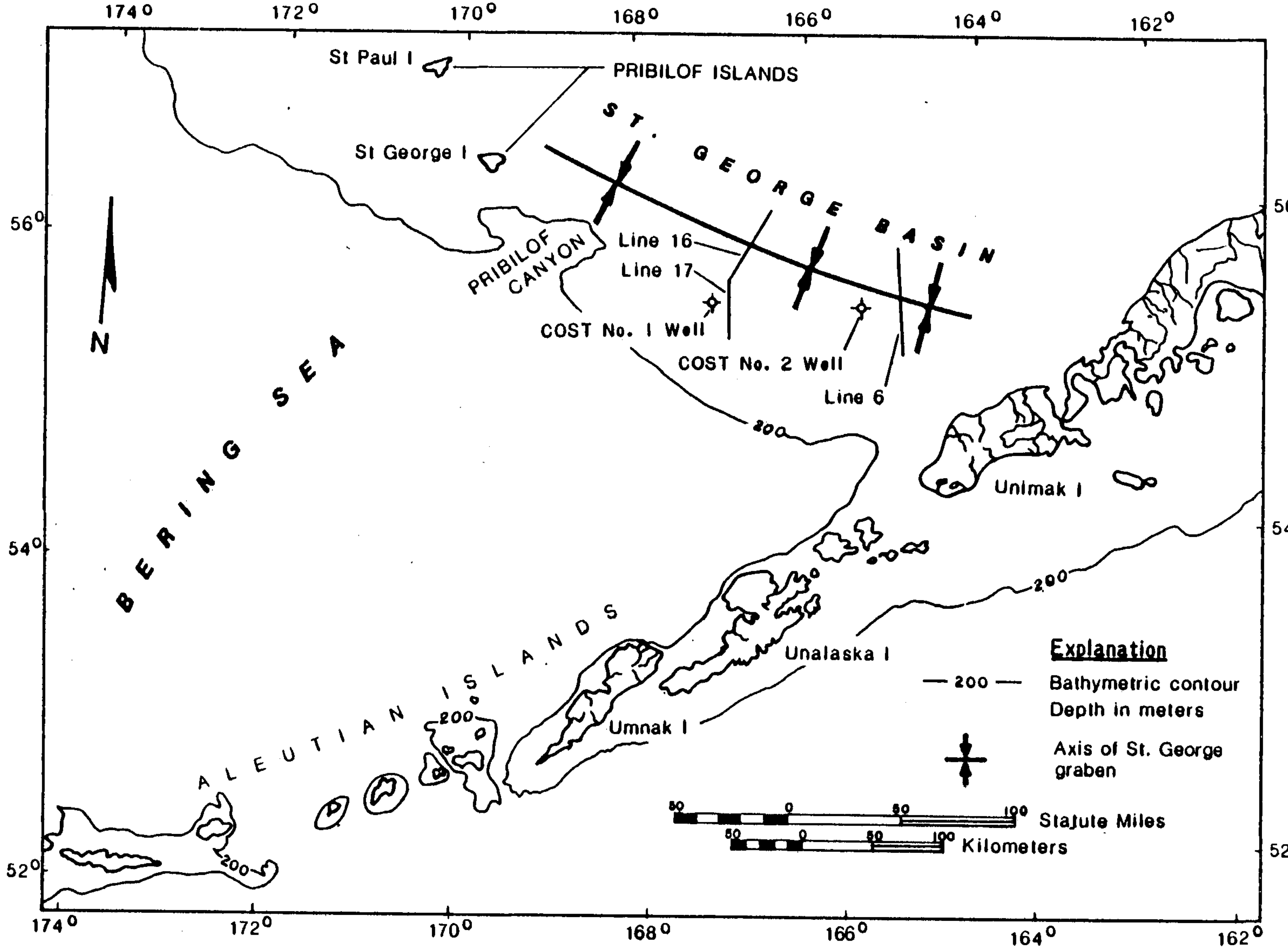


FIGURE 6. Location map of St. George Basin, COST wells, and U.S. Geological Survey seismic lines.

SHALLOW GEOLOGIC SETTING

by

C. Drew Comer

The shallow geologic characteristics of the drill site were identified in a high-resolution geophysical survey (Nekton, Inc., 1980a). This study evaluated potential drilling hazards in shallow sediments. A more detailed discussion of the regional environmental geology is included in the Final Environmental Impact Statement (U.S. Minerals Management Service, 1982), Gardner and others (1979), and Comer (in press).

REGIONAL ENVIRONMENTAL GEOLOGY

The St. George basin is located on the Outer Continental Shelf of the Bering Sea in water depths ranging from 340 to 530 feet. The sea floor is essentially flat and featureless with an average regional slope of less than one degree. According to Gardner and others (1980), the surficial sediments consist mostly of unconsolidated silt and silty sand with small amounts of volcanic ash and diatoms and are mostly relict from a period of low sea level. Very little recent sediment is being transported into the area.

Glacial activity in the Pleistocene caused lower sea levels and exposed much of the shelf. The outer Bering Sea shelf probably fluctuated between sediment-starved conditions, as at present, and sediment-enriched conditions, when lower sea levels made more sediment available by exposing the inner and middle shelf to subaerial erosion. Shallow strata on high-resolution seismic reflection profiles appear as rhythmically interbedded layers of continuous, horizontal reflectors between incoherent, poorly reflective zones. This sequence may represent the low-stand/sediment-rich and high-stand/sediment-starved relationship of Pleistocene deposition.

The main structural feature of the basin is the St. George graben, a large, fault-bounded depression (fig. 6). Numerous faults occur in the area, mostly along the margin of the graben. These faults are high-angle, down-to-the-basin normal faults that usually correlate with acoustic basement offsets (Marlow and Cooper, 1980). Many of the faults rupture near-surface sediments and some cut the sea floor (Comer, in press). Surface offsets of 3 to 6 feet are apparent on some seismic reflection profiles. Some offsets may be due to differential sediment compaction rather than to recent tectonic movement. The area is seismically active, however. Davies (1982) reported three earthquakes in the range of 6.5 to 7.5 on the Richter scale and numerous smaller events in the St. George basin area since 1925. He calculated a 10 percent probability for ground acceleration to exceed 0.2 g at an arbitrary site within the basin in a 40-year period.

The presence of gas in the St. George basin is inferred from acoustic anomalies on seismic reflection profiles. These anomalies may be due to either gas-charged sediment or confined gas accumulations. Shallow gas-charged sediment is under normal to near-normal pressure and poses less of a risk to drilling operations than confined gas accumulations, which may occur in zones with possible abnormal pressure.

SITE-SPECIFIC ENVIRONMENTAL GEOLOGY

The site survey performed by Nekton, Inc., indicated that the sea floor at the well site is essentially flat and featureless. It is underlain by probable Pleistocene strata that roughly parallel the sea floor. Two normal growth faults striking roughly northwest-southeast cut these strata in the vicinity of the well, but do not offset the sea floor. The vertical displacement of these faults is less than 30 feet. Strata within 75 feet of the sea floor are affected. The presence of shallow gas-charged sediments at the proposed drill site was inferred from acoustic anomalies on seismic profiles. The gas is probably of biogenic origin and under normal to near-normal pressure. Although such gas-charged sediments pose far less risk than confined gas accumulations of thermogenic origin, the operator elected to move the well site northwest to an area with no acoustic anomalies. Shallow gas did not prove to be a problem during drilling activities.

SEISMIC REFLECTION CORRELATION
AND
VELOCITY ANALYSIS

by

C. Drew Comer

The seismic stratigraphy of the St. George Basin COST No. 2 well was developed from reflection data collected by the USGS in 1976, and a synthetic seismogram generated from the acoustic log by MMS personnel. Portions of two seismic reflection profiles submitted with the application for permit to drill, 1976 Seiscom Delta lines 27 and 62, were also utilized. Velocity data from the No. 2 well were compared with the No. 1 well. The locations of the wells and the USGS lines in relation to the axis of St. George basin are shown in figure 6.

The synthetic seismogram (fig. 7) was generated from the borehole-compensated sonic log. The log was digitized and the data were entered into a computer program that produced a synthetic seismogram without multiples. The program assumes constant density, horizontal strata, and incident waves that are normal to the reflecting surface and have planar wave fronts. The reflection coefficients calculated by the program were convolved with a standard Ricker wavelet having a frequency range of 8 to 55 Hz. The synthetic seismogram is displayed in both normal and reverse polarity. The seismic reflection profile displayed with the synthetic seismogram is 1976 Seiscom Delta line 62. Figure 8 is a time-stratigraphic column of the No. 2 well based on paleontology.

VELOCITY ANALYSIS

Interval velocities and a time-depth curve (fig. 9) were calculated from the sonic log. The interval velocities increase gradually with depth with no significant reversals or major breaks throughout the Cenozoic section. The velocity of the first interval in the Mesozoic basement (12,550 to 13,275 feet) is unusually low. This is probably due to poor sonic-log data caused by extensive washouts in the well bore above 12,800 feet. The next lower interval, 13,275 to 14,125 feet, has a much higher interval velocity (17,000 feet/second), which is consistent with that expected from the acoustic basement.

Figure 10 is a comparison of time-depth curves generated from the sonic logs of the Nos. 1 and 2 wells. The curve of the No. 2 well is steeper than that of the No. 1 well, indicating a higher average velocity for the No. 2 well. Figure 11 is a comparison of interval velocities, which are also generally higher in the No. 2 well.

It should be pointed out that velocities derived from sonic logs are subject to drift error because of irregularities within the borehole (Tucker, 1982). Also, because the shallowest part of the well was not logged, the sonic log and the synthetic seismogram generated from it are somewhat incomplete.

The sonic log should be integrated with the borehole velocity survey for more accurate results. The velocity survey (check shot data) was not used in this report because of its longer proprietary term.

SEISMIC CORRELATION

Figure 12 shows 1976 USGS seismic line 6, a 24-channel common-depth-point (CDP) profile. Line 6 crosses the St. George graben about 19 miles east of the No. 2 well. The graben is less than 10 miles wide on the southeastern end, but widens to more than 30 miles to the northwest. The horizons marked on the profile are age dates based on paleontology. The acoustic basement horizon is an angular unconformity between Cenozoic strata and the underlying Mesozoic rocks. The basement rocks include Upper Jurassic to Lower Cretaceous clastic sediments at the No. 2 well. The No. 1 well encountered basalt in the basement. Marlow and Cooper (1980) believe that the acoustic basement underlying the southern Bering Sea consists mainly of deformed Mesozoic sedimentary rocks. Vallier and others (1980) reported Upper Jurassic sedimentary rocks from dredge hauls over Pribilof Ridge where the basement shoals to the surface near St. George Island. Upper Cretaceous sedimentary rocks were dredged from the Bering Shelf margin in the Pribilof Canyon (Hopkins and others, 1969).

A basement arch occurs south of the graben, around shot point 2000, and the basement dips gently to the southwest from the crest. This basement high was mapped as the Black Hills Ridge by Cooper and others (1979) and Marlow and others (1979).

The No. 2 well site is located within the first series of down-to-the-basin faults on the south flank of the St. George graben. The sedimentary section in the graben is much thicker 10 miles north of the drill site, however. Figure 12 shows the basement deeper than 4 seconds (two-way travel time) in the graben. The acoustic basement is obscure here, and may be deeper than indicated in figure 12. According to Marlow and Cooper (1980), the St. George basin contains over 30,000 feet of sediment near the axis of the graben.

The offset of strata across the graben faults increases with depth on the downthrown side, indicating deposition contemporaneous with fault movement. It is apparent from the seismic profile (fig. 12) that these growth faults were active well into the late Tertiary. Away from the graben, faults are fewer in number, smaller in magnitude, and generally ceased activity at an earlier time.

The projection of Tertiary horizons into the graben (fig. 12) is somewhat uncertain because of the large offset on the border fault. Nevertheless, it is apparent that a relatively high proportion of Neogene to Paleogene (and possible Upper Cretaceous) section is present in the St. George basin, implying relatively rapid subsidence in the Neogene.

Marlow and Cooper (1980) suggest that basin subsidence may have begun in the Late Cretaceous, so that Upper Cretaceous as well as lower Tertiary sediments may occur in the graben. The basal sedimentary section in the graben probably has no age equivalent in the No. 2 well. This has important implications for

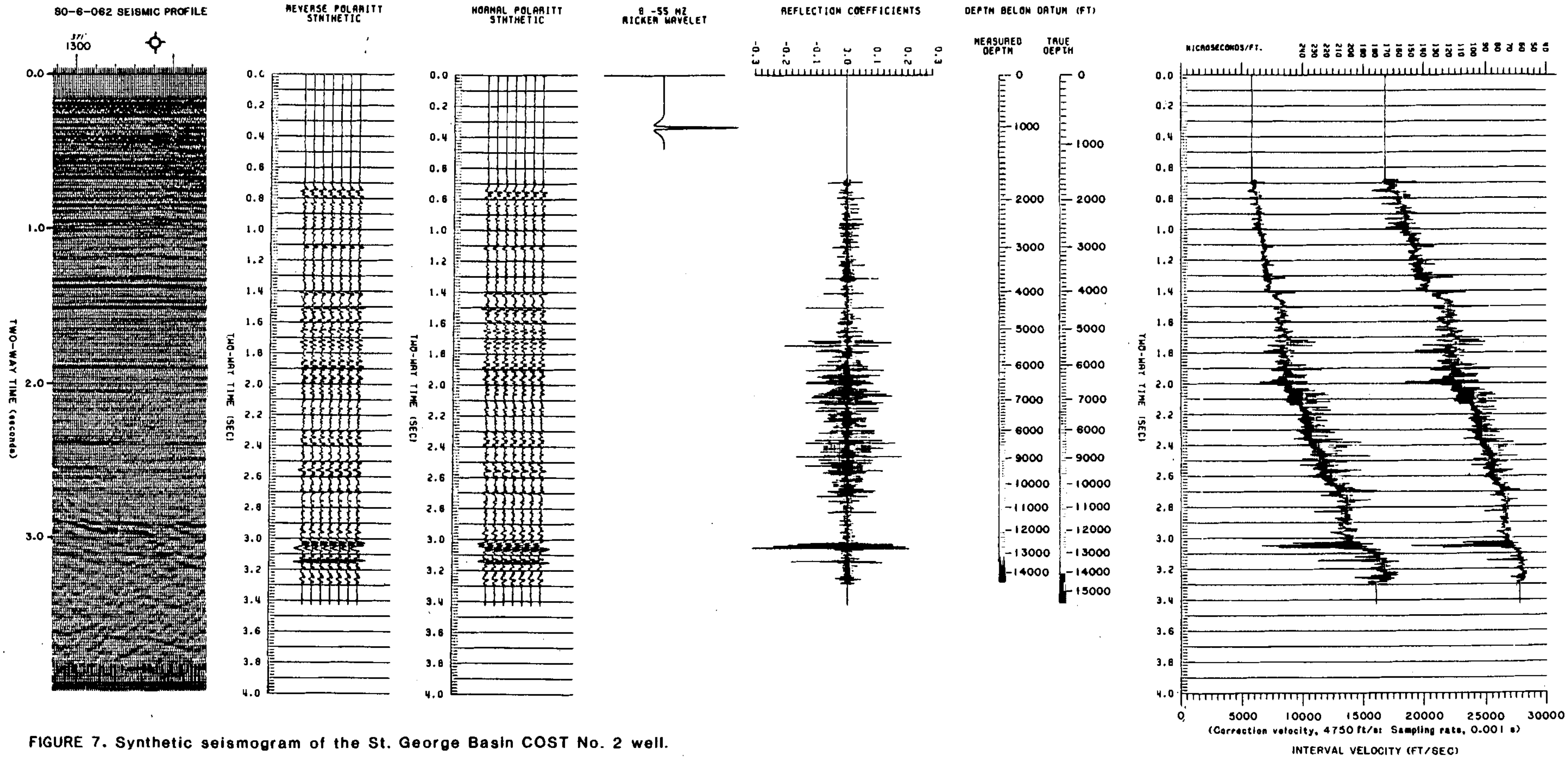


FIGURE 7. Synthetic seismogram of the St. George Basin COST No. 2 well.

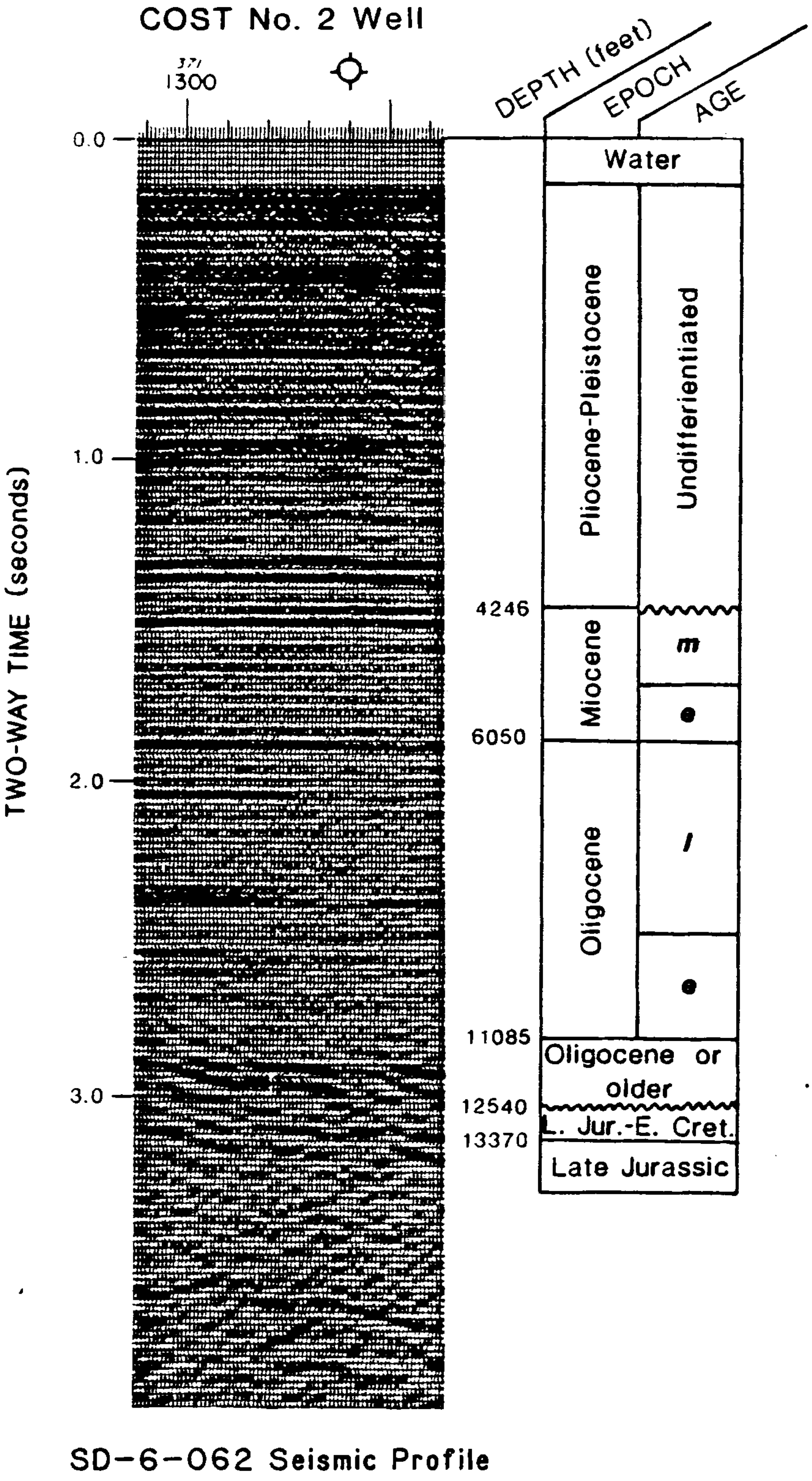


FIGURE 8. Time-stratigraphic column and seismic profile of the St. George Basin COST No. 2 Well.

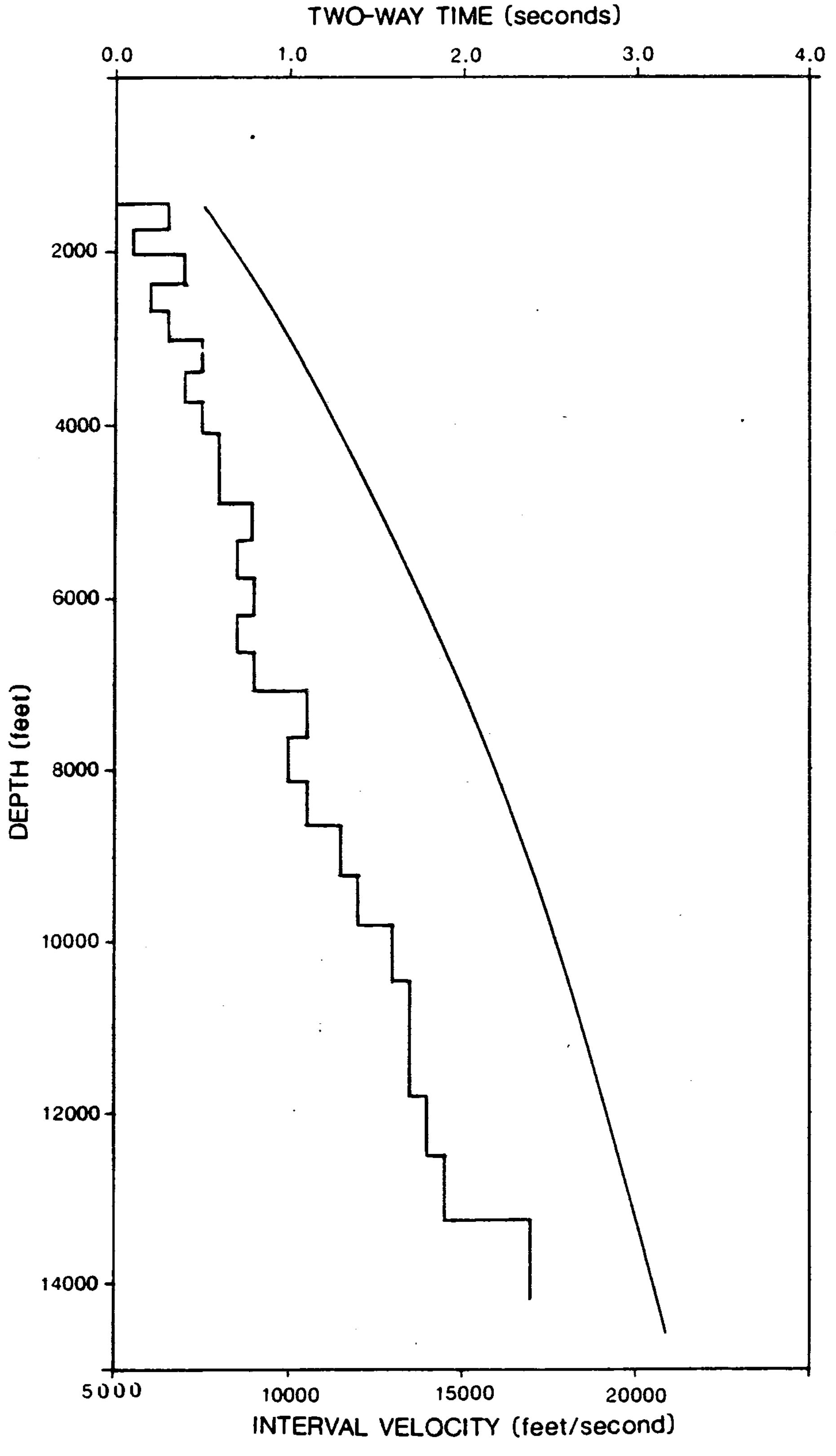


FIGURE 9. Interval velocities and time—depth curve from the sonic log of the St. George Basin COST No. 2 Well.

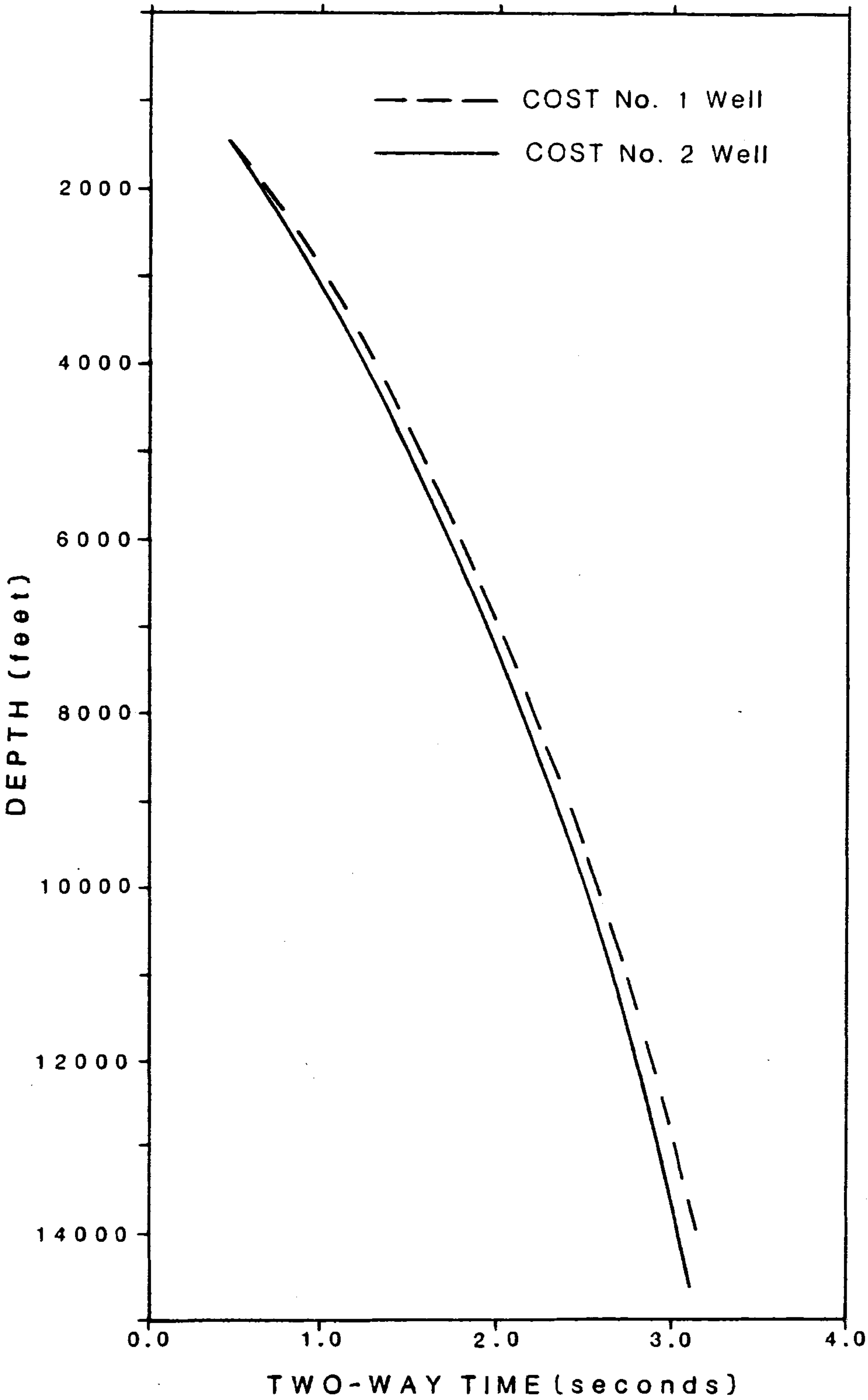


FIGURE 10. Comparison between time-depth curves for the St. George Basin COST No.1 and No.2 wells.

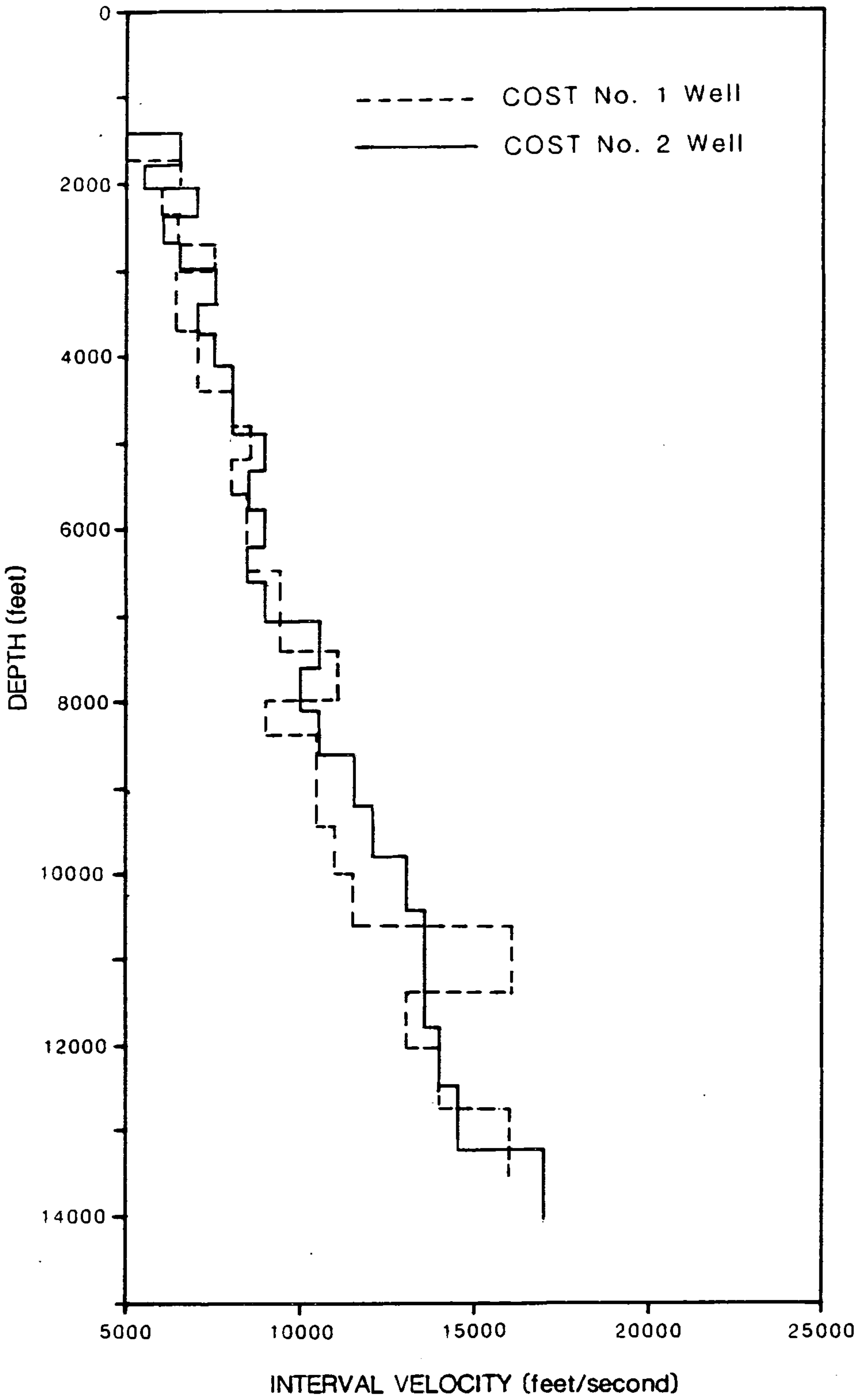


FIGURE 11. Comparison between interval velocities for the St. George Basin COST No.1 and No.2 wells.

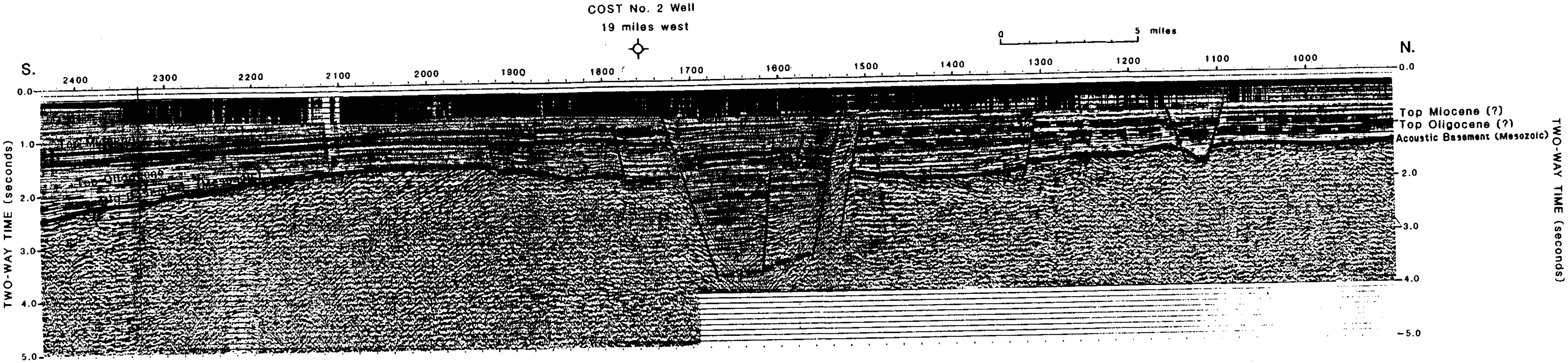


FIGURE 12. U. S. Geological Survey seismic line 6.

both the source rock and reservoir rock potential of the graben sediments. The area outside the graben was probably subaerially exposed in the Late Cretaceous and early Tertiary; consequently, the lowermost graben sediments may have accumulated in a restricted basin with good potential for organic preservation. Marlow and Cooper (1980) believe that coarse clastics and terrigenous debris may have been shed into the graben from the surrounding highlands during late Mesozoic or earliest Tertiary time. If so, the reservoir rock potential in the graben may be better than that of the rocks encountered in the No. 2 well. Basement rocks such as the Upper Jurassic to Lower Cretaceous sediments encountered in the lower 2100 feet of the well may have provided a source for clastic debris. These clastics, when exposed to an additional cycle of erosion, transport, and redeposition, may have been winnowed of fine and chemically unstable material and thus be more mineralogically mature.

PALEONTOLOGY AND BIOSTRATIGRAPHY

by

John A. Larson

Paleoecology and biostratigraphy for the St. George Basin COST No. 2 well were determined by detailed analyses of microfossil assemblages contained in samples recovered from the well. These samples include rotary drill bit cuttings (ditch samples), sidewall cores (SWC), and conventional cores. Ditch samples were recovered at 30-foot intervals between the uppermost sample at 1460 feet and the lowermost sample at the total depth of the well (14,626 feet). Numerous sidewall cores and 17 conventional cores were also taken in the well. The microfossil assemblages examined include Foraminifera, diatoms and silicoflagellates, calcareous nannoplankton, pollen and spores, and dinocysts (dinoflagellate cysts). Radiolaria were very rare and of little biostratigraphic use. The principal sources of data for microfossil identification, abundance, distribution, and environmental implications are the consultant reports prepared for the COST well participants (Biostratigraphics, 1982), the consultant report on a nearby shallow corehole (Anderson, Warren, and Associates, Inc., 1976a), and the author's supplemental identification of Foraminifera from significant stratigraphic intervals. Discrepancies between the biostratigraphy of this report and the consultant's conclusions may be due to minor interpretative differences or to differences in emphasis on the various groups of biostratigraphic indicators. Analysis and evaluation of foraminiferal data, interpretation of data, and synthesis were done by the author. Siliceous microfossil data were interpreted by Donald L. Olson.

The biostratigraphy of the well is discussed in the order that strata were penetrated. Following the conventional practice for biostratigraphy in wells, this report lists highest and lowest fossil occurrences because references to first and last occurrences are potentially confusing. Samples from cores are given somewhat more weight than those from cuttings because cores can be more precisely located and are less subject to contamination. The No. 2 well is correlated with the St. George Basin COST No. 1 well at the conclusion of this report.

Biostratigraphic and paleoenvironmental determinations are based on the entire microfossil and macrofossil suites. The biostratigraphy of the Pliocene and Miocene parts of the well is based primarily on diatoms. Calcareous nannofossils and dinocysts are most important below the Miocene. Foraminifera corroborate the biostratigraphy developed from these microfossil groups. Paleoenvironments referred to as continental (nonmarine) include fluvial, lacustrine, and paludal. Transitional environments include brackish estuaries and hypersaline and hyposaline lagoons. For sediments deposited in marine environments, the paleoenvironment is expressed in terms of bathymetry. These paleobathymetric determinations are based primarily on evidence from foraminiferal populations, but dinoflagellates, calcareous nannofossils, molluscs, echinoderms, and other marine organisms are used as well. The divisions of the marine environment include inner neritic (0 to 60 feet), middle neritic (60 to 300 feet), outer neritic (300 to 600 feet), upper bathyal (600 to 1500 feet), middle bathyal (1500 to 3000 feet), and lower bathyal (3000 to 6000 feet). Abundances of microfossils, where expressed, are given in terms of numbers of specimens per sample: infrequent or very rare, 1 per sample; rare, 2 to 10 per sample; frequent, 11 to 32 per sample; common, 33 to 100 per sample; abundant, 101 to 320 per sample; and very abundant, greater than 320 per sample. Paleoclimatological interpretations are based on diatom assemblages and on pollen and spore assemblages.

PLIOCENE-PLEISTOCENE

Grab samples and shallow corehole samples taken near the No. 1 well indicate that beneath a thin veneer of Holocene sediments, the upper several hundred feet of section in the No. 2 well is probably Pleistocene in age. No paleontology samples were recovered above 1460 feet in the No. 2 well, and there is no information available for further definition of the Pleistocene section. The interval from just below sea floor (452 feet) to 1460 feet is therefore assigned a Pliocene-Pleistocene age. Depositional environments for this interval are undetermined.

PLIOCENE

The Pliocene section (1460 to 4246 feet) is defined principally on the basis of diatom distributions. Even though early and late Pliocene zones can be recognized, there are numerous instances of broken and reworked Miocene diatoms as well. Pyrolysis data and vitrinite reflectance data also indicate possible reworking of sediments in the Pliocene section.

The interval from 1460 to 2980 feet is considered to be probable late Pliocene in age (*Denticulopsis seminae* var. *fossilis* Zone). Two of the species used to define this zone, *Thalassiosira antiqua* (2090 feet) and *Stephanopyxis horridus* (1640 feet), along with *Coscinodiscus pustulatus* (1640 feet) range high in the interval. Other key species present include *Actinocyclus oculatus*, *Coscinodiscus stellaris*, *Denticulopsis seminae*, *Denticulopsis seminae* var. *fossilis*, *Rhizosolenia alata*, and *Thalassiosira gravida*. The upper part of this interval, from 1460 to 1640 feet, lacks distinctive marker diatoms and may be in part Pleistocene in age. However, the complete lack of distinctive Pleistocene diatoms such as *Rhizosolenia curvirostris* prompts the inclusion of the upper part of this section in the late Pliocene.

Possible early late Pliocene strata of the *Denticulopsis kamtschatica*-*Denticulopsis seminae* var. *fossilis* Zone occur from 2720 to 2980 feet. The zone is defined by the overlap of the ranges of the two above-named species. Relatively frequent numbers of *Denticulopsis kamtschatica* range upward to 2720 feet, while *Denticulopsis seminae* var. *fossilis* disappears below 2980 feet.

The section from 2980 to 4246 feet is considered to be early Pliocene in age, in the upper part of the *Denticulopsis kamtschatica* Zone (that is, the *Denticulopsis kamtschatica* "b" and "c" Subzones). Key species include *Cladogramma californica*, *Coscinodiscus robustus*, and the silicoflagellate *Distephanus boliviensis*.

The interval from 2980 to 3620 feet is considered to be possible late early Pliocene, or in the *Denticulopsis kamtschatica* "c" Subzone. The uppermost occurrence of *Cosmiodiscus insignis*, which is used to define the base of this zone, is at 3620 feet. Other species in the interval include *Cosmiodiscus intersectus*, *Coscinodiscus symbalophorus*, and *Thalassiosira punctata*.

The interval from 3620 to 4246 feet may be within the early Pliocene *Denticulopsis kamtschatica* "b" Subzone. Pliocene species such as *Stephanopyxis dimorpha* are present in the lowermost samples of the interval. Older species which would indicate the latest Miocene *Denticulopsis kamtschatica* "a" Subzone, such as *Rouxia californica* and *Nitzschia reinholdii*, were not detected. A significant decrease in diatom and silicoflagellate populations occurs at the base of this interval. No siliceous microfossils were detected in the sidewall core at 4246 feet.

Foraminifera present from 1460 to 2980 feet (late Pliocene) include *Buccella frigida*, *Buccella tenerrima*, *Cassidulina californica*, *Cassidulina teretis*, *Dentalina* sp., *Elphidium bartletti*, *Elphidium clavatum*, *Glandulina laevigata*, *Nonionella labradorica*, *Protoelphidium orbiculare*, *Uvigerina juncea*, and *Virgulinella pertussa*.

The foraminiferal assemblage from 2980 to 3110 feet (possible late early to early late Pliocene) is very sparse. The species present include *Buccella tenerrima*, *Cassidulina californica*, *Glandulina laevigata*, *Melonis pompilioides*, *Trifarina angulosa*, and *Uvigerina juncea*.

In the remainder of the early Pliocene part of the section (3110 to 4246 feet), Foraminifera are very sparse to absent. Those species present (including *Epistominella bradyana*, *Cassidulina californica*, and *Trifarina angulosa*) are very rare.

Dinocysts present from 1460 to 2180 feet include *Lejeunia* spp., *Operculodinium* sp., and *Tectatodinium pellitum*. Reworked Cretaceous and Jurassic forms are also present. From 2180 to 3928 feet, the dinocyst assemblage includes *Lejeunia* sp., *Lejeunia* sp. PC, and *?Operculodinium* sp. 2, which is considered by the consultants to indicate a Pliocene age. The dinocyst assemblage is similar, but somewhat less abundant, from 3928 to 4246 feet. *Lejeunia paratenella* is present at 3928 feet (SWC) and below.

The pollen and spore assemblage in the Pliocene section includes *Alnipollenites* sp., sparse *Tiliaepollenites* sp., *Tsugaepollenites* sp., Betulaceae, sporadic Compositae, sparse, scattered Ericaceae, *Laevigatosporites* sp., *Lycopodiumsporites* sp., and *Sphagnumsporites* sp. Onagraceae are present below 2450 feet. *Rugaepollis fragilis*, a species described from the Miocene-Pliocene section of southern Alaska (Hedlund and Engelhardt, 1970), is present from 2180 to 2270 feet. Below 3928 feet, Ericaceae are more consistently represented, Onagraceae less so, and scattered Compositae and Malvaceae are present in some sidewall cores. *Juglanspollenites* sp. is also present in sidewall cores below 3928 feet.

The Pliocene interval contained no calcareous nannofossils.

Environment

Foraminifera present in the Pliocene section indicate that depositional environments were probably outer neritic between 1460 and 2900 feet. Between 2900 and 3110 feet, the environment was outer neritic to upper bathyal. Although Foraminifera are quite sparse between 3110 and 4246 feet, consistent occurrences of dinocysts and diatoms indicate marine (neritic?) conditions.

The pollen and spore assemblage indicates temperate conditions for the Pliocene. Slightly warmer temperate conditions may be indicated below 3928 feet. Plots of abundance-weighted percentages of warm-water versus cold-water diatoms indicate generally warm (temperate) conditions with sporadic, brief cooling intervals, and a gradual, slight cooling trend from early through late Pliocene.

MIOCENE

The interval from 4246 to 6050 feet is considered to be Miocene in age. Age determinations are derived primarily from diatom data. Calcareous nannofossil data are used to determine the base of the early Miocene.

Siliceous microfossil assemblages over the interval from 4246 (SWC) to 4441 feet (SWC) are very poorly preserved and nondiagnostic. This section contains no definitive Pliocene species and is here termed Miocene undifferentiated. This interval may reflect a low depositional rate or erosion during the late Miocene.

The interval from 4441 (SWC) to 5240 feet is tentatively assigned to the middle Miocene. Diatoms present include *Melosira* aff. *M. sulcata*, poorly preserved *Stephanopyxis* spp., *Stephanopyxis spinosissima*, and *Stephanopyxis superba*. Poorly preserved *Stephanopyxis grunowii* occur below 4790 feet. Zone-diagnostic forms are not present.

The interval from 5240 to 6050 feet is considered to be early Miocene on the basis of poorly preserved specimens of *Actinoptychus heliopelta* (Abbott, 1978; Andrews, 1978) between 5240 and 5690 feet. The lower part of the interval is characterized by abundant *Stephanopyxis turris* var. *intermedia*. Other species present include *Actinoptychus perisetosus*, *Melosira* aff. *M. sulcata*, *Stephanopyxis grunowii*, *Stephanopyxis* cf. *S. superba*, and *Stictodiscus kittonianus*.

Calcareous nannofossils are not present above 5600 feet in the well. The calcareous nannofossils present from 5600 to 5690 feet support a probable early Miocene age. These include *Dictyococcites minutus*, *Reticulofenestra dictyoda*, and *Sphenolithus moriformis*. These species indicate this interval is part of the *Triquetorhabdulus carinatus* Zone, probably the *Cyclicargolithis abisectus* Subzone. The base of the early Miocene is placed at the highest occurrence of Oligocene calcareous nannofossils at 6050 feet.

Dinocyst assemblages in the Miocene section are sparse and nondiagnostic from 4246 to 4441 feet. A sparse dinocyst assemblage present from 4441 to 5240 feet is similar to that seen above in the early Pliocene. The sparse dinocyst population between 5240 and 6050 feet is also similar, except that *Operculodinium* sp. is no longer present.

The Miocene pollen and spore assemblage is similar to that of the early Pliocene, although Onagraceae are sparse below 5240 feet. Juglanspollenites sp. and Ericaceae are more consistently present in sidewall cores in the Miocene section than in the Pliocene.

Foraminifera are very sparse to absent from 4246 to 4520 feet, but are present in rare to frequent numbers and moderate diversity below 4520 feet. Species present include Anomalina glabrata, Bolivina numerosa, Cassidulina crassipunctata, Cassidulina aff. C. laevigata, Cibicides evolutus, Epistominella cf. E. bradyana, Globobulimina pacifica, Haplophragmoides deformes, Haplophragmoides spp., Nonion barleeanum inflatum, Pullenia salisburyi, Sphaeroidina variabilis, Trifarina angulosa, Uvigerina cf. U. hannai, Uvigerina cf. U. hootsi, Uvigerina cf. U. modeloensis, Uvigerina cf. U. subperegrina, Uvigerinella californica?, and Valvulineria cf. V. araucana. Valvulineria cf. V. menloensis occurs below 5720 feet.

Environment

The section from 4246 to 4520 feet is similar to the overlying interval from 3110 to 4246 feet in that both intervals contain sparse foraminiferal faunas. Environments are defined only as marine, possibly neritic. The sediments between 4520 and 5510 feet probably were deposited in outer neritic to upper bathyal environments. From 5510 to 6050 feet, depths are probably upper to middle bathyal. Pollen and spores present indicate temperate conditions slightly warmer than in the Pliocene. Diatom data are too sparse for paleotemperature analysis.

OLIGOCENE

The interval from 6050 to 11,085 feet is Oligocene in age. The top of the interval, and its provisional subdivision into late and early units, are based on calcareous nannofossil occurrences. The base of the early Oligocene is defined by dinocyst distributions.

The late Oligocene (6050 to 9020 feet) is defined here by the presence of several calcareous nannofossils which can be placed in the Sphenolithus distentus and Sphenolithus ciproensis Zones. These include Dictyococcites scrippsae (6050 to 6140 feet), and Cyclicargolithus floridanus, Zygrablithus bijugatus (Oligocene form), Dictyococcites bisectus, and Dictyococcites neogammation (6500 to 6950 feet). Other species present in this interval include Braarudosphaera bigelowi, Coccolithus pelagicus, and Thoracosphaera saxea. Pontosphaera vadosa, probably indicative of the Sphenolithus predistentus Zone, is present from 8930 to 9020 feet, indicating that late Oligocene age sediments are present as deep as 9020 feet.

Early Oligocene sediments extend from 9020 to at least 11,085 feet. The top of this interval is based on the presence of the calcareous nannofossil Reticulofenestra hillae, indicative of the Helicopontosphaera reticulata Zone. Early Oligocene calcareous nannofossils are also present in a core sample taken at 9654.8 feet. These include Coccolithus pelagicus, Dictyococcites minutus, and Dictyococcites scrippsae, indicative of the Helicopontisphaera reticulata Zone to the Reticulofenestra umbilicata Zone. No Tertiary calcareous nannofossils were recorded below 9654.8 feet in the No. 2 well.

The pollen, spore, and dinocyst assemblages present in the upper part (6050 to 6860 feet) of the late Oligocene section are similar to the assemblage present in the early Pliocene and the Miocene sections. From 6860 to 9020 feet, a more recognizable Oligocene (to Miocene) palynological assemblage is present. The dinocyst assemblage is rather poorly developed, but contains Lejeunia spp. and Spiniferites sp. Also present is a species of Cannosphaeropsis, a Cretaceous to Eocene genus, which according to the consultants commonly ranges up into the mid-Tertiary in the Bering Sea area. The pollen assemblage is characterized by consistent occurrences of Juglanspollenites and by sporadic occurrences of Pterocaryapollenites sp., Tiliaepollenites sp., Ericaceae, and Malvaceae.

The dinocyst assemblage below 9020 feet includes species that have been interpreted to denote Oligocene age strata in the Bering Sea area. These indicate that early Oligocene sediments extend to at least 11,085 feet. The assemblage is characterized by Paralecaniella indentata, which is present from 9267.7 feet (core sample) downward. Other species present include Cannosphaeropsis sp., Heteraulacysta sp., and Tuberculodinium vancampoae. Dinocyst diversity drops appreciably in sidewall cores below 11,085 feet. The pollen assemblage from 9020 to 9267.7 feet (core) is similar to that of the late Oligocene interval from 6860 to 9020 feet. Below 9267.7 feet, there is a more consistent population of Tiliaepollenites sp., while Momipites sp., Faguspollenites sp., Liquidambarpollenites sp., and Ulmipollenites are sporadically present. A consistent distribution of Juglanspollenites sp. continues throughout the Oligocene.

Diatom distribution is sporadic in the Oligocene section, and frequencies are very rare to rare. The occurrence of Stephanopyxis marginata at 6673 feet (SWC) supports a late Oligocene age for the upper part of the section. Other diatom species present include Coscinodiscus marginatus, Stephanopyxis grunowii, Stephanopyxis turris var. intermedia, and Melosira aff. M. sulcata. The diatom population becomes increasingly sparse downward, and no diatoms were recovered below 7035 feet.

Foraminifera present in the 6050- to 9020-foot interval support an Oligocene age, although some of the species also range into the Miocene. An Oligocene (to early Miocene) age is indicated by the presence of Pseudoglandulina inflata (6650 to 6680 and 7910 to 7940 feet) and Porosorotalia cf. P. clarki (7190 to 7730 and 8540 to 8600 feet). Other species present in the interval include Anomalina glabrata, Bolivina cf. B. numerosa, Cassidulina crassipunctata, Cassidulina cf. C. laevigata, Elphidella cf. E. sibirica, Epistominella cf. E. bradyana, Globobulimina pacifica, Haplophragmoides spp., Haplophragmoides obliquiloculata, Nonion cf. N. barleeanum, Trifarina angulosa, Uvigerina cf. U. hannai, Uvigerina cf. U. hootsi, and Uvigerina cf. U. modeloensis.

An Oligocene age is also supported by the Foraminifera present from 9020 to 11,085 feet, although some of the species may have ranges extending as high as the early Miocene. The foraminiferal assemblage is similar to that of the late Oligocene section just above, except that Epistominella cf. E. bradyana and Nonion cf. N. barleeanum are absent. Distinctive species present include Rotalia cf. R. beccarii, occurring at 9417 feet (SWC) and from 9590 feet downward, Porosorotalia cf. P. clarki from 9110 to 10,060 feet, and Gaudryina alazanensis from 10,480 to 10,540 feet. Additional species present include Buccella cf. B. oregonense, Cribrononion spp., Dentalina spp., Elphidiella cf. E. sibirica, Elphidium spp., Haplophragmoides becki, and Haplophragmoides deformes.

Environment

The interpretation of Oligocene depositional environments is based primarily on the diversity and abundance of foraminiferal assemblages. The uppermost part of the section (6050 to 6110 feet) is interpreted to represent deposition at upper to middle bathyal depths. Indicated environments are shallower from 6110 to 7725 feet, where outer neritic to upper bathyal conditions were present. Depositional environments were upper to middle bathyal between 7725 and 8570 feet. Outer neritic to upper bathyal conditions prevailed in the 8570- to 9350-foot interval, with undifferentiated neritic conditions present from 9350 to 9417 feet. Faunas present from 9417 to 9980 feet indicate inner to middle neritic conditions. Outer neritic assemblages are present from 9980 to 10,150 feet, and inner to middle neritic conditions from 10,150 to 10,450 feet. Outer neritic conditions are present from 10,450 to 10,720 feet.

Foraminifera are rare from 10,720 to 11,085 feet, but dinocysts are present. A possible transitional to inner neritic environment is indicated for this interval.

The pollen and spore assemblages present suggest temperate to warm-temperate climates during the Oligocene.

OLIGOCENE OR OLDER (POSSIBLE EOCENE)

Oligocene or older (possible Eocene) sediments are present in the interval from 11,085 to 12,540 feet. Microfossils within the interval are sparse. The base of the interval is determined from the first occurrences of Mesozoic calcareous nannofossils and from lithologic evidence. This interval may be correlative with the Eocene strata occurring from 8410 to 10,380 feet in the St. George Basin COST No. 1 well.

The top of the Oligocene or older section is based on the abrupt decrease in dinocyst diversity below 11,085 feet. Sporadic rare to very rare Spiniferites spp., Spiniferites crassipellis, Operculodinium centrocarpum, Paralecaniella indenteta, and Nematosphaeropsis sp. occur below this level, but they are not present in sidewall cores below 11,680 feet.

Terrestrially derived palynomorphs are rare to very rare and are sporadically distributed. Irregular occurrences of Juglanspollenites sp. span the entire interval. Momipites sp. occurs only at 12,535 feet (SWC), and Tiliaepollenites sp. occurs only from 12,300 to 12,390 feet.

Foraminifera are also rare to absent in this part of the section. Species present include Haplophragmoides spp., Haplophragmoides becki, Rotalia cf. R. beccarii, and Globobulimina pacifica. Foraminifera are essentially absent below 11,350 feet.

Environment

The depositional environment from 11,085 to 11,350 feet is transitional to inner neritic based on the presence of very sparse, low diversity foraminiferal faunas and relatively low diversity dinocyst assemblages. Continental to transitional conditions predominate from 11,350 to 12,000 feet, where Foraminifera are essentially absent, but sparse dinocyst assemblages are present. From 12,000 to 12,540 feet, only rare pollen and spores are present, indicating possible continental conditions.

The pollen and spore evidence suggests temperate to warm-temperate conditions. This is not inconsistent with paleobotanical evidence presented by Wolfe (1977) and Wolfe and Poore (1982) indicating that the Eocene climate of the Gulf of Alaska region to the southeast appears to have been temperate (late Eocene) to warm-temperate (middle Eocene).

EARLY CRETACEOUS TO LATE JURASSIC

Early Cretaceous to Late Jurassic age strata are present from 12,540 to 13,370 feet. The top of this interval is placed at a lithologic change characterized by gray-brown siltstone and coal fragments. Age interpretations are based on the distinctive palynomorph assemblage and on calcareous nannofossils.

Early Cretaceous to Late Jurassic age palynomorphs present include *Deltoidospora* sp., *Osmundacidites* sp., *Lycopodiumsporites* sp., *Concavisporites juriensis*, *Rogalskaisporites cicatricosus*, *Neoraistrickia truncata*, and ?*Taurocusporites segmentatus*. No indigenous dinocysts were recorded in this interval.

Poorly preserved fragments of the calcareous nannofossil *Watznaueria*? sp. at 12,608 feet (SWC) support a Mesozoic, probably Cretaceous to Jurassic, age for the interval.

Indigenous Foraminifera were not recovered from this part of the section.

Environment

The absence of Foraminifera and dinocysts suggests possible continental conditions from 12,540 to 13,110 feet. The presence of the calcareous nannofossil *Watznaueria*? sp. at 12,608 feet, however, indicates possible intermittent transitional to neritic conditions. Below this depth, rare to frequent shell fragments (presumably marine) suggest a transitional to possible inner neritic environment from 13,110 to 13,370 feet.

LATE JURASSIC

Late Jurassic age sediments are present from 13,370 to 14,626 feet (TD). The dinoflagellate *Sirmiodinium grossi*, indicative of a Late Jurassic to Early Cretaceous age, is present from 13,370 feet (SWC) to TD. More strongly indicative of a Late Jurassic age are the Oxfordian and Kimmeridgian species Pareodinia osmingtonense and Parvocavatus tuberosus, which occur at 13,770 feet and below. Other species present include Tubotuberella apatella, Ellipsoidictyum cinctum, and Gonyaulacysta cf. G. jurassica.

The pollen and spore assemblage is similar to that observed from 12,540 to 13,370 feet, but is less diverse and less abundant.

No calcareous nannofossils or Foraminifera were recovered from this part of the well.

According to a consultant's report (Marks, 1982), bivalve molluscs recovered from this interval in a conventional core (14,602 to 14,618 feet) indicate an Early Cretaceous to Late Jurassic age. These bivalves include several specimens of Buchia cf. B. piochii, Buchia cf. B. terebratuloides, and Entolium ? sp. Shell fragments were noted in ditch samples throughout the interval.

Environment

The presence of dinocysts, shell fragments, and coal fragments from 13,370 to 13,540 feet indicates transitional to inner neritic conditions for the upper part of this section. Dinocysts and shell fragments are present from 13,540 to 14,626 feet (TD), and coal is essentially absent, suggesting an inner neritic environment.

CORRELATION

The strata in the upper part of the No. 1 and No. 2 wells can be correlated biostratigraphically (fig. 13). Strata representing time-equivalent units (epochs) are of roughly equal thickness in the two wells with the exception of the Oligocene, which is considerably thicker in the No. 2 well, and the undifferentiated Pliocene-Pleistocene section, which also may be thicker in the No. 2 well. In general, depositional environments appear to have been somewhat deeper in the No. 1 well.

Late Mesozoic age sediments in the lower part of the No. 2 well are matched by a thick sequence of basaltic rocks of uncertain age in the No. 1 well.

Holocene

A shallow corehole near the No. 1 well penetrated 9 feet of Holocene sediments before encountering material of Pleistocene age. Comparable information is not available for the No. 2 well, but it is probable that Holocene sediments also form a similar veneer in that area.

Pleistocene

The shallow corehole near the No. 1 well penetrated late and middle Pleistocene age sediments between 9 and 236 feet. Paleodepths were inner to middle neritic in the latest Pleistocene, deepening to middle to outer neritic below 46 feet. Paleoclimates were cool, with a slight warming trend between 46 and 116 feet and between 195 and 217 feet. No Pleistocene age samples were available from the No. 2 well.

Pliocene-Pleistocene

The base of the Pleistocene in each of the wells is an undetermined distance above the first samples at 1600 feet in the No. 1 well and at 1460 feet in the No. 2 well (fig. 13). The section above the uppermost samples is therefore referred to as Pliocene-Pleistocene.

Pliocene

The first samples recovered in each of the wells are of probable late Pliocene age. Pliocene sediments are present from 1600 to 3600 feet in the No. 1 well and from 1460 to 4246 feet in the No. 2 well. The section can be provisionally subdivided into late and early Pliocene intervals at 2109 feet in the No. 1 well and at 2980 feet in the No. 2 well.

The Pliocene paleoenvironment is generally middle to outer neritic in the No. 2 well. The paleodepths for the same interval in the No. 1 well are outer neritic to bathyal. A brief deepening trend at the top of the early Pliocene is present in both wells. The indicated paleoclimate in both wells is temperate, with brief cooling intervals. Pollen evidence suggests warmer temperate conditions in the earliest part of the Pliocene in both wells, and diatom data from the No. 2 well suggest gradual cooling throughout the Pliocene. Slightly higher percentages of warmer water diatoms are present throughout the Pliocene in the No. 1 well.

Miocene

Miocene sediments are present from 3600 to 5370 feet in the No. 1 well and from 4246 to 6050 feet in the No. 2 well. Figure 13 shows a tentative zonation of the Miocene. Late Miocene age sediments are present to a depth of 4600 feet in the No. 1 well, but they are missing or are limited to a 195-foot-thick undifferentiated interval between 4246 and 4441 feet in the No. 2 well. This suggests an unconformable surface or nondepositional interval in the late Miocene at the No. 2 well location. The abrupt disappearance of siliceous microfossils below the base of the late Miocene in the No. 1 well may also represent an unconformity or hiatus. Middle Miocene strata are present from 4441 to 5240 feet and early Miocene from 5240 to 6050 feet in the No. 2 well. In the No. 1 well, early to middle Miocene age sediments extend from 4600 to 5370 feet.

Marine paleodepths were neritic to upper and middle bathyal in the No. 2 well, and middle and lower bathyal in the No. 1 well. Paleoclimates were temperate, possibly slightly warmer than in the Pliocene.

Oligocene

Oligocene age strata comprise the thickest section in the two wells, amounting to more than a third of the sediments in each. This interval extends from 5370 to 8410 feet (3040 feet of section) in the No. 1 well, and from 6050 to 11,085 feet (5035 feet of section) in the No. 2 well. The boundary between the early and late Oligocene is placed at 6810 feet in the No. 1 and at 9020 feet in the No. 2 well. The late Oligocene interval is appreciably thicker than the early Oligocene in the No. 2 well.

Paleoenvironmental trends for this interval are similar in both wells, each being deepest in the late Oligocene and shallowest at the base of the early Oligocene. Paleoenvironments range from upper and middle bathyal to transitional and inner neritic in the No. 2 well. They are slightly deeper in the No. 1 well, ranging from upper and middle bathyal to inner and middle neritic. Conglomeratic sands between 7720 and 7870 feet in the No. 1 well may represent either shelf-edge slump deposits or high-energy, shallow-water deposits or an unconformity. Pollen and spore assemblages suggest temperate to warm-temperate conditions for the Oligocene in both wells.

Eocene

Eocene age sediments are present from 8410 to 10,380 feet in the No. 1 well, with late Eocene age sediments from 8410 to 10,050 feet, and middle Eocene sediments from 10,050 to 10,380 feet. A definite age could not be assigned to the apparently equivalent interval in the No. 2 well (11,085 to 12,540 feet) because the continental to transitional environments there yielded little in the way of age-diagnostic microfossils. This interval in the No. 2 well is referred to as Oligocene or older.

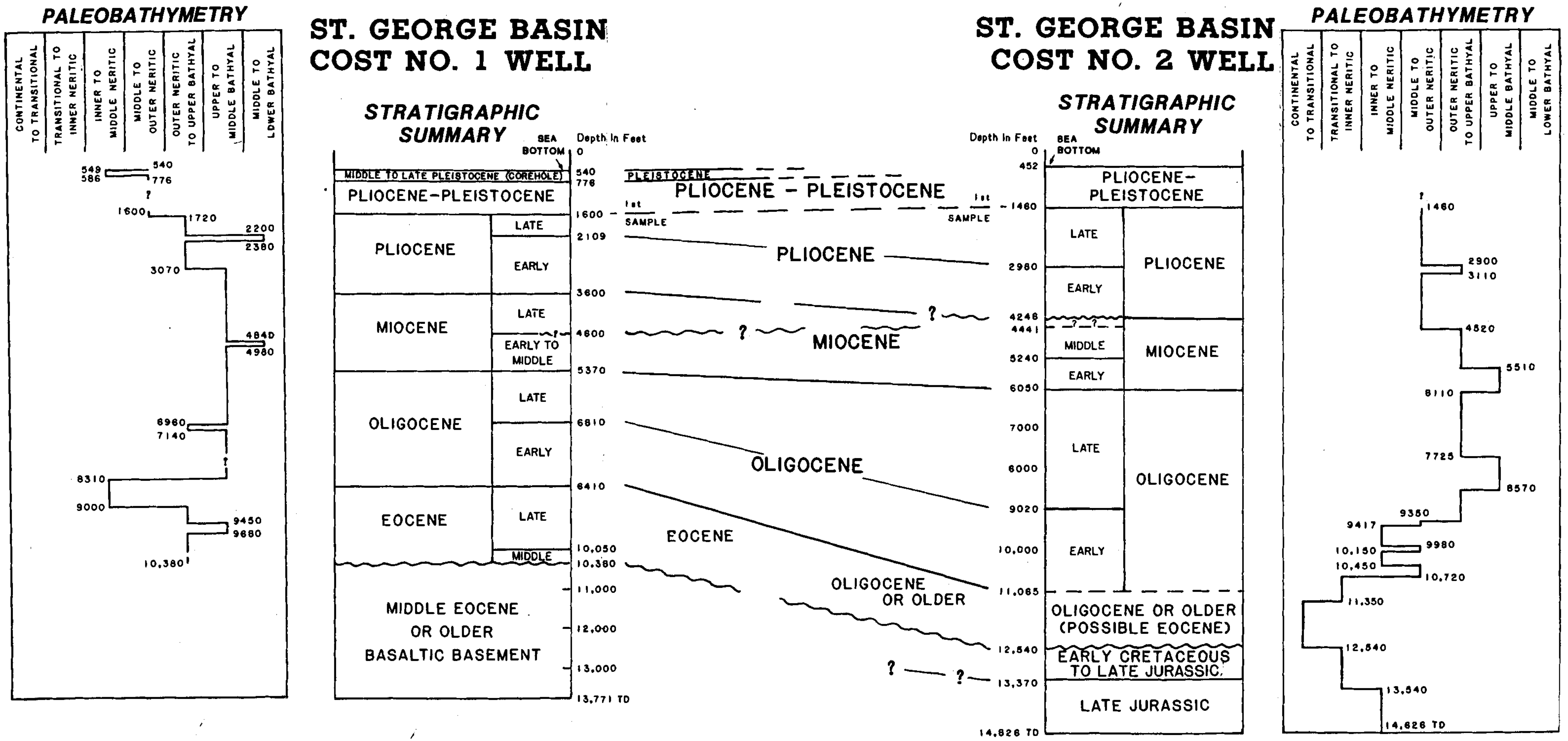


Figure 13. STRATIGRAPHIC SUMMARY, PALEOBATHYMETRY, AND CORRELATION OF ST. GEORGE BASIN COST NO. 1 WELL AND ST. GEORGE BASIN COST NO. 2 WELL

Paleoenvironmental trends in the two wells are dissimilar over most of the Eocene interval. Paleoenvironments in the No. 1 well range from inner and middle neritic at the top of the interval to outer neritic and bathyal at the base. In the No. 2 well, on the other hand, paleoenvironments range from inner neritic at the top to continental at the base. This may indicate an appreciable environmental gradient over the approximately 60 miles separating the two wells.

The pollen and spore assemblage is sparse in both wells, but suggests temperate to warm-temperate conditions. This is consistent with the temperate to warm-temperate Eocene climates indicated in the Gulf of Alaska region (Wolfe, 1977; Wolfe and Poore, 1982).

Middle Eocene or Older

The basaltic sequence present from 10,380 to 13,771 feet (TD) in the No. 1 well has not been precisely dated, nor has its relationship to the older rocks in the lower part of the No. 2 well been determined. It is here considered to be middle Eocene or older.

Early Cretaceous to Late Jurassic

Early Cretaceous to Late Jurassic age rocks are present in the No. 2 well from 12,540 to 13,370 feet. Paleoenvironments are transitional to inner neritic. No equivalent units were encountered in the No. 1 well.

Late Jurassic

Late Jurassic (Oxfordian to Kimmeridgian) age sediments are present from 13,370 to 14,626 feet (TD) in the No. 2 well. Paleoenvironments were possibly inner neritic. No equivalent section is present in the No. 1 well.

LITHOLOGY AND WELL LOG INTERPRETATION

by

J. G. Bolm

This analysis of lithology and reservoir characteristics of the No. 2 well is based on consultants' reports and the examination of samples and well logs. The sample material consists of rotary drill bit cuttings, conventional cores, and thin sections from sidewall and conventional cores, all of which are from below 1460 feet. Well logs cover the interval from 1422 to 14,622 feet.

The well was drilled with a fresh-water mud system, and log responses were normal. Identification of lithology is not a problem, but the strata penetrated are not easily grouped into meaningful lithologic units. The stratigraphy is therefore organized around biostratigraphic units defined elsewhere in this report. Biostratigraphic data and data pertaining to reservoir and source rock quality are presented graphically along with the gamma-ray, spontaneous potential (SP), deep resistivity, density, and sonic logs in plate 1. Framework-clast compositions of sandstone samples from conventional cores are shown in figure 14, and the distribution of authigenic minerals in conventional cores is shown in figure 15.

PLIOCENE (1460 to 4246 feet)

The uppermost 2786 feet of section consists of diatomaceous mudstone, siltstone, muddy sandstone, and minor conglomerate that were deposited in a neritic environment. Pyrite is present locally as an authigenic cement. The sand fraction is dominated by lithic fragments, quartz, and minor amounts of plagioclase feldspar. The lithic component is predominantly volcanic rock fragments. The conglomerate is made up of igneous rock fragments. Core 1, taken near the bottom of this interval, is characterized by extensively bioturbated, poorly sorted, silty, very fine sandstone containing many well-preserved burrows and whole bivalves (fig. 16).

Porosity measurements of sandstone from 13 sidewall cores range from 30.4 to 40.6 percent. Permeabilities for these same samples range from 1.76 to 274 mD. Porosities for 26 sandstone samples from core 1 average 37 percent; permeabilities average 6.6 mD.

The SP log delimits about 1525 feet of porous siltstone, sandstone, and conglomerate. These porous rocks are in beds from less than 10 to approximately 300 feet thick. Most of the beds are 10 to 50 feet thick. Porous beds are thinner and less abundant in the bottom 250 feet of the section than in the upper part. Comparison of the gamma-ray log with the SP log indicates the gamma-ray log is not a reliable indicator of porous rock in this interval. This is probably a result of the abundant shaly matrix. The deep resistivity curve is flat. The shallow curve shows about 0.5 ohm-m greater resistivity than the deep curve in permeable beds, but tracks the deep curve in impermeable beds. The density and sonic curves are jagged because of the presence of many 5- to 25-foot-thick caved intervals in the borehole. The density curve shows

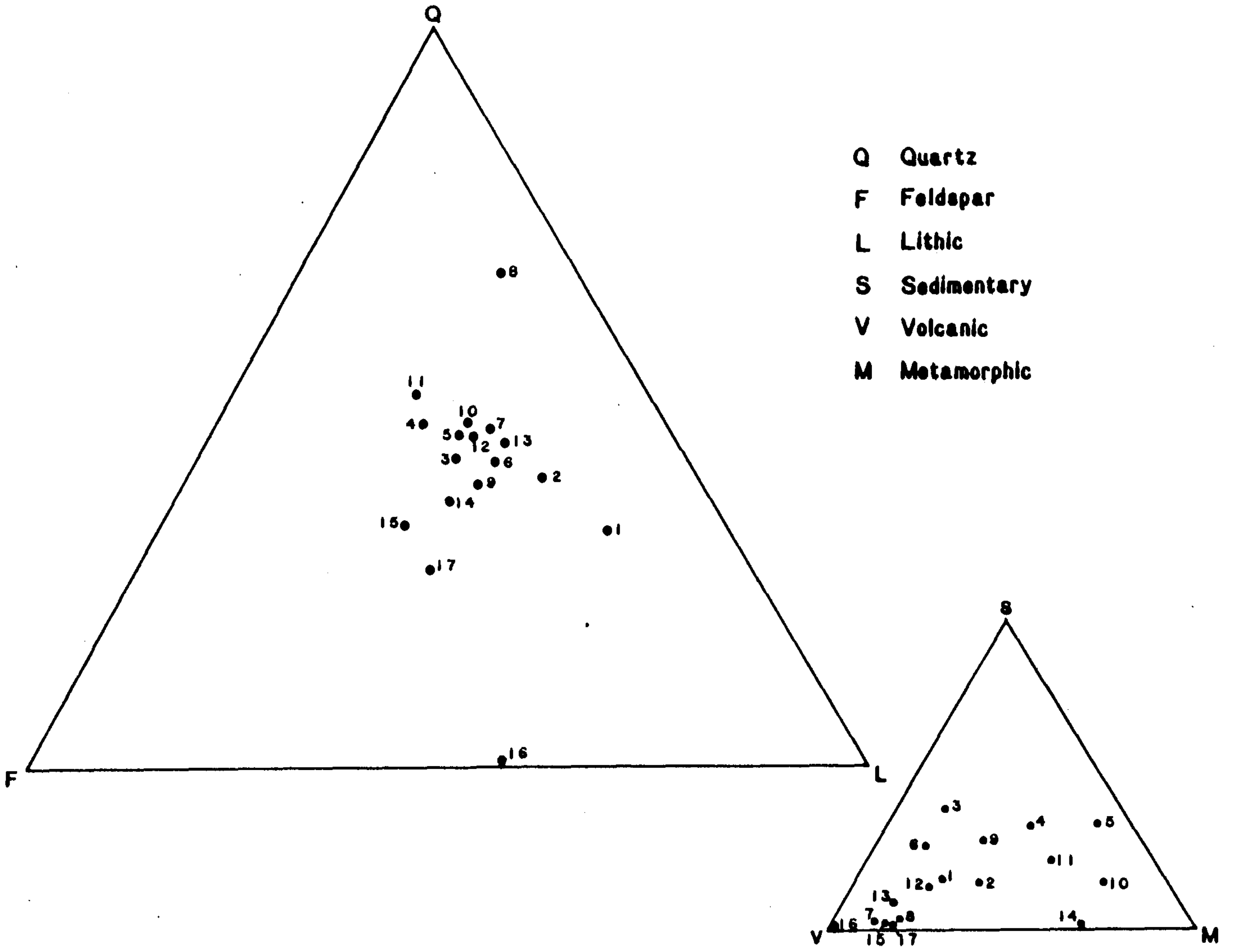


FIGURE 14. FRAMEWORK-CLAST COMPOSITION OF SANDSTONE SAMPLES FROM CONVENTIONAL CORES 1 TO 17, ST. GEORGE BASIN COST NO. 2 WELL. The large triangle shows the average abundances of quartz, feldspar, and lithic (including mica) components, and the small triangle shows the average abundances of volcanic, sedimentary, and metamorphic (including mica) lithologic types in the lithic fraction. After AGAT Consultants, Inc.

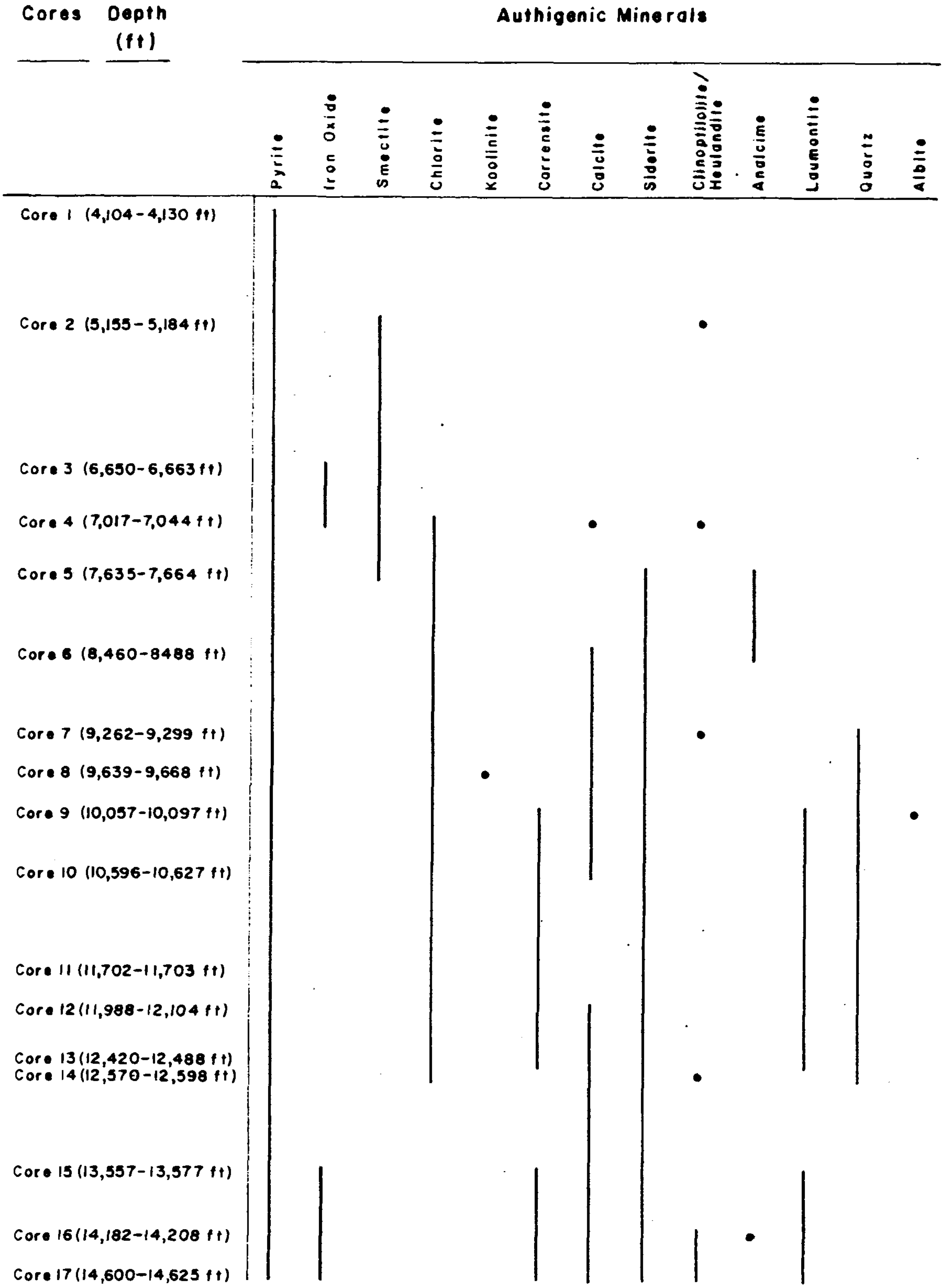


FIGURE 15. DISTRIBUTION OF AUTHIGENIC MINERALS IN CONVENTIONAL CORES, ST. GEORGE BASIN COST NO. 2 WELL.

a general increase from 1.6 to 2.2 g/cm^3. The sonic curve shows a general decrease from 170 to 120 µs/foot downward through the interval. The density log indicates porosities of 33 percent or higher for porous beds; the sonic log indicates porosities of 32 percent or more. The highest porosities exceed the range of the interpretive charts for both the density log (47 percent) and the sonic log (46 percent).

MIOCENE (4246 to 6050 feet)

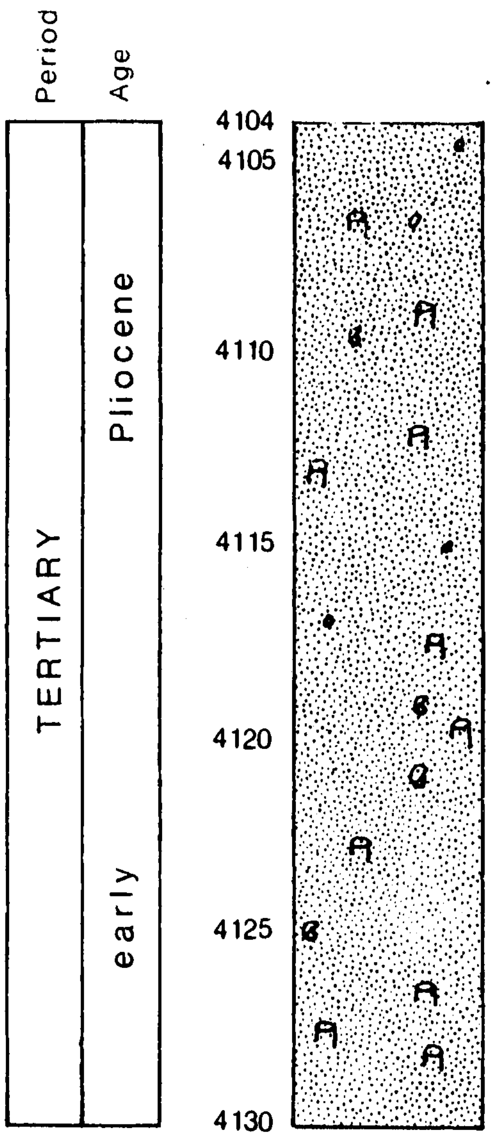
Mudstone, muddy sandstone, and siltstone deposited in neritic and bathyal environments are present from 4246 to 6050 feet. The sand fraction is dominated by rock fragments and quartz grains, with minor amounts of plagioclase and potassium feldspar. The lithic component consists predominantly of volcanic and metamorphic rock fragments. Ductile grains in the sandstone have been deformed by compaction. Smectite, clinoptilolite or heulandite, and less commonly, pyrite, are present as authigenic cements. Core 2 from this interval contains extensively bioturbated, poorly sorted, silty, very fine sandstone with many well-preserved burrows, bivalves, gastropods, and rip-up clasts (fig. 17).

Porosity measurements of sandstone from 7 sidewall cores in this interval range from 25.3 to 31.4 percent. Permeabilities for these same samples range from 68 to 116 mD. Porosities for 9 sandstone samples from core 2 average 29 percent; permeabilities average 30 mD. Comparison of the gamma-ray log with the SP log indicates that the gamma-ray log is not a reliable indicator of porous rock in this interval. The SP log indicates the presence of about 200 feet of porous sandstone and siltstone in 5- to 15-foot-thick beds. Most of these beds are located between 4840 and 5465 feet. The deep resistivity curve is generally flat. The shallow resistivity curve tracks the deep resistivity curve except in permeable beds, where separation of as much as 2.5 ohm-m is displayed. The density log is unreliable below 4900 feet because of poor hole conditions. In the upper part of the section, densities average about 2.2 g/cm^3 and density-derived sandstone porosities range from 29 to 30 percent. The sonic log is somewhat erratic below 4900 feet. Interval transit time generally ranges from 115 to 130 µs/foot. Sonic sandstone porosities range from 28 to 29 percent in the upper part of the interval.

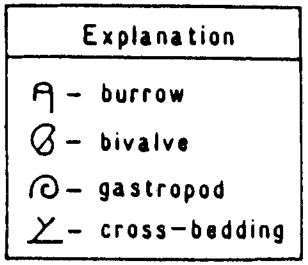
OLIGOCENE (6050 to 11,085 feet)

The interval from 6050 to 11,085 feet consists of interbedded sandstone, muddy sandstone, siltstone, and mudstone deposited in neritic to bathyal environments. Quartz is the most abundant component of the sand fraction of these rocks, but feldspar and lithic fragments together are generally more abundant than quartz. Lithic fragments are somewhat more abundant than feldspar. Both plagioclase and potassium feldspar are present. Volcanic and metamorphic rock fragments together are as abundant as sedimentary rock fragments. Wide variation in the lithic fraction from various depths suggests two or more source terranes.

Ductile grains in sandstones have been deformed throughout this interval. Authigenic minerals include pyrite and iron oxide, the clays smectite, kaolinite, chlorite, and corrensite, and the carbonates calcite and siderite. Zeolites present include clinoptilolite or heulandite, analcime, and laumontite. Authigenic quartz and albite are also present.



Sandstone: olive-gray (5Y 3/2), vaguely mottled, very fine grained, silty, scattered volcanic and granitic pebbles to 7 mm and bivalve shells and fragments, massive except in basal 1 foot where thin beds dip 55°, intensely bioturbated with many preserved burrows.

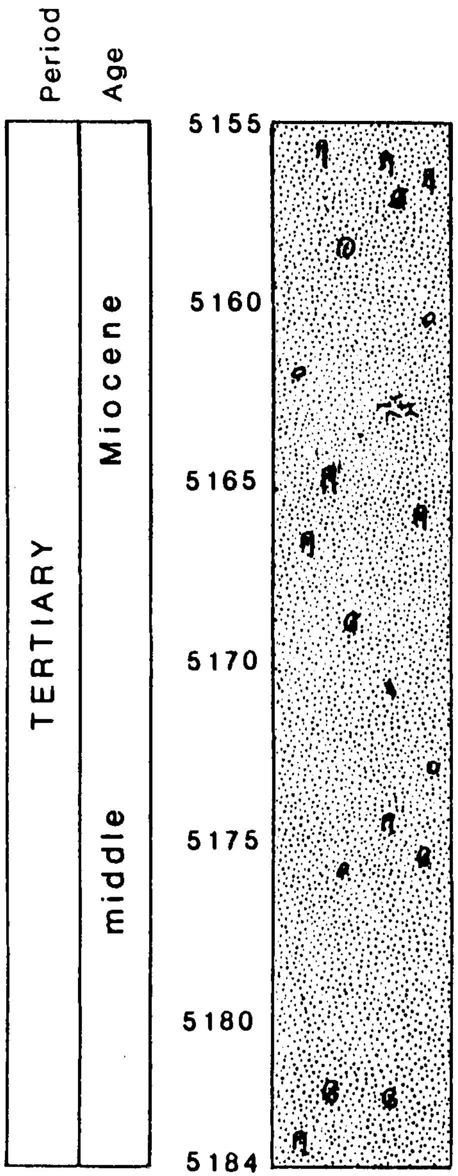


Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
36.8	6.23	.32	.28
37.3	6.32		
37.7	2.28		
36.7	12		
37.3	15		
38.3	1.48		
37.1	4.28		
37.9	6.59		
38.2	21		
41.3	1.68		
37.6	7.55	.40	.25?
39.9	3.38		
39.2	13		
37.7	12		
38.6	3.70		
36.1	14		
36.1	16		
40.9	2.86		
38.1	2.86		
38.4	1.43		
39.1	1.05		
39.7	3.29		
35.6	1.45		
39.3	1.04		
33.8	9.10		
32.3	2.43	.20	.24?

FIGURE 16. DESCRIPTION OF CONVENTIONAL CORE 1, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: grayish-olive-green (5GY 3/2), mottled, very fine grained, silty; scattered granitic and schistose pebbles to 7 mm, siltstone rip-up clasts to 3 cm, carbonaceous debris, and abundant fossil molluscan material; massive, intensely bioturbated with many preserved burrows.

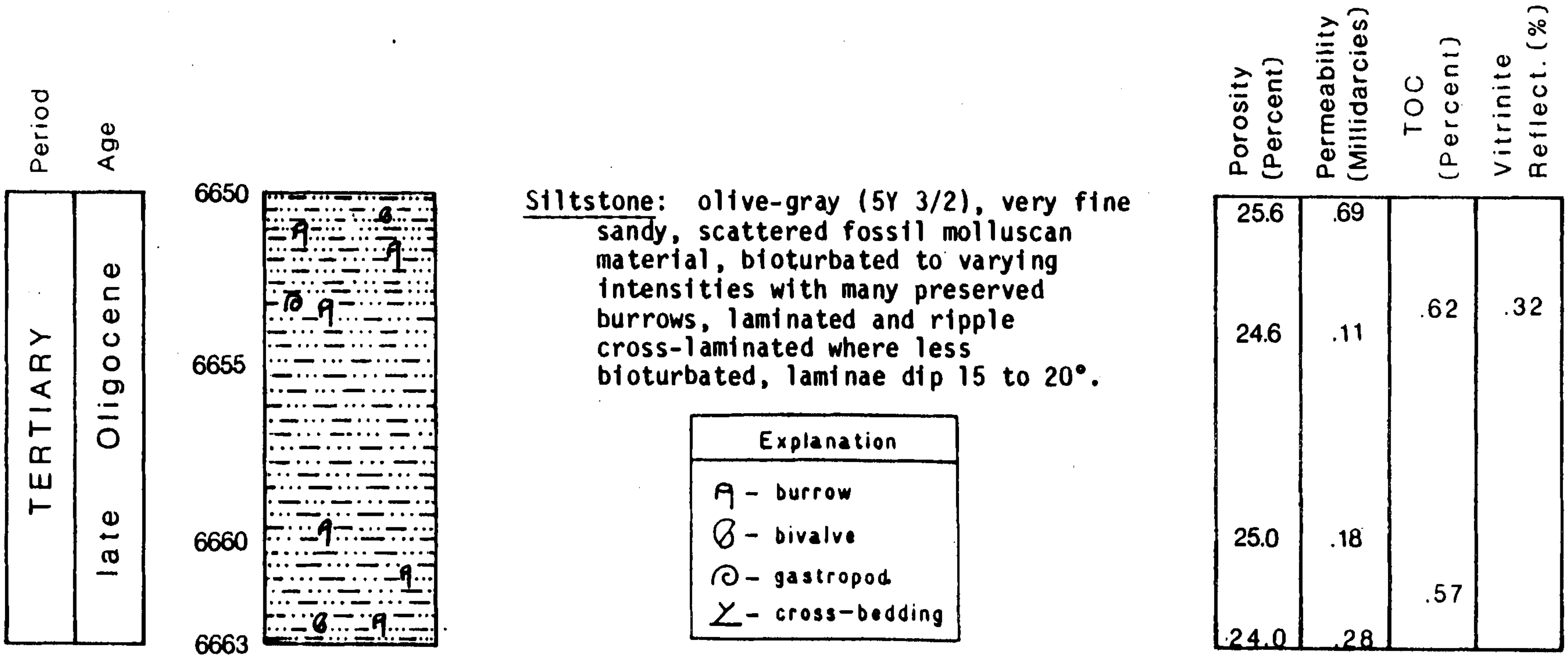
Explanation

- burrow
- bivalve
- gastropod
- cross-bedding

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
27.4	1.87		
		.40	.29
28.3	3.26		
30.4	111		
30.6	45		
29.6	39		
29.2	24		
24.9	10	.30	.28
27.9	8.66		
28.9	25		

FIGURE 17. DESCRIPTION OF CONVENTIONAL CORE 2, ST. GEORGE BASIN COST NO. 2 WELL.

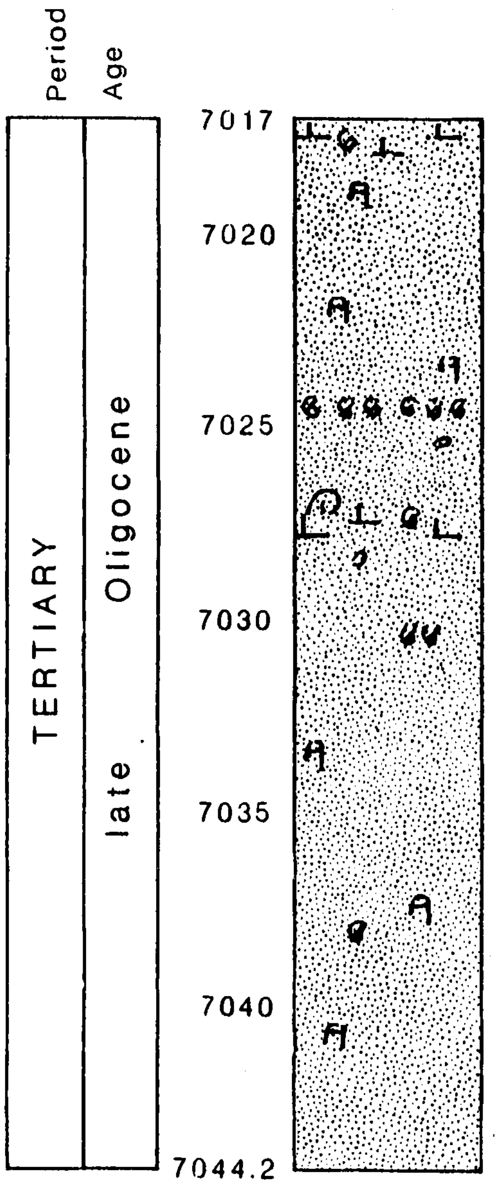
Porosity and permeability data from Core Laboratories, Inc.
TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



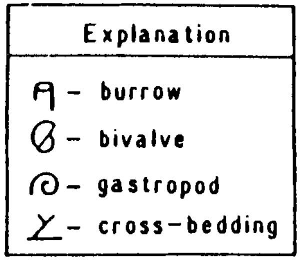
Siltstone: olive-gray (5Y 3/2), very fine sandy, scattered fossil molluscan material, bioturbated to varying intensities with many preserved burrows, laminated and ripple cross-laminated where less bioturbated, laminae dip 15 to 20°.

FIGURE 18. DESCRIPTION OF CONVENTIONAL CORE 3, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.
TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: grayish-olive-green (5GY 3/2), mottled, very fine grained, silty; scattered fossil molluscan material, volcanic pebbles to 2 cm, and carbonaceous debris; calcareous and medium-dark-gray (N 4) from 7017 to 7018.1 and 7027 to 7028.2 feet, massive, bioturbated with some preserved burrows, faintly laminated where bioturbation is not too intense.

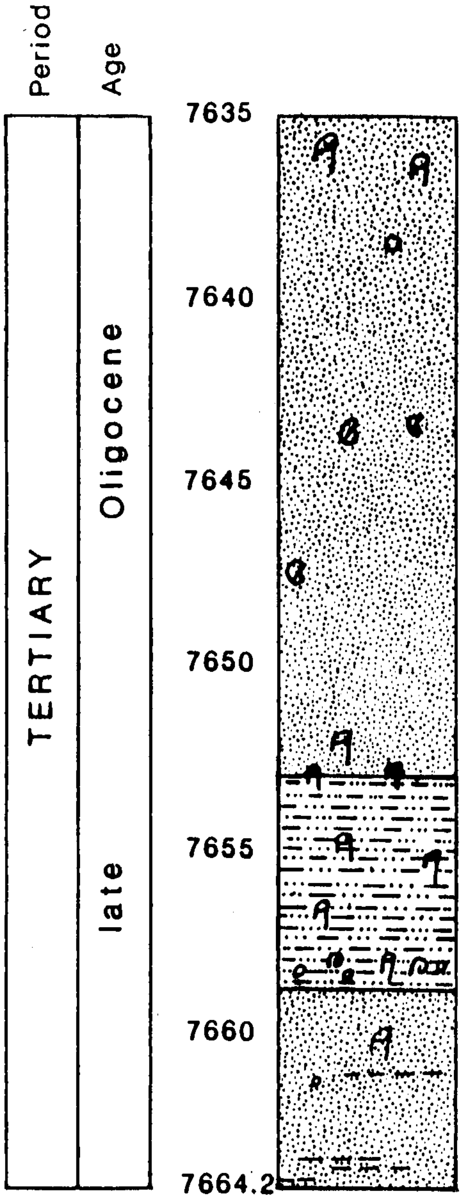


Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect (%)
2.7	<.01	.22	.31
25.3	142		
		.42	.37
23.4	.51		
		.45	.34
27.7	41		

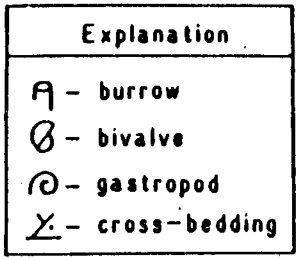
FIGURE 19. DESCRIPTION OF CONVENTIONAL CORE 4, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from



Sandstone: olive-gray (5Y 3/2), very fine grained, silty, rare pebbles to 1 cm, becomes less silty downward from 7645 feet, sand grade increases from very fine to fine between 7651 and 7653 feet, scattered articulated fossil bivalves, bioturbated with some preserved burrows, laminated where bioturbation is not too intense, laminae are subhorizontal.



Siltstone: olive-black (5Y 2/1), very fine sandy, bioturbated with many preserved burrows, ripple cross-laminated where bioturbation is not too intense, fossil gastropod fragments and volcanic pebbles to 6 mm in basal 1 foot.

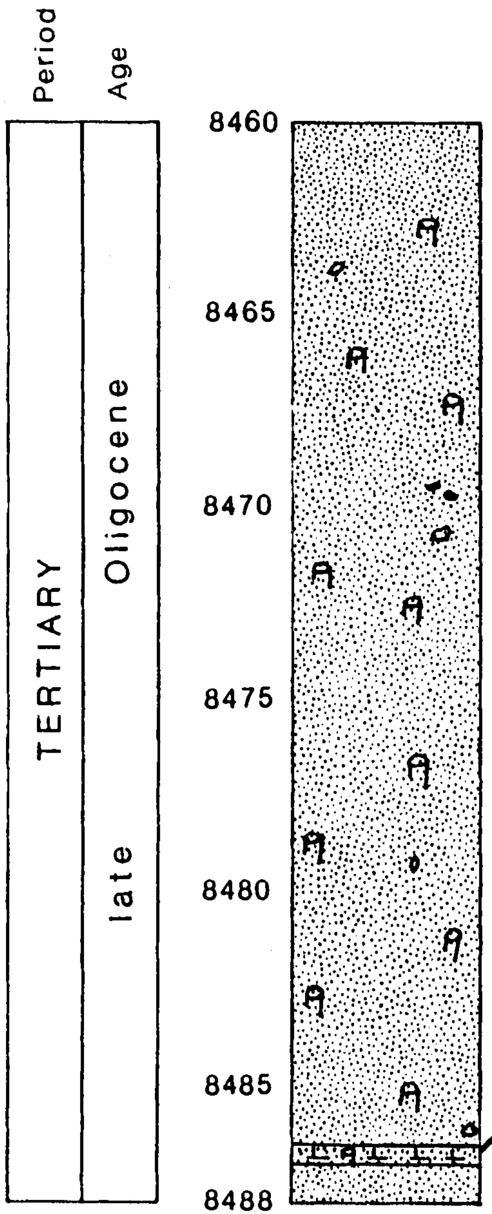
Sandstone: olive-gray (5Y 3/2), very fine to fine-grained, silty, rare pebbles to 5 mm, bioturbated with some preserved burrows, discontinuous shale partings.

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
21.8	.13		
18.3	.04		
		.44	.35
22.9	.70		
24.3	1.28		
23.5	6.42		
22.9	.77		
18.4	.05		
18.7	.05		
23.5	1.66		
26.2	4.63		
26.1	5.48		
24.0	2.25		

FIGURE 20. DESCRIPTION OF CONVENTIONAL CORE 5, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: olive-gray (5Y 3/2), very fine grained, silty, rare volcanic pebbles to more than 7 cm, minor coaly debris, discontinuous wavy siltstone stringers, bioturbated with some preserved burrows, massive.

Sandstone: dark-greenish-gray (5G 3/1), fine-grained, calcareous, bioturbated with compacted burrows.

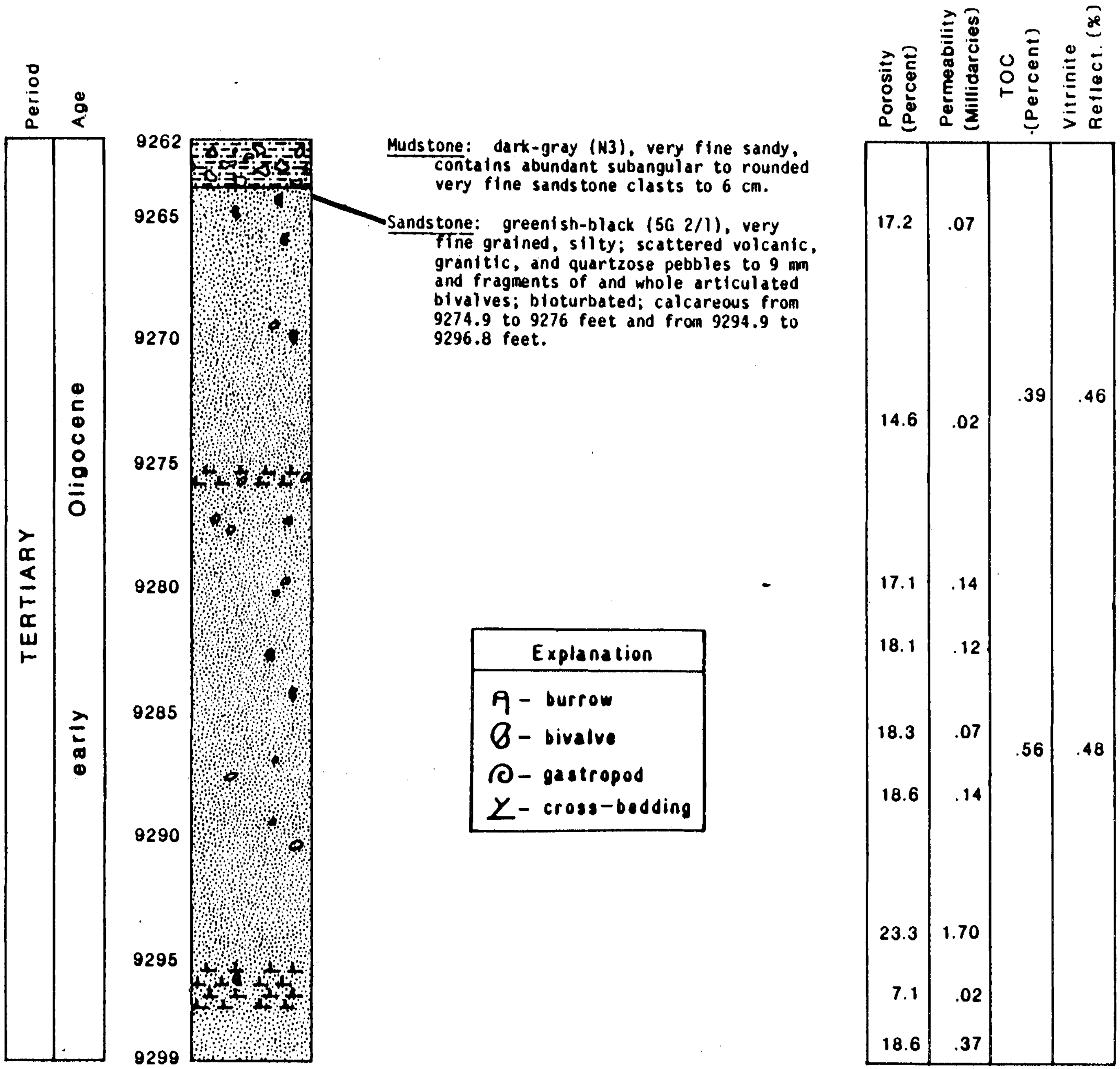
Sandstone: as at top of core.

Explanation

- burrow
- bivalve
- gastropod
- cross-bedding

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
22.9	.66		
24.6	.96		
23.3	.89		
24.2	.80		
22.5	.62		
22.3	.61		
21.9	.50	.22	.40
22.2	.82		
22.5	.74		
22.5	1.34		
20.9	.68		
22.4	1.99		
8.3	.04		
18.8	.72		

FIGURE 21. DESCRIPTION OF CONVENTIONAL CORE 6, ST. GEORGE BASIN COST NO. 2 WELL.
Porosity and permeability data from Core Laboratories, Inc.
TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



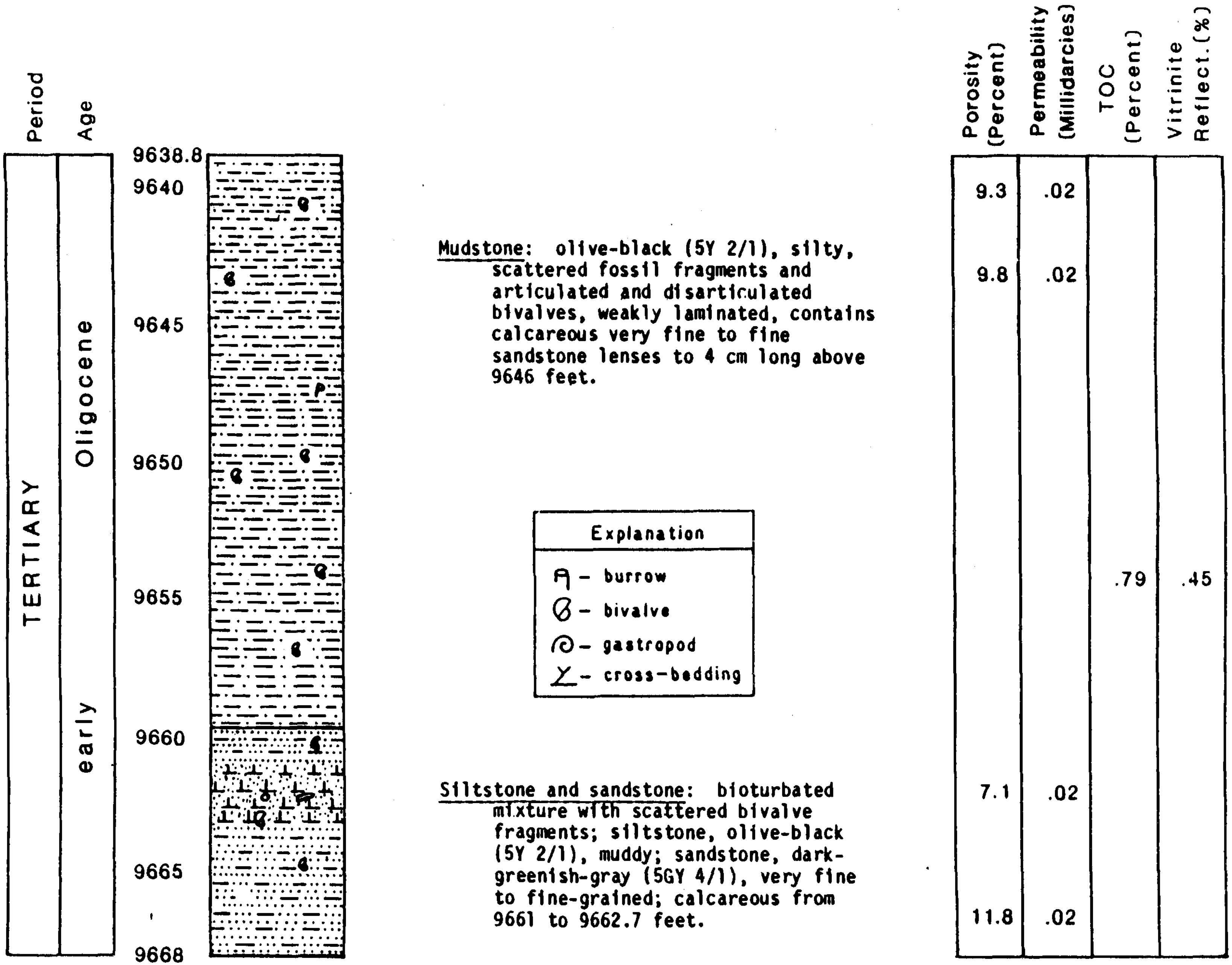
Mudstone: dark-gray (N3), very fine sandy, contains abundant subangular to rounded very fine sandstone clasts to 6 cm.

Sandstone: greenish-black (5G 2/1), very fine grained, silty; scattered volcanic, granitic, and quartzose pebbles to 9 mm and fragments of and whole articulated bivalves; bioturbated; calcareous from 9274.9 to 9276 feet and from 9294.9 to 9296.8 feet.

FIGURE 22. DESCRIPTION OF CONVENTIONAL CORE 7, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Mudstone: olive-black (5Y 2/1), silty, scattered fossil fragments and articulated and disarticulated bivalves, weakly laminated, contains calcareous very fine to fine sandstone lenses to 4 cm long above 9646 feet.

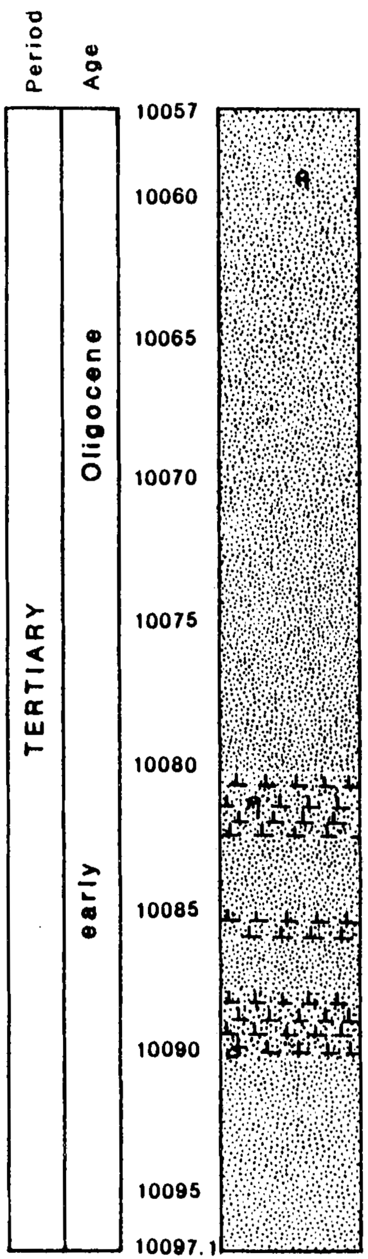
Siltstone and sandstone: bioturbated mixture with scattered bivalve fragments; siltstone, olive-black (5Y 2/1), muddy; sandstone, dark-greenish-gray (5GY 4/1), very fine to fine-grained; calcareous from 9661 to 9662.7 feet.

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
9.3	.02		
9.8	.02		
		.79	.45
7.1	.02		
11.8	.02		

FIGURE 23. DESCRIPTION OF CONVENTIONAL CORE 8, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: greenish-black (5G 2/1), mottled, very fine grained, rare carbonaceous debris and chert clasts to 2 cm; calcareous from 10,081.3 to 10,082.5, 10,084.9 to 10,085.8, and 10,087.6 to 10,089.9 feet; bioturbated with scattered burrows; contains discontinuous shale laminae, which dip about 15° in the bottom 4 1/2 feet of core.

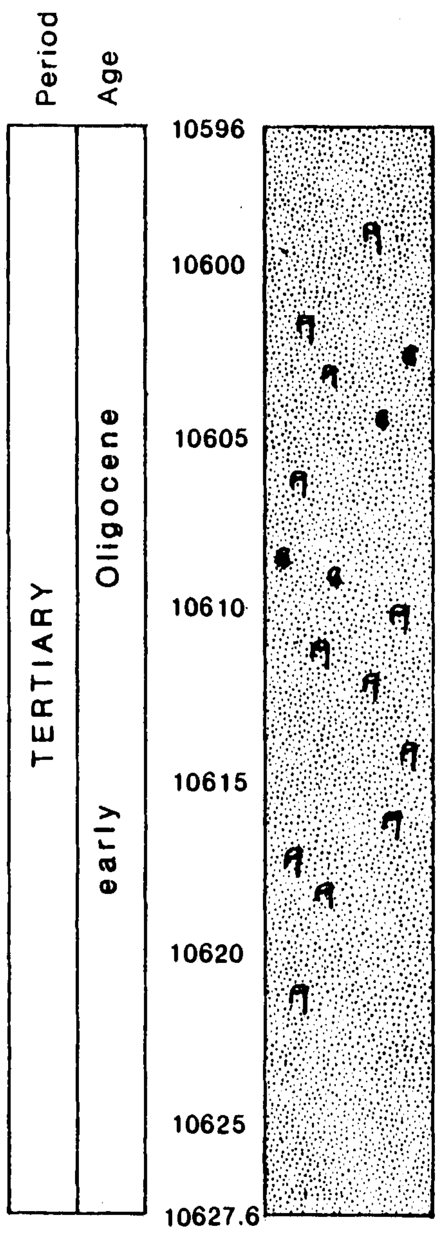
Explanation

ᑎ - burrow
Ø - bivalve
@ - gastropod
⅄ - cross-bedding

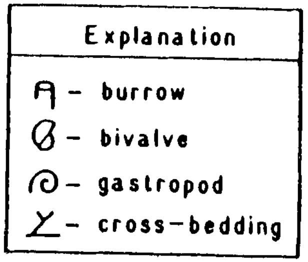
Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect. (%)
22.0	1.48		
17.0	.06		
22.0	65		
19.7	.53		
19.0	.39		
20.6	.88		
19.8	.17		
21.3	.78		
21.4	.65		
22.0	1.48		
21.6	1.28		
20.8	1.72		
20.9	1.51		
20.9	5.71		
20.0	.80		
21.0	.63		
19.8	.96		
19.5	1.35		
18.9	1.06		
17.8	2.28		
19.7	3.67		
19.3	1.98		
17.1	1.32		
18.6	3.00		
18.0	15		
7.4	.06		
15.6	3.05		
15.1	1.12		
15.7	.97		
16.3	1.35		
15.7	1.04		
5.6	.07	.17	.48?
3.0	.15		
13.6	.24		
15.3	.86		
16.0	.87		
15.7	.67		
15.4	.54		
17.3	.94		
15.3	.37		

FIGURE 24. DESCRIPTION OF CONVENTIONAL CORE 9, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.
TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: olive-gray (5Y 3/2), very fine grained, silty, scattered articulated bivalves and bivalve fragments, bioturbated with abundant preserved burrows, scattered wavy siltstone laminae and ripple cross-laminae.

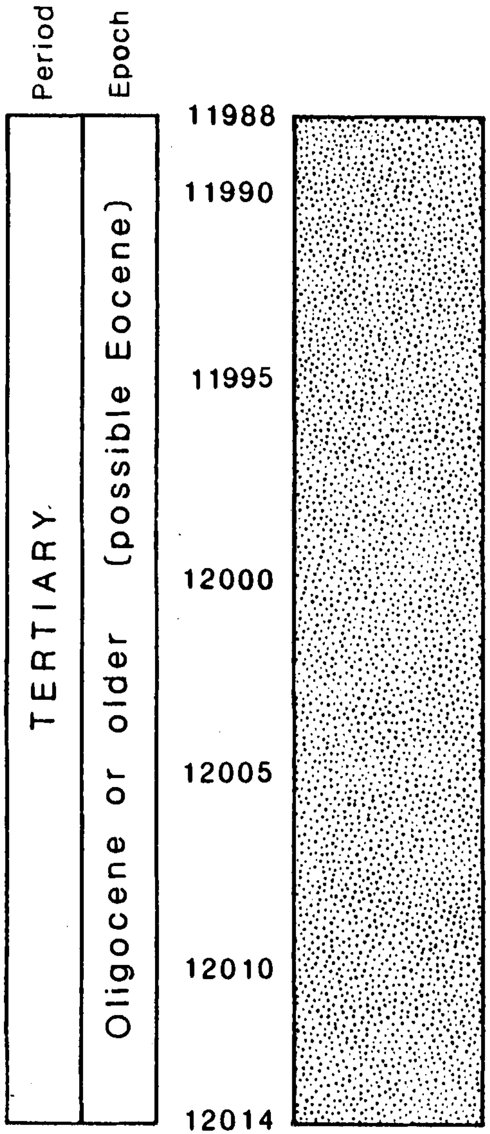


Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect.(%)
15.9	.87		
15.8	.95		
14.9	.36		
13.1	.38		
13.4	.27		
13.7	.22		
13.1	.40		
12.4	.45		
13.7	.62		
13.4	.53	.35	.52
12.6	.38		
14.3	.53		
13.4	.29		
12.6	.34		
13.2	.13		
10.3	.27		
11.4	.02		
11.3	.04		
11.2	.06		
13.3	.19		
14.1	.46		
13.7	.32		
15.0	.52		
13.3	.59		
13.7	.90		
13.5	.65		
12.1	.04		
12.8	.36	.48	.54
13.3	.36		
11.7	.02		
13.0	.21		
11.9	.53		

FIGURE 25. DESCRIPTION OF CONVENTIONAL CORE 10, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: dark-greenish-gray (5GY 4/1), very fine to fine-grained, scattered patches cemented with laumontite, massive; conjugate shear fractures indicate subvertical compression.

Explanation

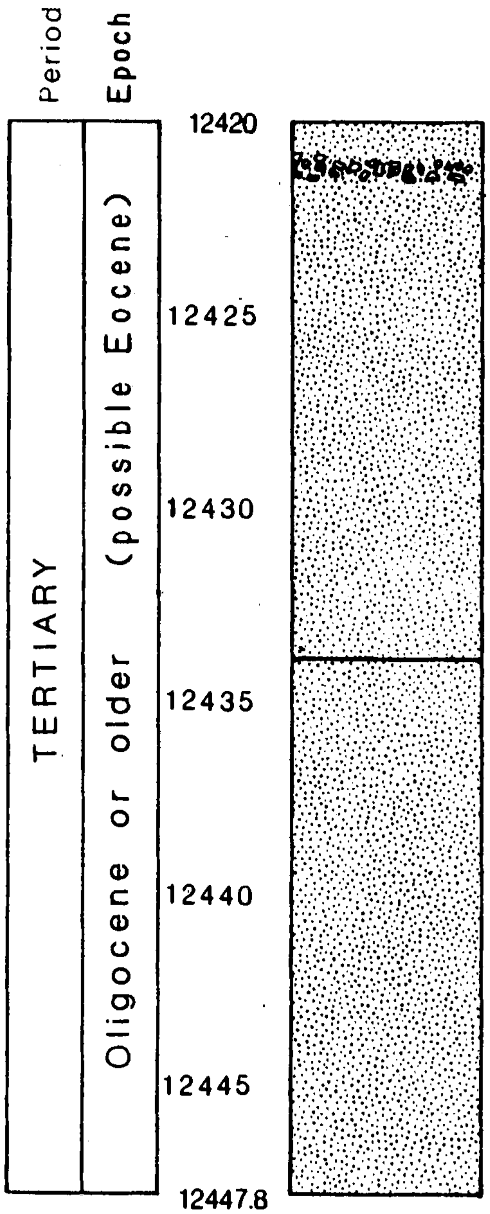
- burrow
- bivalve
- gastropod
- cross-bedding

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)	Vitrinite Reflect.(%)
13.9	1.53		
13.9	2.12		
13.3	1.48		
13.2	1.83		
13.7	1.36		
14.5	5.03		
14.4	2.01		
14.1	5.77		
13.5	1.22		
13.7	1.46		
13.6	1.64		
13.8	1.81		
14.4	2.07		
13.1	1.49		
13.1	1.59		
13.5	1.82		
12.9	1.29		
13.7	1.82		
13.6	1.32		
12.7	1.28		
12.7	1.71		
13.4	2.01		
13.2	1.81		
12.5	1.32		
13.7	1.24	.12	.57?
14.1	1.67		

FIGURE 26. DESCRIPTION OF CONVENTIONAL CORE 12, ST. GEORGE BASIN COST NO. 2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC and random vitrinite reflectance data from Robertson Research (U.S.), Inc.



Sandstone: dusky-brown (5YR 2/2), fine- to medium-grained, angular volcanic clasts to 3 cm in 30°-dipping 6-inch-thick band at 12,421 feet, scattered patches cemented with laumontite, massive, grades into unit below.

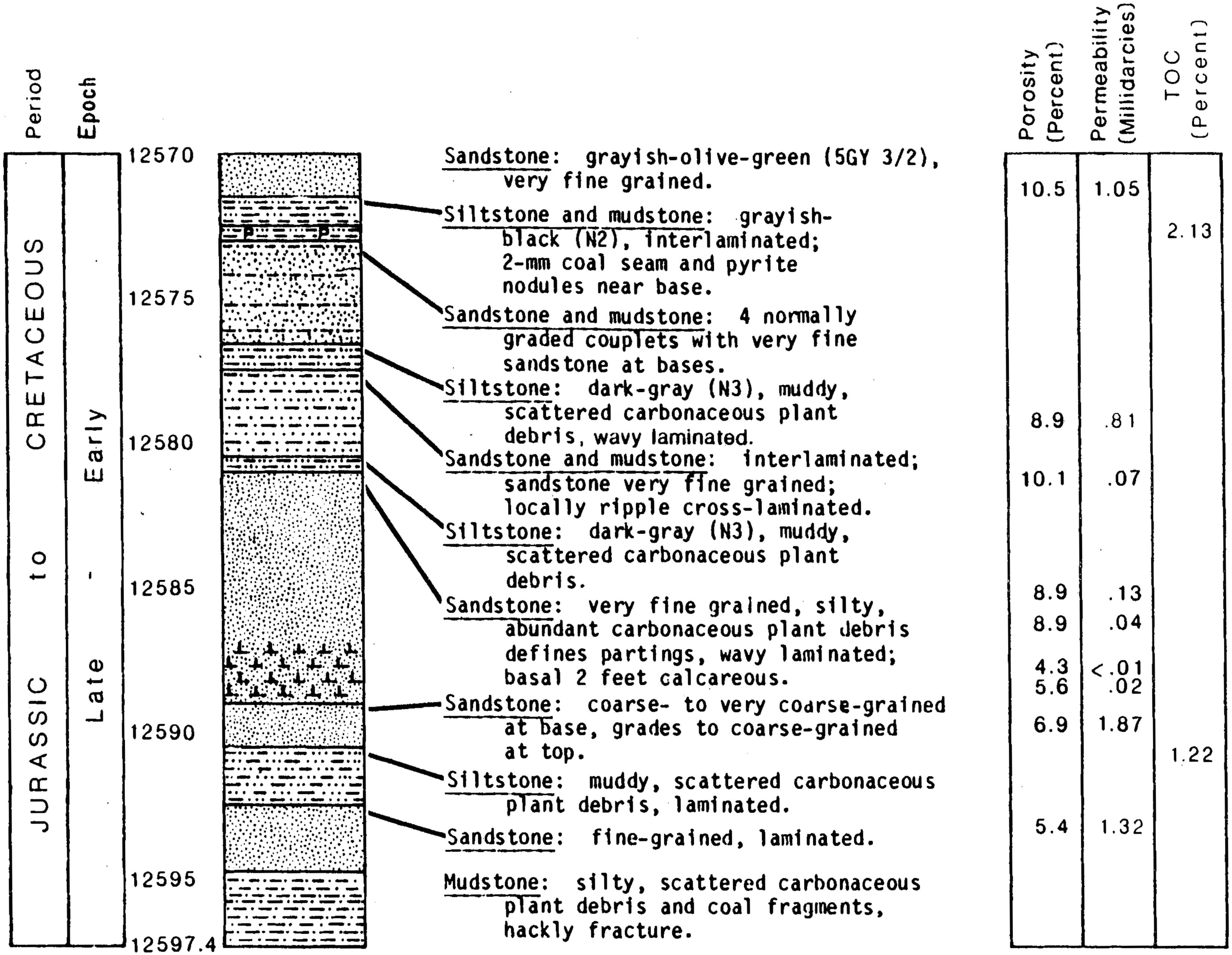
Explanation

- burrow
- bivalve
- gastropod
- cross-bedding

Sandstone: olive-gray (5Y 3/2), fine-grained, scattered patches cemented with laumontite, massive.

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)
13.7	2.53	.12
14.3	4.96	
12.9	4.21	
13.8	5.52	
12.9	4.33	
11.7	5.18	
12.1	4.92	
12.7	12	
11.2	1.95	
12.8	2.18	
13.3	1.74	
13.1	1.40	
13.6	1.04	
12.3	1.00	
11.6	.70	
13.1	1.41	
12.1	1.27	
12.7	.89	
13.5	1.63	
12.1	.91	
12.8	.85	
12.3	.71	
12.5	.82	
12.1	.73	
12.2	.95	
12.5	1.34	
13.1	1.02	

FIGURE 27. DESCRIPTION OF CONVENTIONAL CORE 13, ST. GEORGE BASIN COST NO. 2 WELL.
Porosity and permeability data from Core Laboratories, Inc.
TOC data from Robertson Research (U.S.), Inc.



Sandstone: grayish-olive-green (5GY 3/2), very fine grained.

Siltstone and mudstone: grayish-black (N2), interlaminated; 2-mm coal seam and pyrite nodules near base.

Sandstone and mudstone: 4 normally graded couplets with very fine sandstone at bases.

Siltstone: dark-gray (N3), muddy, scattered carbonaceous plant debris, wavy laminated.

Sandstone and mudstone: interlaminated; sandstone very fine grained; locally ripple cross-laminated.

Siltstone: dark-gray (N3), muddy, scattered carbonaceous plant debris.

Sandstone: very fine grained, silty, abundant carbonaceous plant debris defines partings, wavy laminated; basal 2 feet calcareous.

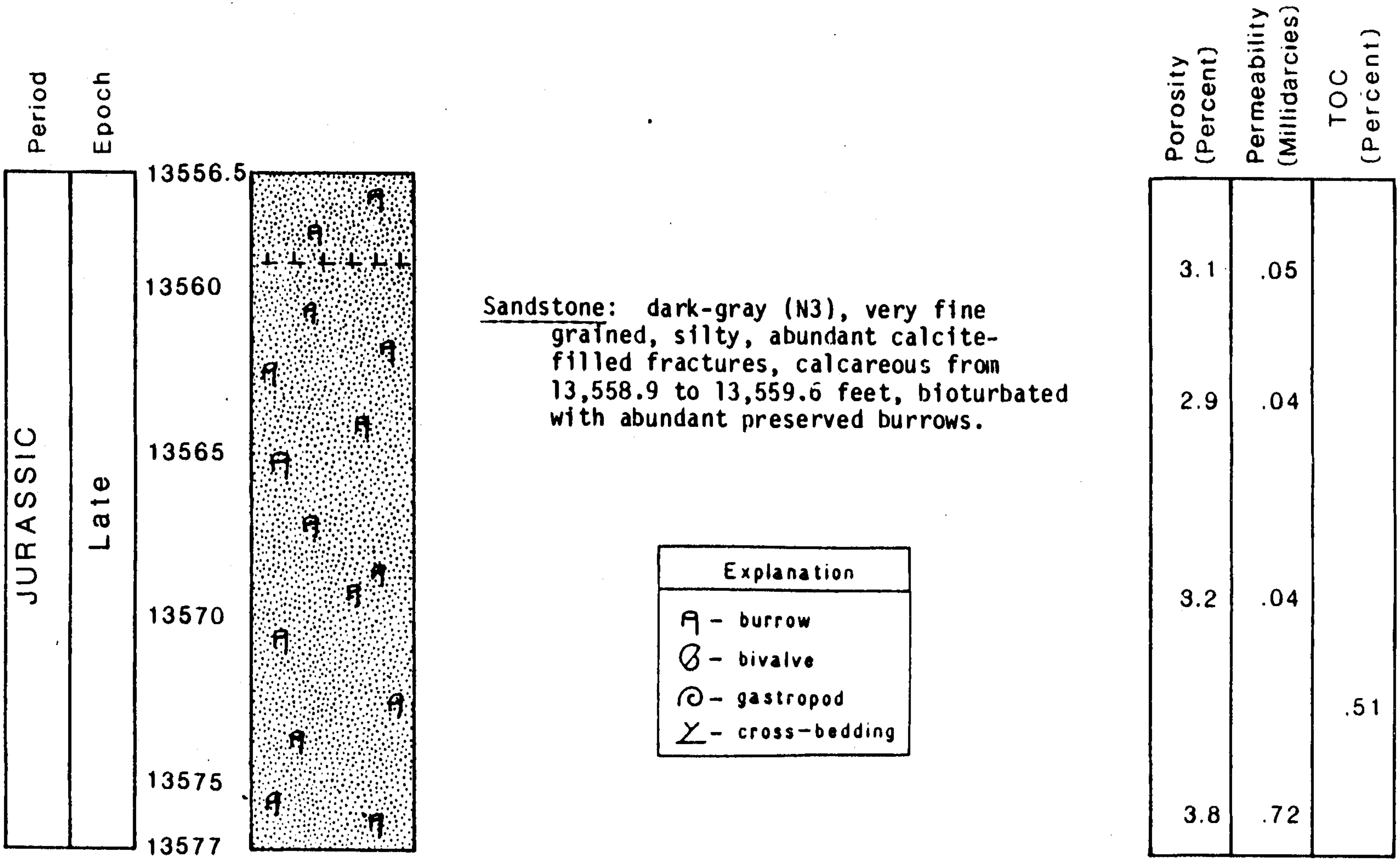
Sandstone: coarse- to very coarse-grained at base, grades to coarse-grained at top.

Siltstone: muddy, scattered carbonaceous plant debris, laminated.

Sandstone: fine-grained, laminated.

Mudstone: silty, scattered carbonaceous plant debris and coal fragments, hackly fracture.

FIGURE 28. DESCRIPTION OF CONVENTIONAL CORE 14, ST. GEORGE BASIN COST NO. 2 WELL.
Porosity and permeability data from Core Laboratories, Inc.
TOC data from Robertson Research (U.S.), Inc.

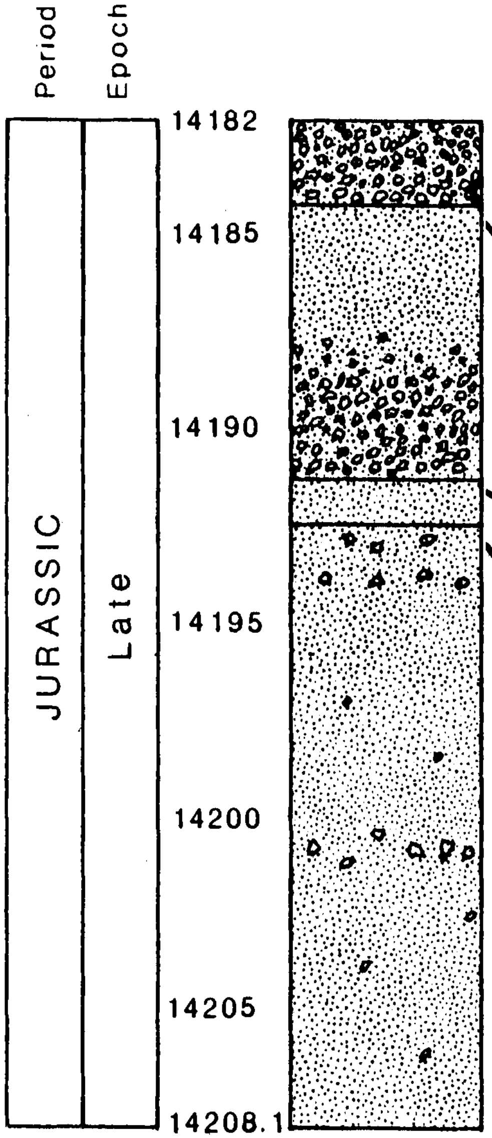


Sandstone: dark-gray (N3), very fine grained, silty, abundant calcite-filled fractures, calcareous from 13,558.9 to 13,559.6 feet, bioturbated with abundant preserved burrows.

FIGURE 29. DESCRIPTION OF CONVENTIONAL CORE 15, ST. GEORGE BASIN COST NO.2 WELL.

Porosity and permeability data from Core Laboratories, Inc.

TOC data from Robertson Research (U.S.), Inc.



Conglomerate: dark-olive-gray (5Y 3/1), subangular to subrounded volcanic clasts to 6 cm in fine to coarse sand matrix, complete size gradation between matrix and coarser clasts, calcite-filled fractures.

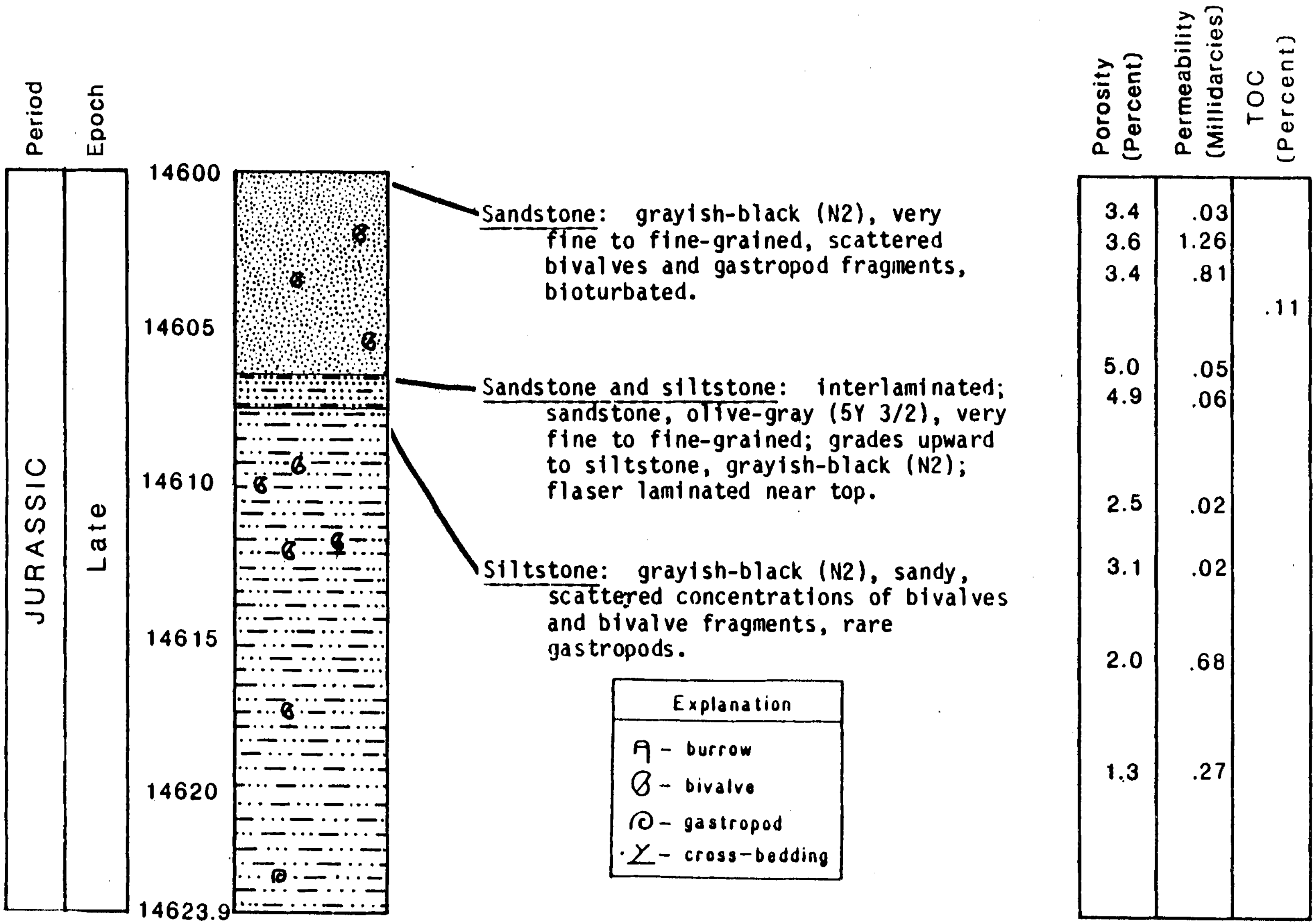
Conglomerate and sandstone: subangular to rounded volcanic clasts to 20 cm (but mostly less than 6 cm) in fine to very coarse sand matrix at base; grades upward to fine to very coarse sandstone at top.

Sandstone: dark-gray (N3), fine- to very coarse-grained, calcite-filled fractures.

Sandstone: olive-gray (5Y 3/2), fine- to coarse-grained, pebbly, thin conglomeratic layers at 14,193, 14,194, 14,201 feet; larger clasts are subangular to subrounded and volcanic and range up to 10 cm in maximum dimension, but most are smaller than 3 cm; abundant calcite-filled fractures.

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)
5.8	.07	
5.5	.03	
5.2	.06	
4.7	.05	
4.6	.02	
4.8	.04	
5.4	.04	
7.9	2.10	
3.7	.27	
10.2	.10	
7.4	.62	
8.4	6.70	
8.1	4.41	
7.2	.56	
9.2	.76	
		.04
9.5	2.25	
9.3	1.31	
9.5	2.68	

FIGURE 30. DESCRIPTION OF CONVENTIONAL CORE 16, ST. GEORGE BASIN COST NO. 2 WELL.
Porosity and permeability data from Core Laboratories, Inc.
TOC data from Robertson Research (U.S.), Inc.



Sandstone: grayish-black (N2), very fine to fine-grained, scattered bivalves and gastropod fragments, bioturbated.

Sandstone and siltstone: interlaminated; sandstone, olive-gray (5Y 3/2), very fine to fine-grained; grades upward to siltstone, grayish-black (N2); flaser laminated near top.

Siltstone: grayish-black (N2), sandy, scattered concentrations of bivalves and bivalve fragments, rare gastropods.

Porosity (Percent)	Permeability (Millidarcies)	TOC (Percent)
3.4	.03	
3.6	1.26	
3.4	.81	
		.11
5.0	.05	
4.9	.06	
2.5	.02	
3.1	.02	
2.0	.68	
1.3	.27	

FIGURE 31. DESCRIPTION OF CONVENTIONAL CORE 17, ST. GEORGE BASIN COST NO. 2 WELL.
TOC data from Robertson Research (U.S.), Inc.
Porosity and permeability data from Core Laboratories, Inc.

Cores 3 to 10 from this interval are described in figures 18 to 25. Extensively bioturbated, poorly sorted siltstone and sandstone with many well-preserved burrows, bivalves, and gastropods are common and indicate marine shelf deposition.

Porosity measurements of sandstone from 44 sidewall cores range from 17.5 to 30.3 percent. Permeabilities for these same samples range from 3.72 to 104 mD. Average porosities of sandstone from conventional cores range from 25 percent for core 3 (6650 to 6664 feet) down to 13 percent for core 10 (10,596 to 10,628 feet). There is a general decrease in average porosity with increasing depth for conventional cores. Average permeabilities of conventional core samples range from less than 1 to 12 mD. There is no discernable relationship between average permeability and depth or average porosity.

The SP log indicates the presence of about 1630 feet of porous sandstone and siltstone. These beds range from 5 to 120 feet thick and are thicker and more abundant below 7850 feet. Comparison of the SP and gamma-ray logs indicates that the gamma-ray log is not a reliable indicator of porous rock in this interval. The deep resistivity curve is generally flat and records a gradual increase in resistivity downward. The shallow resistivity curve tracks the deep resistivity curve in impermeable beds, but the two curves are generally separated by 2 to 3 ohm-m in permeable beds. The density log was strongly affected by extensive caving in this interval. Reliable density measurements range from 2.3 to 2.5 g/cm^3, and reliable density-derived sandstone porosities range from 17 to 27 percent. The sonic log was less affected by hole conditions than was the density log. Interval transit times decrease from 115 to 72 µs/foot downward through this interval. Sonic porosities range from 12 to 29 percent.

OLIGOCENE OR OLDER (11,085 to 12,540 feet)

The interval from 11,085 to 12,540 feet consists of interbedded sandstone and siltstone deposited in nearshore marine or nonmarine environments. The composition of the sand fraction is similar to that of the overlying Oligocene section. Ductile grains in the sandstones have been deformed in the same fashion as in the shallower intervals. Authigenic cements include pyrite, calcite, siderite, quartz, laumontite, chlorite, corrensite, and possibly kaolinite.

Cores 11 to 13 are from this interval. Only 1 foot of sandstone was recovered from core 11, which is not described. The other cores are described in figures 26 and 27. There are no sedimentary structures present that are indicative of any specific depositional environment. Minor glauconite in core 12 (11,988 to 12,014 feet) and in sidewall cores from 11,468, 11,740, and 12,267 feet suggests deposition in a marine shelf environment, although the absence of fossils and burrows detracts from the certainty of that interpretation.

Porosity measurements of sandstone from 10 sidewall cores range from 19.1 to 26.1 percent. Permeabilities for these same samples range from 16 to 121 mD. Average porosities of sandstone from conventional cores range from 12 percent for cores 11 and 13 to 13.5 percent for core 12. Average permeabilities of sandstone from conventional cores range from less than 1 to 2.5 mD. There is no apparent relationship between average permeability and depth or average porosity.

The SP log indicates the presence of about 220 feet of porous sandstone. These beds range from 10 to 60 feet thick. Comparison of the SP and gamma-ray logs indicates that the gamma-ray log is not a reliable indicator of porous rock in this interval. The deep resistivity curve is flat, and the shallow curve follows the deep curve with a difference of about 1 ohm-m between the two. The density log is unreliable below about 11,360 feet because of poor hole conditions. Densities range from 2.50 to 2.55 g/cm^3 in the upper part of the interval. No porous beds are defined by the SP log above 11,360 feet, but the density log indicates porosities of 6 to 11 percent for any sandstone that may be present. The sonic log was not affected as much by washouts as was the density log. Interval transit times decrease from 75 to 70 μs/foot downward through the interval, and sonic porosities range from 11 to 15 percent.

LATE JURASSIC TO EARLY CRETACEOUS (12,540 to 13,370 feet)

The interval from 12,540 to 13,370 feet consists of sandstone, conglomerate, siltstone, and minor amounts of shale. Coal is present in cuttings from the top 60 feet. These rocks were deposited in fluvial or deltaic and possibly marine shelf environments.

The sand fraction of these rocks consists of subequal amounts of plagioclase and potassium feldspar, quartz, and rock fragments. Both metamorphic and volcanic rock fragments are present. The conglomerates are made up of volcanic, sandstone, and siltstone clasts in a sandstone matrix. Ductile grain deformation is common in the sandstones. Pyrite, quartz, smectite, chlorite, calcite, siderite, clinoptilolite or heulandite, and laumontite are present as authigenic cements.

Core 14 is from the top of this interval and is described in figure 28. The graded bedding and parallel, wavy, and ripple lamination seen in thin beds in the core are consistent with deltaic point-bar and crevasse-splay deposition. However, minor glauconite in sandstone deeper in the section suggests that at least part of the interval may have been deposited in a marine environment.

Porosity measurements of sandstone samples from 5 sidewall cores range from 20.9 to 26.1 percent. Permeability measurements, obtained from only two of these samples, are 29 and 79 mD. Porosity measurements of 9 sandstone samples from core 14 average 7.6 percent. Permeability measurements for these same samples average less than 1 mD. The higher porosity and permeability values from sidewall cores are probably a result of fabric disruption caused by percussion.

The SP curve is flat with minor undulations in this interval. This is probably due to low porosity contrasts between lithologies. The gamma-ray log suggests the presence of about 250 feet of nonporous sandstone or conglomerate in 40- to 100-foot-thick beds. The deep resistivity curve is blocky above 12,800 and below 13,200 feet. From 12,800 to 13,200 feet the curve is variably undulating or jagged over a range of about 30 ohm-m. The shallow resistivity curve follows the deep resistivity curve with separations of up to 20 ohm-m (but less than 5 ohm-m in most cases). There is no apparent correlation between the separation of the two curves and the presence of sandstone or conglomerate suggested by the gamma-ray log. Extensive washouts above 12,800 feet make the density log unusable in the upper 260 feet. Local washouts in the lower part of the interval are reflected by many sharp excursions of the density curve to low values. The average rock density in uncaved parts of this interval is 2.5 g/cm^3, which indicates a sandstone porosity of about 8 percent. The sonic log is erratic above 12,800 feet. Below that depth, interval transit times generally range from 60 to 65 µs/foot, which indicates sandstone porosities of 3 to 7 percent.

LATE JURASSIC (13,370 to 14,626 feet)

The interval from 13,370 to 14,626 feet consists of sandstone, siltstone, and conglomerate deposited in a marine environment.

Feldspar and rock fragments are present in roughly equal amounts in the sand fraction of rocks from this interval. The quartz content ranges from zero to almost a third of the sand fraction. Both plagioclase and potassium feldspar are present. The rock fragments in the sandstone are almost exclusively volcanic. The conglomerates are made up of large volcanic clasts in a sandstone matrix. Ductile grain deformation is common. Pyrite, iron oxide, calcite, siderite, corrensite, clinoptilolite or heulandite, analcime, and laumontite are present as authigenic cements.

Cores 15, 16, and 17 are from this interval and are described in figures 29, 30 and 31. The extensively bioturbated, poorly sorted, very fine sandstone with preserved burrows seen in core 15 suggests deposition in a marginal marine environment. The sandstone and conglomerate of core 16 are similar in aspect to facies A of Mutti and Ricci Lucchi (1972) and may have been deposited in submarine channels. The bioturbated, laminated and cross-laminated, fine-grained rocks of core 17, which contain many whole and fragmented bivalves and gastropods, were probably deposited in a marine shelf environment.

Sandstone porosity measurements from 8 sidewall cores range from 15.1 to 26.5 percent. Permeabilities, obtained for only three of these samples, range from 36 to 164 mD. Sandstone porosities average 3 percent in the 4 samples from core 15 and in the 9 samples from core 17. Porosities of 18 sandstone samples from core 16 average 7 percent. Permeabilities average 1.23 mD for the 18 samples from core 16 but are much lower for samples from the other cores. Permeabilities average 0.21 mD for the 4 samples from core 15 and 0.36 mD for the 9 samples from core 17.

The SP curve undulates gently, probably because of low porosity contrast among lithologies in the interval. The gamma-ray log does not exhibit any character that would permit lithologic interpretation. Extensive washouts in the uppermost 60 feet made the resistivity, density, and sonic logs unreliable above 13,430 feet. Below this depth the deep resistivity curve is flat with minor local undulations. The shallow resistivity curve generally follows the deep resistivity curve with a 0- to 10-ohm-m separation between the curves. The density log shows densities from 2.55 to 2.65 g/cm^3 for rocks below 13,430 feet. This indicates sandstone porosities of 3 to 5 percent. The sonic curve is quite flat below 13,430 feet, and interval transit times are clustered very closely around 60 µs/foot. This indicates sandstone porosities of about 3 percent.

POROSITY AND PERMEABILITY

Porosity and permeability determinations from sidewall and conventional cores from the well are presented in table 2. Above about 6500 feet there is good agreement between the porosities of sandstone samples from conventional cores and those from nearby sidewall cores. Below 6500 feet sandstone samples from sidewall cores have generally higher porosities than those from nearby conventional cores. This disparity increases with depth. Throughout the well, sandstone samples from sidewall cores display generally higher permeabilities than do sandstone samples of similar porosity from conventional cores. Figure 32 presents a plot of average porosity against depth for sandstone samples from conventional cores, and figure 33 presents a plot of average permeability against average porosity for the same samples. Although a general decrease in porosity with depth is evident in figure 32, average sandstone porosities exceed 10 percent down to at least 12,700 feet. Figure 33 shows considerable scatter in the relationship between porosities and permeabilities of sandstone samples. It is apparent that average permeabilities of 10 or more millidarcies are restricted to sandstone units with average porosities greater than about 20 percent. Such units are not present below 8000 feet.

Porosity and permeability data from sandstone samples from both sidewall and conventional cores are presented graphically in plate 1. Porosity and permeability values have been integrated over 500-foot thicknesses and are represented by symbols that show the mean value and range for each interval. The number of sandstone samples in each interval is given under the symbol.

Postdepositional porosity and permeability reduction is due to compaction, ductile grain deformation, and cementation. Clays and zeolites are the most common authigenic cements. Dissolution of volcanic rock fragments, plagioclase, and hornblende has occurred throughout the well. The dissolved material was subsequently precipitated as authigenic cements, most of which are hydrous and of lower density than the original material dissolved. The net effect has been a reduction in porosity.

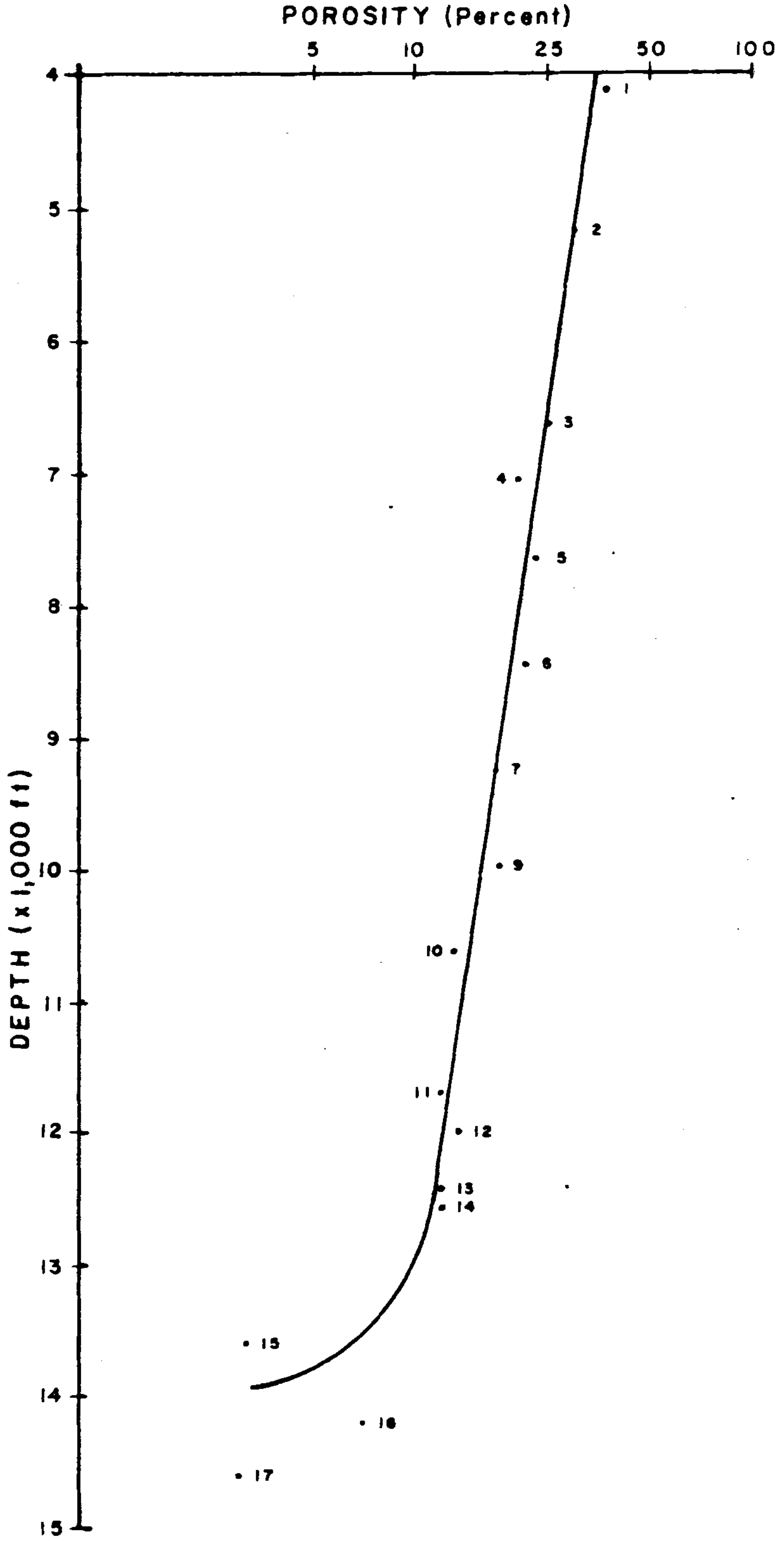


FIGURE 32. PLOT OF AVERAGE POROSITY AGAINST DEPTH FOR SANDSTONE SAMPLES FROM CONVENTIONAL CORES 1 TO 17, ST. GEORGE BASIN COST NO. 2 WELL.

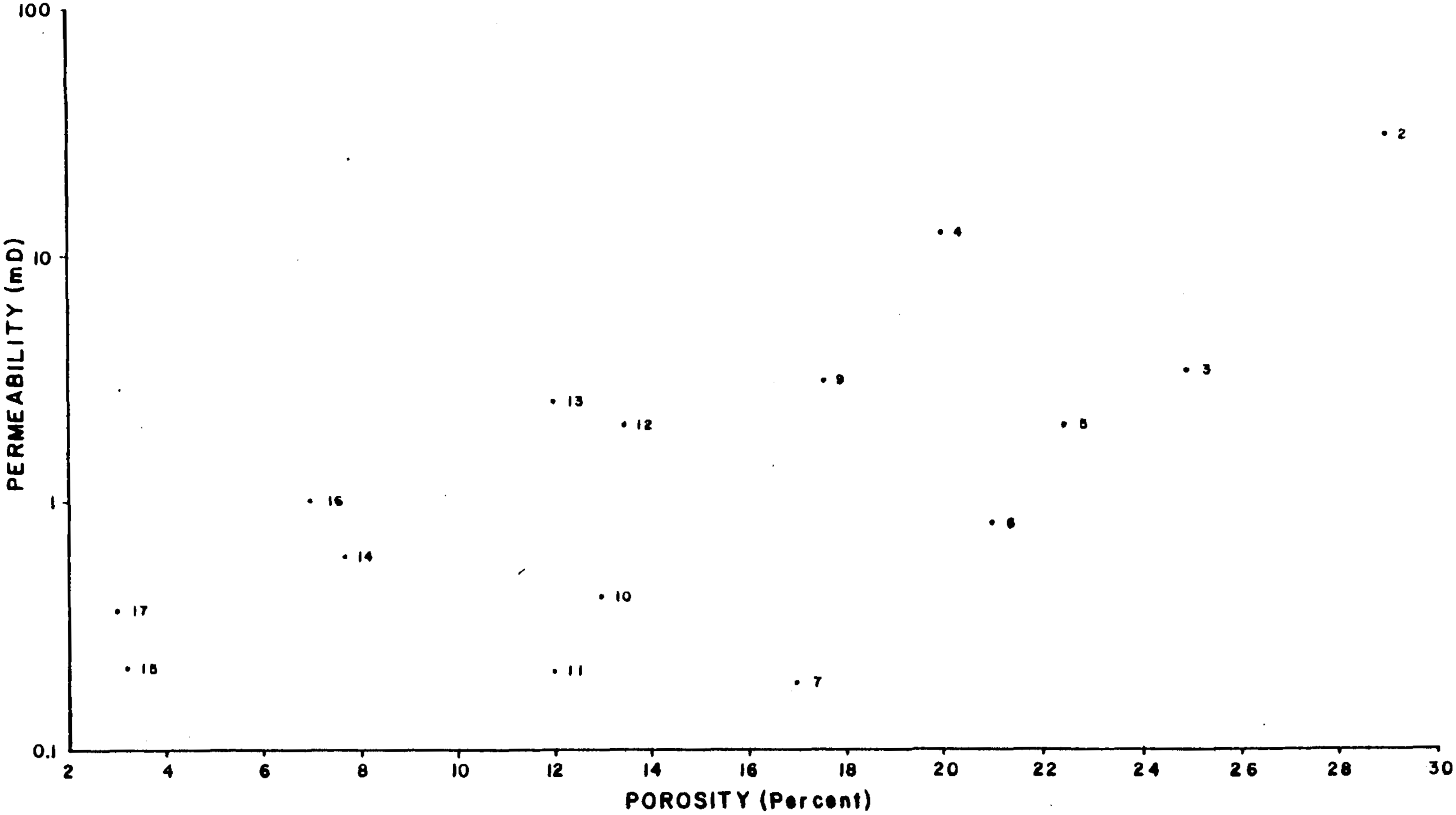


FIGURE 33. PLOT OF AVERAGE PERMEABILITY AGAINST AVERAGE POROSITY FOR SANDSTONE SAMPLES FROM CONVENTIONAL CORES 1 TO 17, ST. GEORGE BASIN COST NO. 2 WELL.

Table 2. POROSITY AND PERMEABILITY
(From Core Laboratories, Inc.)

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
1555.0	sltst;sdy;carb	46.1	16	Sidewall
1610.0	sltst;sdy	41.7	27	Sidewall
2142.0	same	37.1	51	Sidewall
2544.0	same	40.5	11	Sidewall
2708.0	ss;vf-fgr	37.9	94	Sidewall
2835.0	same	36.7	147	Sidewall
2917.0	sltst;sdy	41.0	0.73	Sidewall
3060.0	ss;vf-fgr	38.3	103	Sidewall
3132.0	same;slty	40.6	67	Sidewall
3482.0	ss;vf-mgr,slty	37.6	186	Sidewall
3516.0	same	40.4	274	Sidewall
3622.0	ss;vf-fgr,vslty	38.3	19	Sidewall
3739.0	same	40.5	27	Sidewall
3758.0	ss;vf-fgr	35.6	91	Sidewall
3830.0	same;slty	36.6	32	Sidewall
3970.0	ss;vf-fgr,vslty	38.7	7.73	Sidewall
4005.0	sltst;sdy	40.1	0.87	Sidewall
4081.0	ss;vf-fgr,vslty	30.4	2.21	Sidewall
4104.0	ss;vf-mgr,slty	36.8	6.23	Core 1
4105.0	same	37.3	6.32	Core 1
4106.0	same	37.7	2.28	Core 1
4107.0	same	36.7	12	Core 1
4108.0	same	37.3	15	Core 1
4109.0	same	38.3	1.48	Core 1
4110.0	same	37.1	4.28	Core 1
4111.0	same	37.9	6.59	Core 1
4112.0	same	38.2	21	Core 1
4113.0	ss;vf-fgr,slty	41.3	1.68	Core 1
4114.0	ss;vf-mgr,slty	37.6	7.55	Core 1
4115.0	same	39.9	3.38	Core 1
4116.0	same	39.2	13	Core 1
4117.0	same	37.7	12	Core 1
4118.0	same	38.6	3.70	Core 1
4119.0	same	36.1	14	Core 1
4120.0	same	36.1	16	Core 1
4121.0	same	40.9	2.86	Core 1
4122.0	same	38.1	2.86	Core 1
4123.0	same	38.4	1.43	Core 1
4124.0	same	39.1	1.05	Core 1
4125.0	same	39.7	3.29	Core 1

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
4126.0	ss;vf-mgr,slty	35.6	1.45	Core 1
4127.0	same	39.3	1.04	Core 1
4128.0	ss;f-mgr,slty	33.8	9.10	Core 1
4129.0	same	32.3	2.43	Core 1
4220.0	ss;vf-fgr,vslty	33.1	1.76	Sidewall
4306.0	sltst;sdy	28.1	0.07	Sidewall
4430.0	same;vsdy	28.4	0.33	Sidewall
5064.0	ss;f-mgr,slty	29.1	113	Sidewall
5152.0	same	26.4	101	Sidewall
5155.0	same	27.4	1.87	Core 2
5161.0	same	28.3	3.26	Core 2
5165.0	ss;f-mgr	30.4	111	Core 2
5167.0	same	30.6	45	Core 2
5170.0	same	29.6	39	Core 2
5172.0	same	29.2	24	Core 2
5176.0	same;sltst lam	24.9	10	Core 2
5181.0	same;slty	27.9	8.66	Core 2
5184.0	same	28.9	25	Core 2
5223.0	ss;fgr,slty	28.4	68	Sidewall
5371.0	same	26.3	70	Sidewall
5458.0	ss;f-mgr,slty	27.8	116	Sidewall
5848.0	same	25.3	92	Sidewall
6007.0	ss;fgr,slty	31.4	115	Sidewall
6083.0	ss;fgr,cly	26.2	44	Sidewall
6224.0	same	28.8	56	Sidewall
6339.0	same,foss	27.4	52	Sidewall
6345.0	ss;vf-fgr,slty,cly	28.7	35	Sidewall
6650.7	ss;vf-mgr,sl calc	25.6	0.69	Core 3
6654.7	ss;vf-fgr,sl calc	24.6	0.11	Core 3
6655.0	sltst;cly	24.4	14	Sidewall
6659.7	ss;vf-fgr,sl calc	25.0	0.18	Core 3
6663.2	same	24.0	0.28	Core 3
6681.0	ss;fgr	29.0	104	Sidewall
6797.0	ss;vf-fgr	30.3	101	Sidewall
6830.0	same	28.4	53	Sidewall
6947.0	same	29.4	101	Sidewall
7017.6	ss;vf-fgr,vcalc	2.7	< 0.01	Core 4
7019.3	ss;vf-mgr,slty	25.3	1.42	Core 4
7020.0	ss;vf-fgr	27.3	85	Sidewall
7035.4	ss;vf-mgr,slty	23.4	0.51	Core 4

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
7043.1	ss;f-mgr,slty	27.7	41	Core 4
7072.0	ss;vf-fgr	28.1	80	Sidewall
7200.0	ss;vf-fgr,cly	23.2	25	Sidewall
7342.0	sltst;v cly,sdy	24.0	165	Sidewall,frac
7385.0	sltst;v cly	20.6	2.72	Sidewall
7450.0	ss;vf-fgr,cly	24.2	31	Sidewall
7636.6	ss;vf-fgr,sl slty	21.8	0.13	Core 5
7638.0	ss; vf-fgr,cly	26.0	37	Sidewall
7642.2	ss;vf-fgr,sl slty	18.3	0.04	Core 5
7648.4	ss;vf-mgr	22.9	0.70	Core 5
7649.4	same	24.3	1.28	Core 5
7651.6	same	23.5	6.42	Core 5
7652.3	same	22.9	0.77	Core 5
7653.6	ss;vfgr,slty	18.4	0.05	Core 5
7656.5	same	18.7	0.05	Core 5
7659.4	ss;f-mgr,slty	23.5	1.66	Core 5
7661.4	same	26.2	4.63	Core 5
7662.5	same	26.1	5.48	Core 5
7663.6	same	24.0	2.25	Core 5
7668.0	ss;vf-fgr,cly	25.1	22	Sidewall
7823.0	ss;vfgr,slty	25.0	32	Sidewall
7849.0	same	26.9	91	Sidewall
7926.0	same	26.7	63	Sidewall
8016.0	same	26.5	103	Sidewall
8092.0	same	26.2	57	Sidewall
8224.0	same	26.9	29	Sidewall
8396.0	same	23.9	22	Sidewall
8460.5	ss;f-mgr,slty	22.9	0.66	Core 6
8462.5	same	24.6	0.96	Core 6
8464.6	same	23.3	0.89	Core 6
8467.5	same	24.2	0.80	Core 6
8469.8	same	22.5	0.62	Core 6
8470.0	ss;vfgr,slty	25.6	19	Sidewall
8472.5	ss;f-mgr,slty	22.3	0.61	Core 6
8475.6	same	21.9	0.50	Core 6
8477.8	same	22.2	0.82	Core 6
8479.7	same	22.5	0.74	Core 6
8481.9	same	22.5	1.34	Core 6
8483.5	same	20.9	0.68	Core 6
8485.4	same	22.4	1.99	Core 6

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
8486.7	ss;vf-mgr,vcalc	8.3	0.04	Core 6
8487.3	ss;vf-mgr,slty	18.8	0.72	Core 6
8534.0	ss;vfgr,slty	23.9	20	Sidewall
8710.0	ss;vfgr,v cly	20.5	5.61	Sidewall
8894.0	ss;vf-fgr,cly	25.6	32	Sidewall
9057.0	ss;vf-fgr,v cly	25.0	11	Sidewall
9162.0	ss;vfgr	22.6	50	Sidewall
9244.0	ss;vfgr,cly	24.6	25	Sidewall
9265.2	ss;vf-fgr,slty,glauc	17.2	0.07	Core 7
9273.2	same	14.6	0.02	Core 7
9279.7	ss;vf-mgr,slty,glauc	17.1	0.14	Core 7
9282.5	same	18.1	0.12	Core 7
9284.0	ss;vfgr,cly	21.7	38	Sidewall
9285.4	ss;vf-mgr,slty,glauc	18.3	0.07	Core 7
9288.4	same	18.6	0.14	Core 7
9292.0	ss;vfgr,cly	21.2	70	Sidewall
9293.7	ss;f-cgr,slty,glauc	23.3	1.70	Core 7
9296.5	ss;vf-cgr,glauc,vcalc	7.1	0.02	Core 7
9298.4	ss;f-cgr,slty,glauc	18.6	0.37	Core 7
9326.0	ss;vfgr,cly	25.7	29	Sidewall
9332.0	same	24.3	34	Sidewall
9548.0	ss;vf-fgr,cly	21.9	3.72	Sidewall
9596.0	ss;vfgr,slty	17.5	13	Sidewall
9628.0	ss;vf-fgr,slty	24.7	11	Sidewall
9640.2	sltst;vsdy,glauc,sl calc	9.3	0.02	Core 8
9643.2	sltst;sdy;glauc	9.8	0.02	Core 8
9658.0	sltst,v cly	23.2	1.99	Sidewall
9661.7	ss;vf-mgr,slty,glauc,calc	7.1	0.02	Core 8
9666.7	ss;vf-fgr,slty	11.8	0.02	Core 8
9974.0	ss;vfgr,cly	25.1	18	Sidewall
10044.0	same	22.4	17	Sidewall
10057.3	ss;vf-fgr,calc	22.0	1.48	Core 9
10058.3	ss;vf-fgr,slty	17.0	0.06	Core 9
10059.3	same	22.0	65	Core 9
10060.0	ss;vfg,cly	22.4	24	Sidewall
10060.1	ss;vf-fgr,glauc	19.7	0.53	Core 9
10061.5	ss;vf-fgr,slty	19.0	0.39	Core 9
10062.3	ss;vf-fgr,mica	20.6	0.88	Core 9
10063.2	ss;vf-fgr,slty,sc carb	19.8	0.17	Core 9
10064.1	ss;vf-fgr,slty	21.3	0.78	Core 9
10065.3	same	21.4	0.65	Core 9

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
10066.3	ss;vf-fgr,slty	22.0	1.48	Core 9
10067.3	same	21.6	1.28	Core 9
10068.3	same	20.8	1.72	Core 9
10069.1	same	20.9	1.51	Core 9
10070.1	same	20.9	5.71	Core 9
10071.2	same	20.0	0.80	Core 9
10072.3	same	21.0	0.63	Core 9
10073.2	same	19.8	0.96	Core 9
10074.3	same	19.5	1.35	Core 9
10075.2	same	18.9	1.06	Core 9
10076.2	same	17.8	2.28	Core 9
10077.2	same	19.7	3.67	Core 9
10078.4	same	19.3	1.98	Core 9
10079.2	same	17.1	1.32	Core 9
10080.4	same	18.6	3.00	Core 9
10081.1	same	18.0	15	Core 9
10082.3	ss;vfgr,slty,calc	7.4	0.06	Core 9
10083.3	ss;vf-fgr,slty,sl calc	15.6	3.05	Core 9
10084.2	same	15.1	1.12	Core 9
10085.1	same	15.7	0.97	Core 9
10086.2	same	16.3	1.35	Core 9
10087.2	same	15.7	1.04	Core 9
10088.1	ss;vf-fgr,v calc	5.6	0.07	Core 9
10089.4	same	3.0	0.15	Core 9
10090.1	same	13.6	0.24	Core 9
10091.2	ss;vf-vfg,slty	15.3	0.86	Core 9
10092.0	ss;vfgr,cly	24.2	9.56	Sidewall
10092.6	ss;vf-vfg,slty	16.0	0.87	Core 9
10093.2	same	15.7	0.67	Core 9
10094.4	same	15.4	0.54	Core 9
10095.1	same	17.3	0.94	Core 9
10096.2	same	15.3	0.37	Core 9
10134.0	ss;vfgr	22.8	24	Sidewall
10206.0	ss;vf-fgr	22.7	12	Sidewall
10298.0	same	22.0	11	Sidewall
10596.4	ss;fr-fgr,cly,mica	15.9	0.87	Core 10
10597.3	same	15.8	0.95	Core 10
10598.4	same	14.9	0.36	Core 10
10599.4	same	13.1	0.38	Core 10
10600.5	same	13.4	0.27	Core 10

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
10601.7	ss;fr-fgr,cly,mica	13.7	0.22	Core 10
10602.2	same	13.1	0.40	Core 10
10603.5	same	12.4	0.45	Core 10
10604.6	same	13.7	0.62	Core 10
10605.0	ss;vf-fgr	22.1	57	Sidewall
10605.5	ss;fr-fgr,cly,mica	13.4	0.53	Core 10
10606.5	ss;fr-fgr,cly,mica	12.6	0.38	Core 10
10607.6	ss;vfgr,cly,mica	14.3	0.53	Core 10
10608.8	same	13.4	0.29	Core 10
10609.5	ss;vf-fgr,cly,mica	12.6	0.34	Core 10
10610.4	same	13.2	0.13	Core 10
10611.7	same	10.3	0.27	Core 10
10612.7	ss;vfgr,slty,mica	11.4	0.02	Core 10
10613.9	same	11.3	0.04	Core 10
10614.7	same	11.2	0.06	Core 10
10615.7	same	13.3	0.19	Core 10
10616.4	same	14.1	0.46	Core 10
10617.7	same	13.7	0.32	Core 10
10618.4	same	15.0	0.52	Core 10
10619.6	same	13.3	0.59	Core 10
10620.8	same	13.7	0.90	Core 10
10621.5	same	13.5	0.65	Core 10
10622.7	sltst;sdy	12.1	0.04	Core 10
10623.5	ss;vfgr,slty,mica	12.8	0.36	Core 10
10624.5	same	13.3	0.36	Core 10
10625.6	same	11.7	0.02	Core 10
10626.5	same	13.0	0.21	Core 10
10627.6	same	11.9	0.53	Core 10
10995.0	ss;vf-fgr	22.3	56	Sidewall
11105.0	same	20.9	89	Sidewall
11468.0	ss;vf-fgr,glauc,sl calc	26.1	47	Sidewall
11485.0	same	25.3	121	Sidewall
11702.5	ss;vf-mgr,glauc	12.0	0.20	Core 11
11740.0	ss;vf-fgr,sc glauc, sl calc	19.9	42	Sidewall
11872.0	same	22.5		Sidewall
11936.0	same	20.0	60	Sidewall
11970.0	same	20.1		Sidewall
11988.7	ss;vf-mgr,glauc	13.9	1.53	Core 12
11989.5	same	13.9	2.12	Core 12
11990.5	same	13.3	1.48	Core 12

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
11991.5	ss;vf-mgr,glauc	13.2	1.83	Core 12
11992.6	same	13.7	1.36	Core 12
11993.4	same	14.5	5.03	Core 12
11994.5	same	14.4	2.01	Core 12
11995.0	ss;vf-fgr,sc glauc, sl calc	19.1	64	Sidewall
11995.3	ss;vf-mgr,glauc	14.1	5.77	Core 12
11996.3	same	13.5	1.22	Core 12
11997.5	same	13.7	1.46	Core 12
11998.6	same	13.6	1.64	Core 12
11999.6	same	13.8	1.81	Core 12
12000.7	same	14.4	2.07	Core 12
12001.5	same	13.1	1.49	Core 12
12002.5	same	13.1	1.59	Core 12
12003.5	same	13.5	1.82	Core 12
12004.5	same	12.9	1.29	Core 12
12005.6	same	13.7	1.82	Core 12
12006.7	same	13.6	1.32	Core 12
12007.5	same	12.7	1.28	Core 12
12008.5	same	12.7	1.71	Core 12
12009.5	same	13.4	2.01	Core 12
12010.5	same	13.2	1.81	Core 12
12011.6	same	12.5	1.32	Core 12
12012.6	same	13.7	1.24	Core 12
12013.7	same	14.1	1.67	Core 12
12267.0	ss;vf-mgr,sc glauc, sl calc	20.5	16	Sidewall
12420.3	ss;m-cgr,glauc	13.7	2.53	Core 13
12422.3	same	14.3	4.96	Core 13
12423.6	same	12.9	4.21	Core 13
12424.6	same	13.8	5.52	Core 13
12425.4	same	12.9	4.33	Core 13
12426.5	same	11.7	5.18	Core 13
12427.5	same	12.1	4.92	Core 13
12428.4	same	12.7	12	Core 13
12429.5	same	11.2	1.95	Core 13
12430.5	ss;f-cgr,glauc	12.8	2.18	Core 13
12431.5	same	13.3	1.74	Core 13
12432.5	same	13.1	1.40	Core 13
12433.5	same	13.6	1.04	Core 13
12434.6	same	12.3	1.00	Core 13
12435.6	same	11.6	0.70	Core 13

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
12436.2	ss;f-cgr,glauc	13.1	1.41	Core 13
12437.6	ss;f-mgr,glauc	12.1	1.27	Core 13
12438.6	same	12.7	0.89	Core 13
12439.4	same	13.5	1.63	Core 13
12440.4	same	12.1	0.91	Core 13
12441.6	same	12.8	0.85	Core 13
12442.6	same	12.3	0.71	Core 13
12443.6	same	12.5	0.82	Core 13
12444.5	same	12.1	0.73	Core 13
12445.4	same	12.2	0.95	Core 13
12446.5	same	12.5	1.34	Core 13
12447.7	same	13.1	1.02	Core 13
12485.0	ss;vf-mgr,sc glauc, sl calc	22.4	59	Sidewall
12540.0	same	23.0		Sidewall
12550.0	same	20.9	29	Sidewall
12560.0	sh;muddy,frac	16.8		Sidewall
12571.3	ss;vf-mgr,fn sh inbd	10.5	1.05	Core 14
12579.2	ss;vf-mgr	8.9	0.81	Core 14
12581.3	same	10.1	0.07	Core 14
12585.5	ss;vf-fgr,fn sh inbd	8.9	0.13	Core 14
12586.3	same	8.9	0.04	Core 14
12587.9	ss;vf-mgr	4.3	<0.01	Core 14
12588.4	same	5.6	0.02	Core 14
12589.7	ss;f-cgr	6.9	1.87	Core 14
12593.0	ss;vf-fgr,shy	21.7		Sidewall
12593.1	ss;f-cgr	5.4	1.32	Core 14
12675.0	sltst;sdy,calc	17.9	35	Sidewall
12747.0	ss;vf-fgr,calc	22.6	79	Sidewall
12820.0	ss;vf-fgr	26.1		Sidewall
13412.0	ss;vf-mgr,peb,calc	15.8	36	Sidewall
13465.0	ss;vf-fgr,calc	26.5		Sidewall
13559.3	ss;vf-fgr,shy	3.1	0.05	Core 15
13563.2	same	2.9	0.04	Core 15
13569.4	same	3.2	0.04	Core 15
13575.7	same	3.8	0.72	Core 15
13963.0	ss;vfgr,foss	22.2		Sidewall
14044.0	ss;vf-fgr,sl calc	23.0		Sidewall
14182.6	ss;vf-mgr,sc peb	5.8	0.07	Core 16
14183.6	same	5.5	0.03	Core 16
14184.4	same	5.2	0.06	Core 16

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
14185.5	ss;vf-mgr,sc peb	4.7	0.05	Core 16
14186.2	same	4.6	0.02	Core 16
14186.5	ss;vf-fgr,sl calc	23.5		Sidewall
14187.5	ss;vf-mgr,sc peb	4.8	0.04	Core 16
14188.6	same	5.4	0.04	Core 16
14189.1	same	7.9	2.10	Core 16
14190.2	ss;vfgr	3.7	0.27	Core 16
14191.6	ss;vf-fgr	10.2	0.10	Core 16
14193.3	ss;vf-cgr,sc peb	7.4	0.62	Core 16
14194.8	same	8.4	6.70	Core 16
14195.8	same	8.1	4.41	Core 16
14196.8	same	7.2	0.56	Core 16
14198.4	same	9.2	0.76	Core 16
14200.4	same	9.5	2.25	Core 16
14204.3	same	9.3	1.31	Core 16
14206.3	same	9.5	2.68	Core 16
14290.0	ss;vf-mgr,calc	21.6	164	Sidewall
14311.0	same	23.7	163	Sidewall
14490.0	ss;vf-fgr,shy,calc	15.1		Sidewall
14601.2	ss;vfgr,shy,fn calc lams	3.4	0.03	Core 17
14602.2	same	3.6	1.26	Core 17
14603.4	same	3.4	0.81	Core 17
14606.4	same	5.0	0.05	Core 17
14607.2	same	4.9	0.06	Core 17
14610.6	same	2.5	0.02	Core 17
14612.2	same;calc	3.1	0.02	Core 17
14615.8	same	2.0	0.68	Core 17
14619.2	same	1.3	0.27	Core 17

ORGANIC GEOCHEMISTRY

By
Tabe O. Flett

INTRODUCTION

The organic geochemical program for the St. George Basin COST No. 2 well was designed to evaluate the petroleum potential of rocks in the eastern region of the St. George Basin. A detailed analytical program was recommended and carried out by Robertson Research (U.S.), Inc., and was approved, with modifications, by Atlantic Richfield Company (ARCO), who acted as operator on behalf of the participants. ARCO also authorized a preliminary geochemical evaluation that was performed by Exploration Logging (USA), Inc. (Exlog). All organic geochemical analyses reported for the No. 2 well are summarized by Dow (1982) and by Russ (1982). All depths are measured relative to the Kelly Bushing, which was 77 feet above mean sea level and 452 feet above the sea floor.

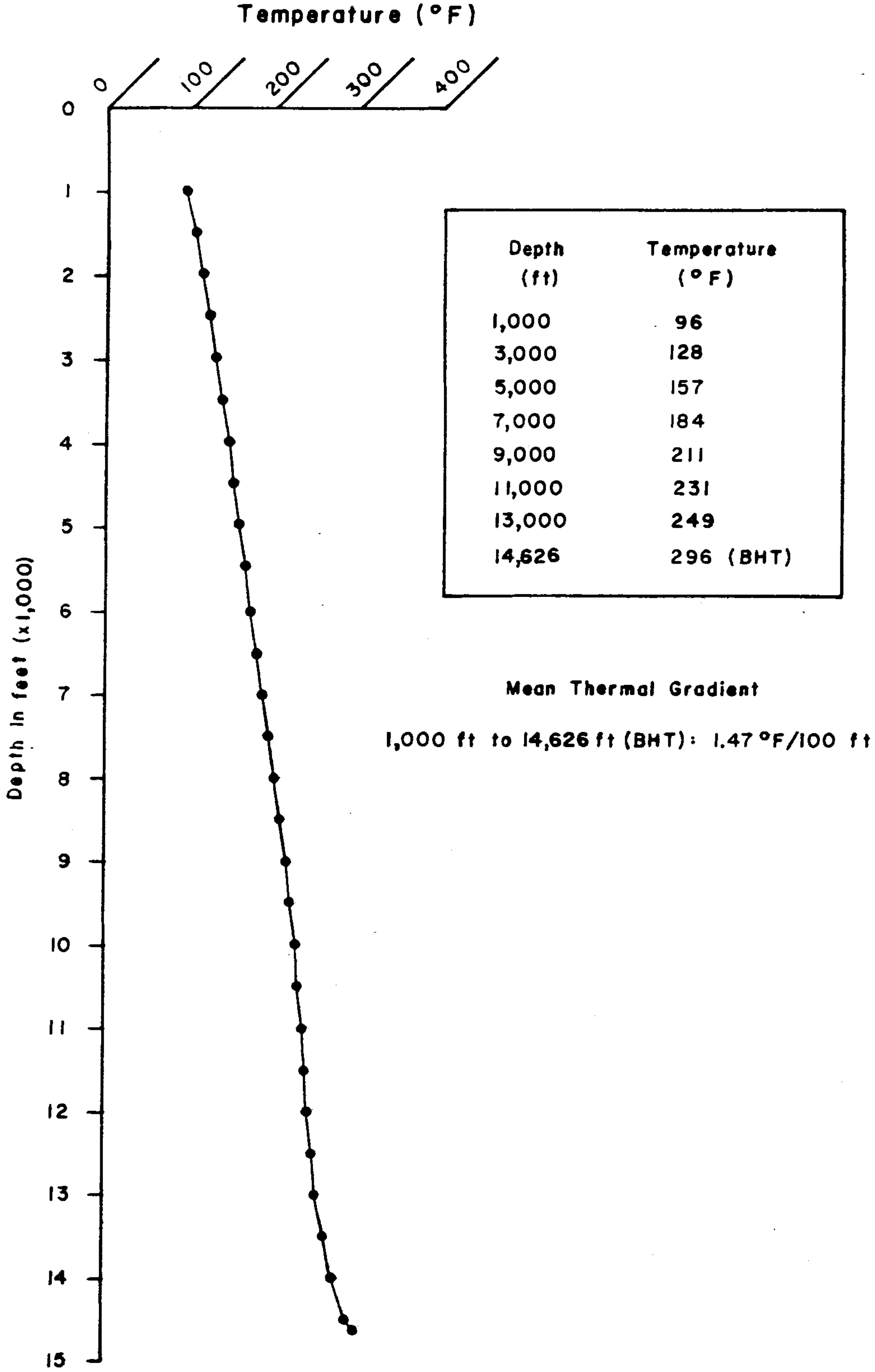
Samples selected by ARCO and sent to Robertson Research (U.S.), Inc., included canned cuttings collected at 60-foot intervals, sidewall cores taken at approximately 100-foot intervals, and representative plugs and chips from 16 conventional cores. Robertson Research did not receive any samples from core 11 (11,702 to 11,741 feet), from which there was little recovery.

Headspace gas from canned cuttings was analyzed for C_1-C_6+. The cuttings were then washed, described, and a representative sample analyzed for total organic carbon (TOC). Samples with a TOC of greater than 0.3 weight percent were analyzed with Rock-Eval pyrolysis (hereafter referred to as pyrolysis). Sidewall and conventional core samples were also analyzed for TOC and with pyrolysis. Finally, samples were selected from cuttings, sidewall cores, and conventional cores at approximately 300-foot intervals for kerogen isolation, vitrinite reflectance (R_0), spore coloration index (SCI), and elemental analysis. Soxhlet extraction, elution chromatography, and saturate-fraction gas chromatography were performed upon conventional core samples.

The study completed by Exploration Logging (USA), Inc., included TOC and pyrolysis analyses of cuttings, conventional cores, and mud samples to the total depth of 14,626 feet. Headspace gas was analyzed to 9620 feet. The results of these analyses agree favorably with data obtained by Robertson Research. Exploration Logging data are plotted (pl. 2) at about 500-foot intervals to indicate the reproducibility of the measurements.

GEOTHERMAL GRADIENT

The apparent mean geothermal gradient for the No. 2 well, 1.47°F per 100 feet, was computed from raw data collected during log run 3 by Schlumberger, Ltd., on August 23, 1982, and is plotted in figure 34. This average value is computed for the interval between 1000 and 14,626 feet, where the maximum recorded temperature was logged 10.5 hours after cessation of circulation.



Depth (ft)	Temperature (°F)
1,000	96
3,000	128
5,000	157
7,000	184
9,000	211
11,000	231
13,000	249
14,626	296 (BHT)

Mean Thermal Gradient

1,000 ft to 14,626 ft (BHT): 1.47 °F/100 ft

FIGURE 34. High–resolution thermometer data from the St. George Basin COST No. 2 Well, 10.5 hrs after circulation ceased.

(Data from Schlumberger, Ltd.)

ORGANIC CARBON

Total organic carbon content from sidewall and conventional cores is recorded on plate 2 along with sample descriptions. TOC values for cuttings as well as sidewall and conventional cores appear on plate 1. Organic carbon is not abundant in the No. 2 well. TOC values are generally less than 0.5 percent with the exception of the intervals between 5000 and 7000 feet and between 7800 and 10,500 feet, where TOC is frequently between 0.5 and 1.0 percent and in a few instances in excess of 1.0 percent. The higher values tend to occur in siltstone and occasionally in fine-grained sandstones.

A minimum organic carbon content of 0.5 percent in shales is generally regarded as necessary to generate oil for a commercial accumulation (Hunt, 1979; Tissot and Welte, 1978). Values in excess of 1 percent are much better because most rocks contain recycled organic material which is carbonized and cannot produce petroleum. Also, a critical amount of hydrocarbons must be present before expulsion is possible because the specific adsorption capacity of the source rock must first be satisfied. Finally, sufficient hydrocarbons for movement of a pressure-driven hydrocarbon phase have to be available. The amount of organic matter present in the section penetrated by the No. 2 well suggests that the rocks at this location are unlikely to be a source for commerical amounts of petroleum.

DESCRIPTION OF KEROGEN

Kerogen was examined in reflected and transmitted light. Results of the reflected-light petrography and the hydrogen-to-carbon ratio (H/C) from chemical analyses of the kerogen are depicted in figure 35.

Three petrographic classes of kerogen, plus amorphous material, a subgroup within the exinite or liptinite category, are reported in this study. They are:

1. Amorphous (algal or structureless colloidal matter)
2. Exinite (herbaceous, lipid-rich relics)
3. Vitrinite (woody and humic components)
4. Inertinite (hard, carbon-rich, nonreactive, brittle particles)

Most of the kerogen examined from the No. 2 well contained about 50 percent vitrinite. The experience of Robertson Research has been that samples containing less than 35 visual percent of amorphous material plus exinite generally yield only dry gas and that oil sources usually contain over 65 percent of these maceral types (Dow and O'Connor, 1982). Only one sample, containing coal, exceeded the 65 percent threshold, and three additional samples contained more than 35 percent of the amorphous kerogen alone. These samples are listed in table 3. All are derived from siltstone or sandstone, and all possess relatively low organic carbon contents except for the coal-bearing sidewall sample from 12,555 feet.

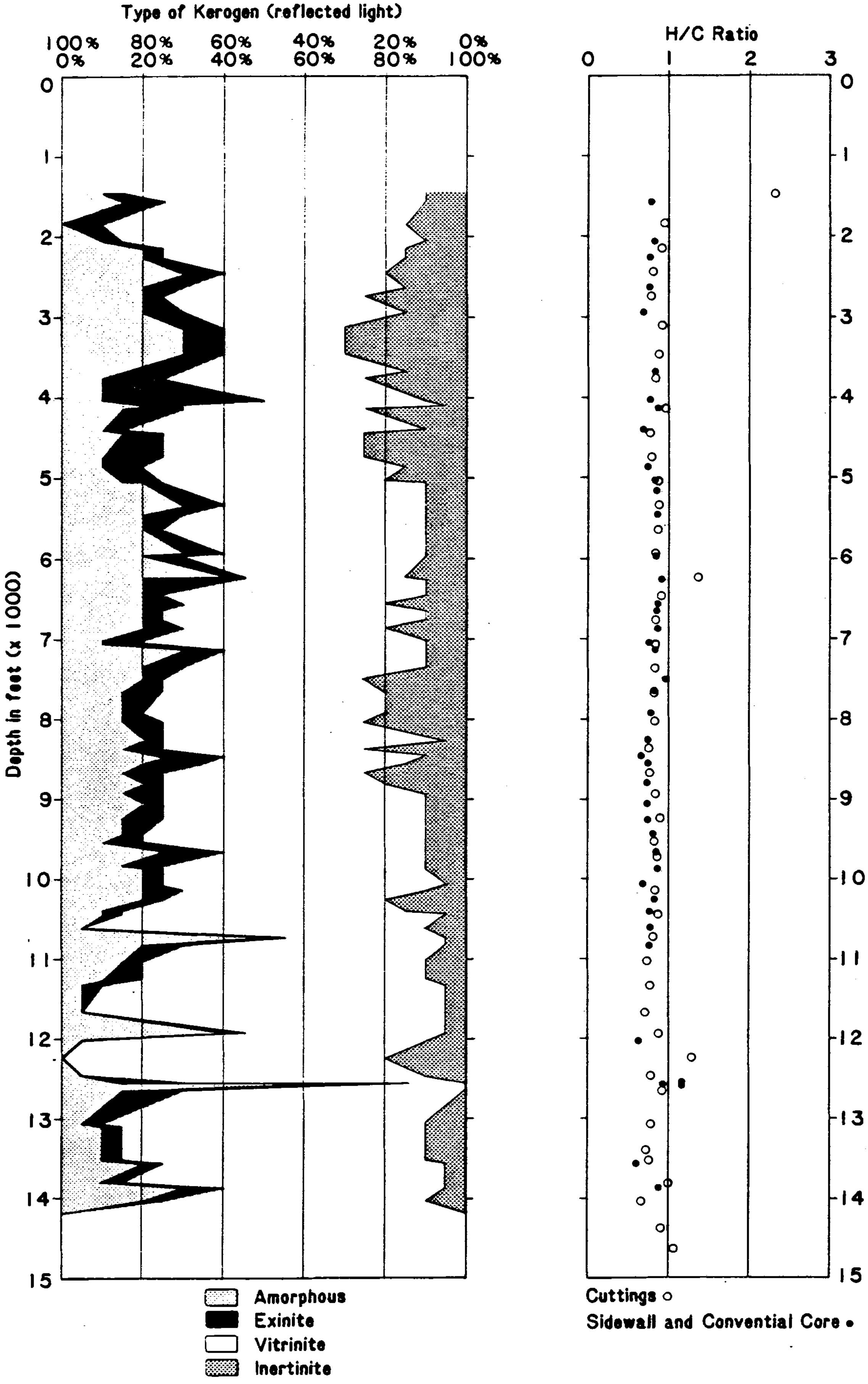


FIGURE 35. CLASSIFICATION OF ORGANIC MATTER

Table 3. Samples containing more than 35 percent amorphous kerogen.

Depth (feet)	Amorphous Kerogen (%)	TOC (%)	H/C	Sample Type and Description
6,230	40	0.69	1.34	Cuttings Sample 85% siltstone; 15% sandstone
10,730	50	0.25	0.80	Cuttings Sample 95% sandstone; 5% siltstone
11,930	40	0.18	0.88	Cuttings Sample 100% sandstone
12,555	70	2.30	1.16	Sidewall Core 100% siltstone; trace carbonaceous material*

* Cuttings collected between 12,560 and 12,620 feet contained coal fragments.

The H/C ratio ranged from about 0.96 near the surface to a minimum of 0.60 at 13,573 feet with two exceptions noted in table 3 and a third high value (H/C = 2.31) at 1490 feet. Vitrinite in humic kerogen frequently exhibits H/C values between 0.3 and 1.0, and woody kerogen, roughly the equivalent of vitrinite, frequently exhibits an H/C ratio of approximately 0.72 (Hunt, 1979).

The hydrogen and oxygen indices from pyrolysis of sidewall and conventional core samples are plotted on a modified van Krevelen diagram in figure 36. The hydrogen indices are low, generally less than 100, and fall along and below the Type III maturation curve. The sidewall core sample from 12,555 feet and the conventional core sample from 12,586 feet were collected from a lithologic sequence containing minor amounts of coal. According to Robertson Research, the samples collected in the vicinity of 8800 feet contained "traces of carbonaceous material," probably also coal. The conventional core sample from 9656 feet was a hard, dark-gray-brown siltstone with some argillaceous material. There is no evidence that Type I or Type II kerogen is present in the sedimentary section penetrated in the No. 2 well.

THERMAL MATURATION

The level of thermal alteration attained by carbon-bearing sediments can be evaluated in a variety of ways. Figure 37 displays well profiles of the random vitrinite reflectance (R_0), kerogen fluorescence intensity, spore coloration index (SCI), and T_2-max from the second pyrolysis response.

Robertson Research (U.S.), Inc., reports that the abundance of terrestrial kerogen in most of the samples produced very good vitrinite reflectance data. Because of this, the R_0 profile is considered the most reliable indicator of thermal maturity for the well. The only significant problems are high rank, recycled organic matter in some shallow samples, occasional oxidized vitrinite, solid bitumen and pseudovitrinite, and minor caving in a few of the samples.

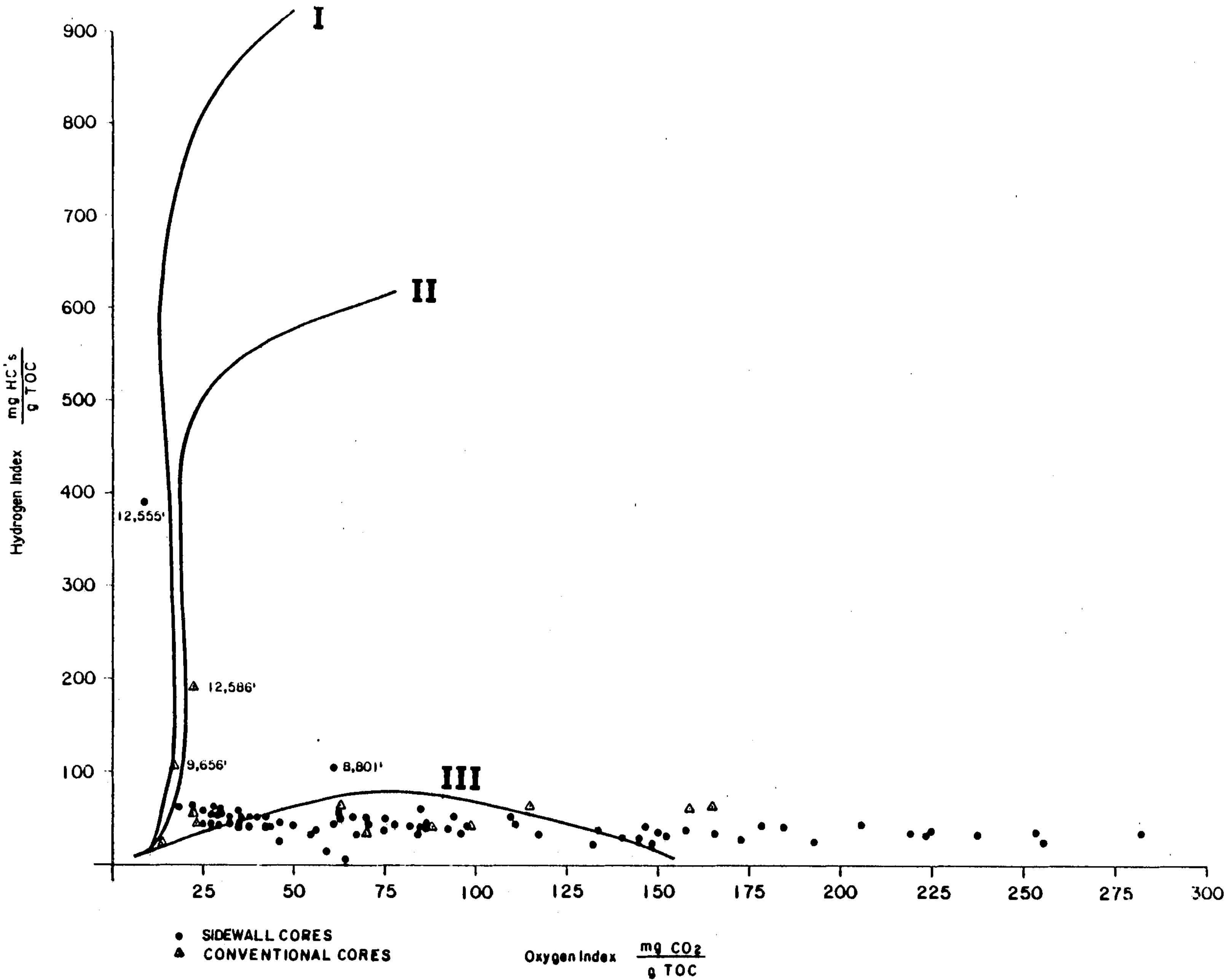


FIGURE 36. Modified van Krevelen diagram. Data from Rock–Eval pyrolysis of sidewall and conventional core samples. (Data from Robertson Research (U.S.), Inc.)

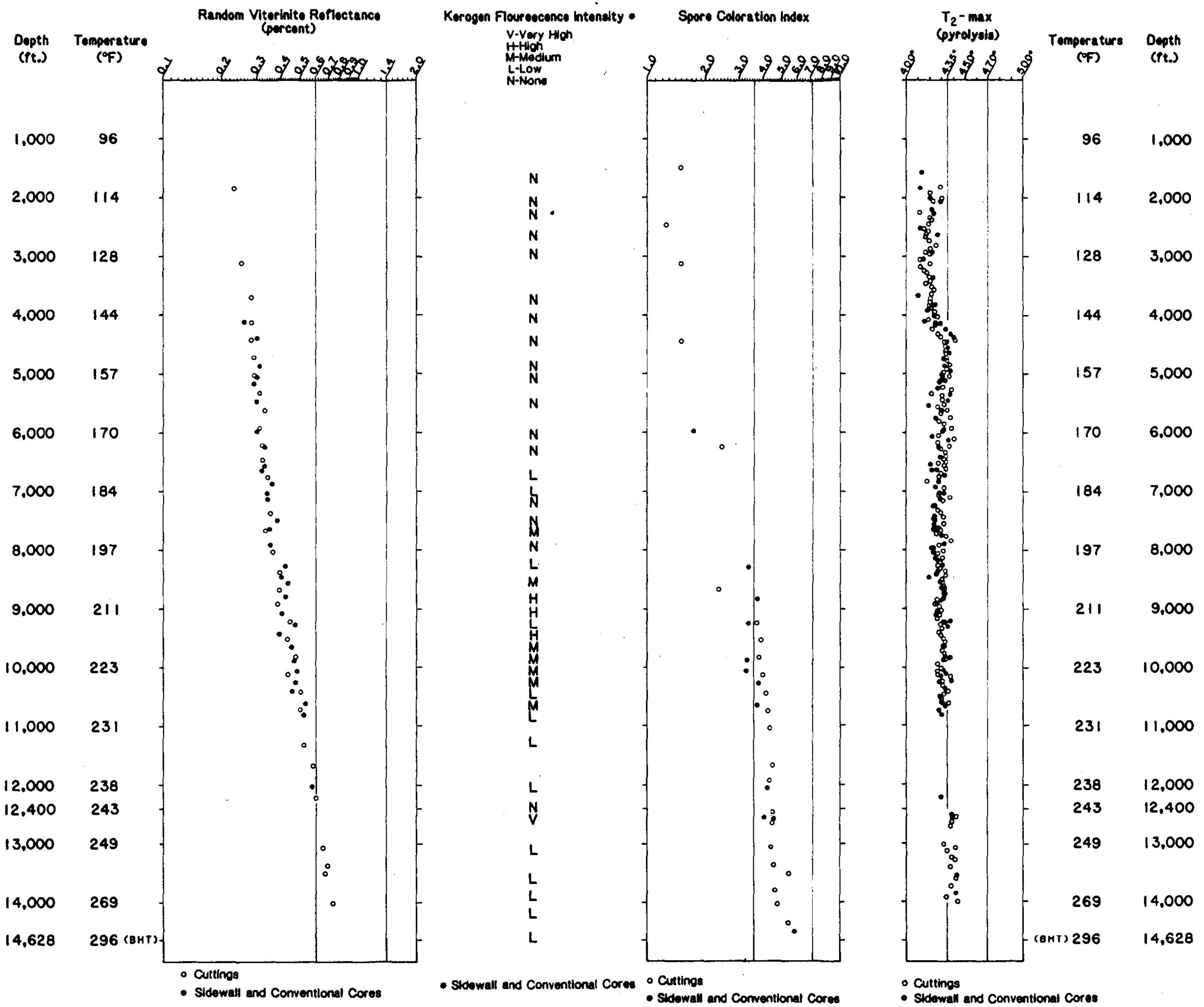


FIGURE 37. SELECTED INDICATORS OF THERMAL MATURATION FROM SIDEWALL AND CONVENTIONAL CORES ANALYZED BY ROBERTSON RESEARCH (U.S.) INC.

It is likely that R_0 values from this well do, in fact, constitute the most reliable indicators of thermal maturity, particularly between 5000 and 11,000 feet. Data from this interval, when plotted on a well profile, produce a reasonably linear curve that projects to a minimal value of 1.8 or 2.0 percent at the surface, which one would expect if the entire section was deposited under conditions of essentially continuous deposition with no significant periods of erosion (Dow, 1977). Representative R_0 histograms for the intervals from the surface to 5000 feet, from 5000 to 11,000 feet, and from 11,000 to 14,010 feet are reproduced in figure 38.

The R_0 measurement from the shallowest sample plotted on figure 37 is from cuttings collected at 1850 feet. Figure 38a shows that only two R_0 measurements were available at this data point. They were apparently assumed to represent two separate modes, and only the lower value (0.23 percent) was plotted. This value agrees favorably with the segments of the R_0 profile plotted from more reliable data. More observations were generally available for the other points plotted. Many mean R_0 values observed from the surface to 5000 feet were too high and were not plotted. These samples probably contain large amounts of recycled vitrinite.

The sidewall core from 8565 feet is a textbook example of excellent R_0 data (figure 38b). The mean value plotted on the R_0 profile from this population is 0.43 percent. Fifty observations were made and the population is unimodal. A minimum of 50 observations is desirable for a statistically reliable sample, but unfortunately there is often not enough vitrinite in a kerogen sample to yield that many observations.

The cuttings sample from 14,010 feet yielded the deepest recorded R_0 value for the No. 2 well (figure 38c). Samples from greater depths were studied by Robertson Research, but the mean R_0 values for these samples are anomalously high and probably represent recycled material. The sample from 14,010 feet represents only 18 observations, of which 11 are believed to represent primary kerogen. The mean R_0 value for these 11 values is 0.73 percent. The broadening of the histogram, that is to say, the increase in the standard deviation for the population, is characteristic of more mature kerogen. However, this normally begins to occur at an R_0 of 1 percent or more (Hunt, 1979). The higher R_0 values in the population may represent recycled material in this case, or they could represent a few members of a statistically inadequate population that possesses a higher mean value. Such an increase in R_0 could be produced by the unconformity indicated on plate 1 at approximately 12,540 feet.

R_0 values reach 0.6 percent, the generally recognized threshold of commercial oil generation (Hunt, 1979), at about 12,400 feet. The maximum mean R_0 value observed was 0.73 percent at 14,010 feet, well below the 1.35 percent threshold where liquid hydrocarbons are believed to deteriorate to gaseous hydrocarbons at a significant rate (Dow, 1982).

In the No. 2 well, the intensity of kerogen fluorescence under reflected light increases toward the top of the oil-generation maturity zone. This increase is never very great, apparently because of the very poor oil convertibility of the kerogen. Higher levels of fluorescence intensity seem to occur generally where coal or carbonaceous fragments have been observed in the samples.

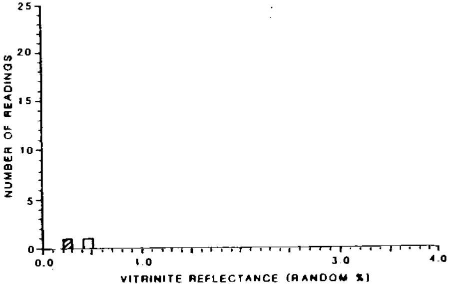
Robertson Research reported that the spore coloration index data were of unusually poor quality due to an abundance of recycled or oxidized organic matter. Apparent discoloration, possibly caused by bituminous material, was common, especially in samples down to 8000 feet. Because of these problems, Robertson Research feels that the SCI values suggest a slightly higher level of maturity than actually exists. On the basis of an interpretive diagram that correlates maturation indices and zones of petroleum generation and destruction (Dow, 1982), the lower limit of peak oil generation should occur between 9000 and 10,000 feet. The SCI data generally parallel the R_0 data, and given the uncertainties noted, it seems reasonable to assume that peak oil generation is not likely to occur at less than 10,000 feet at this location. The 12,400-foot figure yielded by the R_0 data is probably a better estimate.

Barker (1974), Claypool and Reed (1976), and Espitalié and others (1977) have suggested that T_2-max, the temperature at which maximum evolution of thermal hydrocarbons occurs during pyrolysis, can be used to characterize the degree of thermal maturation of kerogen. However, these measurements are influenced by the testing laboratory's instrumentation and technique, the rate of heating, the type of kerogen, the presence of recycled or oxidized organic matter, downhole contamination, and the presence of solid bitumen (Tissot and Welte, 1978; Dow, 1982).

Robertson Research suggests that the zone of peak oil generation is defined by the limiting T_2-max values 435°C and 470°C. The lower threshold value is reached slightly below a depth of 4200 feet, and the upper threshold value is not approached in the No. 2 well. No samples were analyzed between 11,000 and 12,000 feet by Robertson Research.

A sudden increase in T_2-max values from approximately 420°C to 435°C occurs at about 4200 feet, the same depth as the transition from Pliocene to Miocene sediments according to Minerals Management Service paleontologists. This sudden increase in T_2-max could be attributed to a greater content of recycled material. However, R_0 data suggest that greater amounts of recycled vitrinite are present in the upper 4000 or 5000 feet of the well. T_2-max values tend to remain relatively constant (between 430°C and 435°C) from 4200 to 10,815 feet, and probably to 12,208 feet if the single sidewall core value which appears to conform to this trend beneath the hiatus in pyrolysis data (11,000 to 12,000 feet) is accepted. Below 12,400 feet, the T_2-max data exhibit a slightly greater statistical variation and appear to exceed 435°C more frequently. The most probable explanation of the T_2-max data is that recycled kerogen has influenced the values between 4200 and 12,000 feet, and that the zone of peak oil generation occurs below 12,400 feet.

T_2-max values provided by Exlog are available but were not plotted on figure 37 because of the problems associated with direct comparison of mixed sets of pyrolysis data. However, there is reasonably good agreement between the measurements provided by the two laboratories. The following observations made by Exlog regarding possible contamination of samples submitted for pyrolysis are significant. From 11,240 to 11,300 feet a hardened resin or epoxy, possibly fiberglass from the DLWD tool, was observed. (DLWD stands for downhole logging while drilling. It is a logging tool that measures short normal and mud resistivities, gamma ray, mud temperatures, and provides directional information



*= R_o= MATURITY= ▨

ORDERED REFLECTANCE VALUES:

*0.23
0.47

NUMBER OF R_o VALUES REPRESENTING PRIMARY VITRINITE: 1

MEAN VALUE	0.23
STANDARD DEVIATION	0.00
MEDIAN	0.23
MODE	0.25

Figure 38a. Representative histogram of vitrinite reflectance measurements from cuttings sample at 1850 feet, St. George Basin COST No. 2 Well.

*= R_o= MATURITY= ▨

ORDERED REFLECTANCE VALUES:

*0.38
*0.39
*0.40
*0.40
*0.40
*0.40
*0.40
*0.40
*0.40
*0.40
*0.40
*0.40
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*0.40
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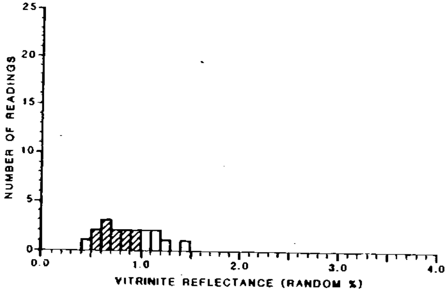
*0.45
*0.45
*0.45
*0.45
*0.51
*0.52
*0.54
*0.60
*0.63

NUMBER OF R_o VALUES REPRESENTING PRIMARY VITRINITE 50

MEAN VALUE	0.43
STANDARD DEVIATION	0.05
MEDIAN	0.42
MODE	0.45

Figure 38b. Representative histogram of vitrinite reflectance measurements from a sidewall core at 8,565 feet, St. George Basin COST No. 2 Well.



*= R_o= MATURITY= ▨

ORDERED REFLECTANCE VALUES:

0.44
*0.50
*0.54
*0.64
*0.66
*0.67
*0.72
*0.78
*0.84
*0.85
*0.91
*0.92
1.00
1.05
1.10
1.19
1.26
1.45

NUMBER OF R_o VALUES REPRESENTING PRIMARY VITRINITE: 11

MEAN VALUE	0.73
STANDARD DEVIATION	0.14
MEDIAN	0.72
MODE	0.65

Figure 38c. Representative histogram of vitrinite reflectance measurements from cuttings sample at 14,010 feet, St. George Basin COST No. 2 Well.

while drilling is in progress.) Between 11,360 and 11,960 feet a resinous material was also observed. The result of such contamination is that the T_2-max values may have been reduced. At 12,200 feet and between 12,620 and 12,740 feet, plastic spheres called "Lubra Beads" were added to the drilling mud, and this may have affected the pyrolysis analyses, particularly the T_2-max values.

There is fairly good agreement among the indicators of thermal maturity that sufficient maturity for peak oil generation exists below 12,400 feet. The level of thermal maturation in the No. 2 well does not increase to the point that liquid hydrocarbons would have been extensively converted to gaseous products. The maximum level of thermal maturation reached by sediments in this well appears to be rather low compared to the present day thermal gradient. However, contamination by cuttings from superjacent lithologic units and a statistically inadequate number of R_0 measurements from sidewall and conventional core samples below 12,540 feet may have yielded artificially low thermal maturity data and thus obscured geochemical indications of the Mesozoic-Cenozoic unconformity.

HYDROCARBON SOURCE POTENTIAL

Plate 2 displays the following data: selected sample descriptions, TOC from sidewall and conventional cores, C_{15}+ extractable bitumens (C_{15}+ BIT), $\frac{C_{15}\text{+ BIT}}{\text{TOC}}$, carbon preference index (CPI) from conventional cores, the genetic potential (S_1+S_2) from pyrolysis of sidewall and conventional cores, and the volume and wetness of headspace gas from canned cuttings samples. Wetness (in percent) is defined as $\frac{[\ C_2+C_3+C_4\ ]}{[C_1+C_2+C_3+C_4]} \times 100$ in this report.

The total organic carbon content of these sediments has already been discussed and found to be generally rather low except where coal is present in the samples. The low TOC is not surprising in view of the preponderance of fine-grained sandstones and siltstones encountered in the well.

The C_{15}+ total organic extract reported from conventional core samples from 4104 to 14,605 feet is also relatively low. Bayliss and Smith (1980) suggest that a good C_{15}+ BIT anomaly should be greater than 1000 ppm. Only conventional core 3 yielded a measurement in excess of this threshold (1266 ppm at 6658 feet). This core contained carbonaceous fragments, presumably coal. Coal bitumens are thought to come from the exinite fractions of coals (Hunt, 1979).

Hunt (1979) points out that petroleum originates within a finite temperature range within the earth's crust. When suitable source rocks are within this temperature range for an adequate amount of time, an increase in the ratio of the C_{15}+ extractable bitumen to TOC is observed (Larskaya and Zhabrev, 1964; Tissot and others, 1971). Larskaya and Zhabrev's studies of Mesozoic and Cenozoic rocks in the Western Ciscaspian region also showed that bitumen yields from fine-grained rocks in sedimentary basins are related to kerogen type. When amorphous matter was present, the $\frac{C_{15}\text{+ BIT}}{\text{TOC}}$ was high and increased rapidly with temperature. Where the rocks contained predominantly coaly particles, the $\frac{C_{15}\text{+ BIT}}{\text{TOC}}$ was very small and changed little with increasing temperature.

The C_{15}+ bitumen to TOC ratios from the No. 2 well generally range from 0.05 to 0.10 and do not exhibit any marked tendency to increase even though present temperatures reach 296°F and R_o exceeds 0.6 percent below 12,400 feet. The few high values are listed in table 4 and appear to be associated with samples contaminated with pipe grease and diesel oil. Tissot and Welte (1978) note that when bitumen to TOC ratios exceed 0.20 they are abnormally high and may indicate the presence of nonindigenous bitumens.

Table 4. Conventional core samples with high $\frac{C_{15}+\text{ BIT}}{\text{TOC}}$ ratios.

CORE NUMBER	DEPTH (feet)	$\frac{C_{15}+\text{ BIT}}{\text{TOC}}$	COMMENTS
1	4,130	0.322	Pipe grease
3	6,658	0.221	No sample description available
16	14,199	0.152	Igneous rock, pipe grease, and diesel oil
17	14,605	0.125	Igneous rock, pipe grease, and diesel oil

The carbon preference index from conventional core samples was computed using the original Bray and Evans (1961) formula (C_{24} through C_{34}). These values range from 0.36 to 5.11, and the high values tend to occur at depth rather than in the first few thousand feet of the well. CPI values equal to or slightly greater than 1.0 in immature sediments are characteristic of marine organisms (Hunt, 1979), but microscopic identification and chemical analyses indicate that Type III humic kerogen is present in nearly all samples. Robertson Research states that the conventional core samples yielded only minor amounts of extractable organic material, which may account for the erratic nature of the CPI data. They also noted that none of the extracts recovered resembled crude oil in composition.

Rock-Eval pyrolysis is performed by heating whole rock samples at a predetermined rate in an inert atmosphere. Free or adsorbed hydrocarbons present in the rock are volatilized first at a moderate temperature. As the temperature increases, pyrolysis of kerogen generates hydrocarbons and hydrocarbon-like compounds. Finally, oxygen-bearing volatiles such as carbon dioxide and water are evolved. Relative amounts of the hydrocarbons are measured by a flame ionization detector, and quantities of oxygen-bearing compounds by a thermal conductivity detector. These three measurements are usually reported in weight-to-weight ratios of evolved gas to rock sample and are abbreviated by the symbols S_1, S_2, and S_3, respectively. The temperature T_2-max, already referred to in the maturation section of this report, is the temperature at which the maximum evolution of pyrolytic hydrocarbons (the S_2 peak) occurs. The hydrogen and oxygen indices plotted on the modified van Krevelen diagram (fig. 36) are defined as S_2/organic carbon and S_3/organic carbon, respectively, and are reported in milligrams of gas per gram of organic carbon.

Studies by Claypool and Reed (1976) indicate that the S_1 peak is directly proportional to the concentration of extractable C_{15}+ hydrocarbons and the S_2 peak is approximately proportional to the organic carbon content of the rock. The sum S_1+S_2 is termed the genetic potential by Tissot and Welte (1978) because it accounts for both type and abundance of organic matter. They suggest the following threshold values for evaluating the oil and gas potential of source rock.

Table 5. Suggested threshold values for genetic potential (S_1+S_2) from pyrolysis (From Tissot and Welte, 1978).

S_1+S_2 (ppm)	Source Rock Potential
Less than 2000	No oil. Some gas.
2000 to 6000	Moderate source rock.
Greater than 6000	Good source rock.

Except for the sediments between 12,555 and 12,591 feet, where the samples contain coal, S_1+S_2 values from the well are all less than 2000 ppm and, with one additional exception at 8801 feet, less than 1000 ppm.

Headspace gas can provide evidence that the kerogen in a sediment has actually generated hydrocarbons, though gases present in a sediment are not necessarily indigenous. Amounts of headspace gas in the No. 2 well are relatively low, generally less than 1.0 liter of hydrocarbons per can of cuttings, and never in excess of 2.5 liters per can. Except for a few erratic measurements, high values are associated with coal or carbonaceous material. Wetness does not exceed 50 percent and is generally less than 25 percent. It is closer to 0 at depths less than 7000 feet.

By way of comparison, the same kinds of observations made by Robertson Research on canned cuttings samples of similar kerogen-bearing sediments with a slightly more favorable genetic potential from the Norton Sound COST No. 2 well yielded headspace gas contents frequently in excess of 10 liters and nearer to 100 liters in zones of greater organic richness. In such zones, wetness reached 76 percent (Turner [ed.], 1983).

SUMMARY AND CONCLUSIONS

Geochemical data from the No. 2 well indicate a predominantly Type III, humic kerogen commonly found in what Demaison (1981) has termed a "type C" organic facies. Geochemical characteristics of such an organic facies and analyses from the No. 2 well at an R_o of 0.5 percent are given in table 6.

Table 6. Geochemical characteristics of Demaison's "type C" organic facies and analogous values from the St. George Basin COST No. 2 well.

	Demaison's Typical Type C Organic Facies $R_o = 0.5\%$	COST No. 2 well Depth = 10,500 ft. $R_o = 0.5\%$
H/C	0.8 to 1.0	0.75 to 0.76
Hydrogen Index (HI)	25 to 125 $\frac{\text{mg Hydrocarbons}}{\text{g TOC}}$	53 $\frac{\text{mg Hydrocarbons}}{\text{g TOC}}$
Oxygen Index (OI)	50 to 200 $\frac{\text{mg } CO_2}{\text{g TOC}}$	43 $\frac{\text{mg } CO_2}{\text{g TOC}}$

A "type C" organic facies is typically the product of a mildly oxic depositional environment and may include both marine and nonmarine sediments, slope and rise deposits, and exinite-rich coals. Hydrocarbons formed in this type of organic facies tend to be gas prone, sometimes with condensate hydrocarbons. Visual identification of the kerogen present in the No. 2 well suggests that much of the organic matter was derived from terrestrial sources and was reworked before final deposition.

Organic matter is not abundant in the sedimentary section penetrated by this well. Siltstones with only a very limited ability to generate hydrocarbons are present between 5000 and 7000 feet and between 7800 and 10,500 feet.

Sufficient maturity for peak oil generation appears to exist below about 12,400 feet, but the presence of reworked kerogen introduces a degree of uncertainty into this interpretation. The maximum level of thermal maturation attained by sediments at this location is low given the thermal gradient that currently exists.

Only small amounts of light hydrocarbons are present in these sediments, and the wetness of the hydrocarbons is low. Total $C_{15}+$ extractable organic matter is low, as is the genetic potential determined by Rock-Eval pyrolysis.

Although minor amounts of solid bituminous material were found, no evidence of crude oil, oil-associated gases, or oil-generating capability was discovered in the No. 2 well. There is little evidence that significant amounts of hydrocarbon have been generated in the section penetrated by the St. George Basin COST No. 2 well. Any hydrocarbons generated by these sediments are likely to be dry gas.

ENVIRONMENTAL CONSIDERATIONS

by

Allen J. Adams

ARCO Exploration Company, as operator for itself and other participants, submitted a letter to the Minerals Management Service (formerly the Conservation Division, USGS) dated June 18, 1981, for the proposed drilling of a Deep Stratigraphic Test well in the St. George Basin area of the Alaska Outer Continental Shelf. Documents submitted in support of this proposal included a Drilling Plan, an Environmental Report, an Oil-Spill Contingency Plan, and a Coastal Zone Consistency Certification. A site-specific biological survey and a geohazards survey at the primary and alternate sites were required to investigate environmental conditions before approval of the Geological and Geophysical (G&G) Permit application for the Deep Stratigraphic Test well. The applicant followed 30 CFR Part 251 in submission of the G&G Permit application.

A Deep Stratigraphic Test well is intended for the acquisition of geological and engineering data to determine the potential for hydrocarbon accumulation within a proposed sale area. It is commonly drilled off-structure and it is not intended that any hydrocarbon accumulations be found. The St. George Basin COST No. 2 well was drilled off-structure. The information gathered from this test well was used to further evaluate the hydrocarbon potential of the area covered by OCS Lease Sale No. 70 (St. George Basin) held on April 12, 1983.

As part of the permit application review, MMS prepared an Environmental Assessment (EA). The EA serves as a decision-making document to determine if the proposed action is or is not a major Federal action significantly affecting the quality of the human environment in the sense of the National Environmental Policy Act (NEPA), Section 102(2)(C). An EA addresses and includes the following: a description of the proposed action, a description of the affected environment, environmental consequences, alternatives to the proposed action, unavoidable adverse environmental effects, and controversial issues.

On the basis of existing data and regulations, MMS took specific environmental conditions under advisement before approving the drilling plan and monitored these conditions during drilling operations. Included were geological (see Shallow Geologic Setting chapter), meteorological, oceanographic, biological, cultural, and economic considerations.

METEOROLOGICAL AND OCEANOGRAPHIC DATA

Most of the Bering Sea lies in subarctic latitudes, and cyclonic atmospheric circulation predominates in the region. Cloudy skies, moderately heavy precipitation, and strong surface winds characterize the marine weather. Storms are more frequent in the fall than in the summer.

There are two dominant current patterns in the St. George Basin area: a counter-clockwise eddy over the western Aleutian Basin and a clockwise eddy in the vicinity of Rat Island. Wave heights greater than 10 feet are common less than 10 percent of the time in June, July, and August, but may be common 12 to 14 percent of the time in May and September. No problems with superstructure icing occurred.

Sea ice conditions observed in the St. George Basin area consist primarily of highly mobile belts and patches that have broken away from the Kuskokwim Bay area to the northeast. Windrowed strings, belts, and patches are the normal state. In extremely cold years, patches of slush may form briefly during February or March in the presence of ice from outside the area.

Because limited meteorological and oceanographic data were available, the MMS issued the Guidelines for Collection of Meteorological, Oceanographic and Performance Data and required the operator to collect meteorological information to aid in future operations within the St. George Basin. During setup and operation, climatic and sea state conditions were monitored to ensure that local conditions did not exceed rig tolerances or jeopardize human safety. Winds, barometric pressure, air and water temperatures, waves, currents, and ice conditions were monitored. All environmental data collected during the drilling of this well are available to the public.

BIOLOGICAL DATA

The Bering Sea, and especially the Bristol Bay Region, is one of the most biologically productive offshore areas in the United States. Several of the world's largest known concentrations of commercial fish, marine mammals, and marine bird populations are found in this area. Current estimates indicate about 27 million marine birds are seasonally present, with several colonies containing over a half million individuals.

A site-specific marine biological survey was designed by MMS in concert with other Federal and State agencies to provide biological data at proposed Deep Stratigraphic Test sites. Through the use of underwater video and photographic documentation, plankton tows, infaunal sampling, and trawling, ARCO (Nekton, 1980b) determined the relative abundance and types of organisms present in various habitats. These studies were conducted from August 8 to August 11, 1980. The results are summarized as follows:

1. Fish were the dominant component of the trawl catch at both the primary and alternate sites and accounted for at least 90 percent of the total individuals and 90 percent of the total weight of each trawl. The

flathead sole (Hippoglossoides elassodon) and the walleye pollock (Theragra chalcogramma) were the most abundant flatfish and roundfish at both sites.

2. Epibenthic invertebrates were taken in very low numbers at both sites. The commercially important Tanner crab was collected in low numbers at the alternate sites, but was not present at the primary site.

3. Demersal fish and epibenthic invertebrates observed on video recordings were similar at both sites, with zoarcids and roundfish the most abundant organisms at the primary site, and Tanner crabs the most abundant at the alternate site. The epibenthic community, bottom composition, and topography are generally similar at and between the sites.

4. Taxonomic diversity and density were higher at the alternate site. Polychaete annelids were numerically dominant at both sites, followed by echinoderms, molluscs, and arthropods.

5. The relative abundance, total number of organisms per cubic meter, and species composition of the plankton were similar at the two sites. Copepods were the most abundant planktonic organism at both sites.

On the basis of the biological survey conducted by Nekton, the area supported no unique habitats or species that would require rejection or modification of the drilling program. No additional biological resources were discovered during the drilling operations. No adverse impacts on existing biological resources were apparent from drilling activities.

Marine Mammals and Endangered Species

Several endangered whale species are present in the St. George Basin area on an occasional or regular basis. These include the bowhead, Pacific right, fin, sei, blue, humpback, gray, and sperm whales. A consultation with the National Marine Fisheries Service (NMFS) was requested pursuant to Section 7 of the Endangered Species Act of 1973, and a response providing a nonjeopardy opinion was issued by NMFS on April 28, 1981. On the basis of information received from all interested parties and an MMS evaluation, it was determined that approval of the proposed action would not affect any endangered species or critical habitat.

Fisheries

Unalaska is the primary port for the Aleutian Islands-Bering Sea management area, which includes Aleutian Islands waters west of Scotch Cap on Unimak Island and all waters of the Bering and Chukchi seas to the east of the United States/Russian Convention Line of 1867. Present fisheries activity centers around the exploitation and processing of king and Tanner crab, plus comparatively minor amounts of salmon, halibut, Dungeness crab, Korean crab, shrimp, and groundfish. Employment in seafood processing has grown dramatically over the past 10 years as a result of the westward movement of shellfish exploitation by U.S. fishermen. There are 16 shore-based processing plants located in the Unalaska area.

Major foreign fishing areas for groundfish and flounders within the St. George Basin are located along the 100-fathom contour from Unimak Pass to and beyond the Pribilof Islands. At least one-third of the groundfish fishing effort in the Bering Sea occurs within the proposed St. George Basin lease area. The primary U.S. activity consists of pot fisheries for king and Tanner crabs.

CULTURAL RESOURCES

It was determined that cultural and archeological surveys would not be required for the St. George Basin test well sites, as they were located in low-probability areas for cultural resources. If the TV transects and side-scan sonar surveys had indicated unexplained anomalies, a review by a qualified marine archeologist would have been performed. No such anomalies were detected. No cultural resources were identified during drilling operations.

DISCHARGES INTO THE MARINE ENVIRONMENT

The applicant disposed of drill cuttings and waste drilling mud into the ocean in compliance with existing orders.

Past studies on the fate and effects of routine discharges into the marine environment from offshore oil and gas activities indicated that such discharges are not likely to significantly affect the marine environment. Bentonite is a continuous additive to the drilling mud, whereas barite is added as necessary for increasing mud weight. Bentonite and barite are insoluble, nontoxic, and inert. Other additives were used in minor concentrations, and most were used only under special conditions. These additives either were nontoxic or would chemically neutralize in the mud or upon contact with seawater. No oil-based mud was used.

Some excess cement was introduced into the marine environment while cementing shallow casing strings up to the sea floor.

Liquid wastes, including oil from the oil/water separator, were transported from the drilling vessel by supply boats and disposed of in approved onshore locations. Solid wastes were compacted and similarly transported to an approved onshore disposal site.

CONTINGENCY PLANS FOR OIL SPILLS

Plans for preventing, reporting, and cleaning up oil spills were addressed in the Oil-Spill Contingency Plan (OSCP), which was a part of the

Drilling Plan. The OSCP listed the equipment and material available to the permittee and described the capabilities of such equipment under different sea and weather conditions. The plan also included a discussion of logistical support and identified specific individuals and their responsibilities in implementing the OSCP. Two response levels were organized: an onsite oil-spill team and an onshore support organization. The onsite oil-spill team was structured to provide immediate containment and cleanup capability for operational spills, such as may result from the transfer of fuel oil, and to initiate control actions for large uncontained spills. The onshore support organization was structured to provide additional equipment and manpower to clean up large spills.

One thousand feet of containment boom, an oil-spill skimmer, sorbents, oil storage containers, dispersants, collectants, and hand chemical application equipment were located on the drilling vessel. Several oil-spill training drills were conducted to ensure familiarization with this equipment by the onsite oil-spill team. The operation also had access to additional oil-spill response equipment located at onshore staging points. The OSCP also identified additional equipment that was available from other response organization sources, agreements to commit these resources, and requirements for obtaining the equipment.

During the drilling operation, a fuel transfer line ruptured and approximately 30 gallons of diesel fuel were spilled into the water. The onsite oil-spill team deployed the containment boom and cleaned up the spilled fuel with sorbent pads. There were no other spills resulting from this drilling operation.

The probability of encountering hydrocarbons that could cause a blowout at any depth was minimized in this case by locating the well off-structure. The operator drilled the well according to the OCS Orders and utilized standard well control equipment and procedures. The casing and cementing programs (OCS Order No. 2) and subsequent abandonment requirements (OCS Order No. 3) were designed to prevent leakage or contamination of fluids within a permeable zone.

The site was cleared of all pipe and other material on or above the ocean floor upon completion of the well.

As part of the EA process, the proposed program was submitted for comments to the appropriate Federal and State agencies, as well as to interested parties. Responses were included as part of the EA. On the basis of EA No. AK-81-3, the Conservation Manager, Alaska Region, signed a Finding of No Significant Impact (FONSI) on October 26, 1981, for ARCO's proposed action and determined that an Environmental Impact Statement was not required. A notice was issued to that effect. MMS consequently issued a letter to ARCO approving their proposed action. The EA and the FONSI documents are available for review in the public file in the office of the Regional Supervisor, Field Operations, Minerals Management Service, 800 A Street, Anchorage, Alaska 99501.

SUMMARY

The ARCO St. George Basin COST No. 2 well was drilled to a measured depth of 14,626 feet. The Kelly Bushing was 77 feet above sea level and 452 feet above mudline. The water depth was 375 feet. The well site was approximately 110 miles northwest of Cold Bay, Alaska. The well was drilled from the SEDCO 708, a self-propelled semisubmersible drilling rig. Drilling commenced on May 19, 1982, and the well was completed on September 2, 1982. Four strings of casing were set during drilling: 30-inch casing at 570 feet, 20-inch casing at 1423 feet, 13 3/8-inch casing at 4965 feet, and 9 5/8-inch casing at 10,035 feet. The drilling fluid for the first 1400 feet was seawater; the drilling mud varied from 9.3 to 9.8 pounds/gallon thereafter.

Logging runs were made at depths of 4976 feet, 10,135 feet, and 14,622 feet. The types of well logs run are listed in the Operational Summary chapter. No drill stem tests were made.

Seventeen conventional cores, 337 sidewall cores, and well cuttings collected at 30-foot intervals (from 1460 to 14,626 feet) were analyzed for porosity, permeability, lithology, organic geochemistry, and paleontology.

As required by 30 CFR 251, the operator (ARCO) filed a Drilling Plan, Environmental Report, Oil-Spill Contingency Plan, and Coastal Zone Consistency Certification. In addition, the MMS (formerly USGS, Conservation Division) required a geohazards survey, geotechnical survey, and site-specific biological survey. The zooplankton, infauna, epifauna, vagile benthos, and pelagic fauna were collected and analyzed. Particular emphasis was placed on protecting local and migratory marine mammals and avifauna. Waste discharges into the environment were minimal, nontoxic, and in compliance with Federal environmental protection regulations.

Stratigraphic units in the No. 2 well were defined on the basis of microfossil content, lithological and log characteristics, correlation with the No. 1 well, seismic character, and absolute dating techniques. The strata encountered in the No. 2 well were undifferentiated Plio-Pleistocene to 1460 feet, Pliocene to 4246 feet, Miocene to 6050 feet, Oligocene to 11,085 feet, possible Eocene to 12,540 feet, Early Cretaceous or Late Jurassic to 13,370 feet, and Late Jurassic to 14,626 feet (TD).

The Cenozoic sedimentary section consists of interbedded sandstone, siltstone, mudstone, diatomaceous mudstone, and conglomerate. These sediments are predominantly from volcanic source terranes. Mineralogically, the sediments are physically and chemically unstable. Porosity and permeability have been reduced by ductile grain deformation, cementation, and authigenesis. Permeabilities are lower than might be expected for given porosities.

The Mesozoic sedimentary section consists of sandstone, siltstone, shale, conglomerate, and minor amounts of coal. Porosities and permeabilities are low.

Three seismic horizons in the No. 2 well were mapped and correlated across the St. George graben: the basement unconformity between Cenozoic and Mesozoic strata, the top of the Oligocene, and the top of the Miocene. The time-depth curve calculated from the sonic log is less steep in the No. 1 well than in the No. 2 well, and interval velocities are lower in the No. 1 well than in the No. 2 well.

Geochemical analyses show a predominantly type III, humic kerogen. The section is low in total organic carbon. Siltstones with a very limited potential for generating hydrocarbons are present below 5100 feet. Thermal maturation is low. Sufficient maturity for peak oil generation may exist below 12,400 feet. The sedimentary section penetrated appears to be gas prone at best.

It is probable that strata with better source rock and reservoir characteristics than those encountered in the No. 2 well are present in other parts of the basin, particularly along the flanks of the graben.

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APPENDIX

Well Data and Consultants Reports Available for Public Inspection, St. George Basin COST No. 2 Well

Schlumberger Offshore Services
Anchorage, AK

2 in. Dual Induction - SFL
Runs 1, 2, 3

2 in. Dual Induction - SFL with Linear Correlation
Runs 1, 2, 3

5 in. Dual Induction - SFL
Runs 1, 2, 3

2 in. Borehole Compensated Sonic Log
Runs 1, 2, 3

5 in. Borehole Compensated Sonic Log
Runs 1, 2, 3

2 in. Long Spaced Sonic
Runs 1, 2, 3

5 in. Long Spaced Sonic
Runs 1, 2, 3

5 in. Sonic Waveform 8 ft
Runs 1, 3

5 in. Sonic Waveform 10 ft
Runs 1, 3

5 in. Sonic Waveform 12 ft
Runs 1, 2

2 in. Compensated Formation Density Gamma-Gamma
Runs 1, 3

5 in. Compensated Formation Density Gamma-Gamma
Runs 1, 3

2 in. Compensated Neutron Formation Density
Run 1

5 in. Compensated Neutron Formation Density
Runs 1, 3

5 in. HDT
    Run 1

Cyberdip
    Run 2

2 in. NGT
    Run 2

5 in. NGT
    Runs 2, 3

2 in. Compensated Formation Density NGT
    Runs 2, 3

5 in. Compensated Formation Density NGT
    Runs 2, 3

5 in. High Resolution Continuous Dipmeter
    Run 2

Repeat Formation Tester
    Run 1 Tests 1, 2, 3, 4

5 in. PML
    Run 1

5 in. Cement Bond Log
    Run 2

5 in. High Resolution Dipmeter
    Run 3

5 in. High Resolution Thermometer

Arrow Plot Correlation
    Run 3

Geodip Pattern Zones - Sepias and Listings
    10,126-10,460 ft
    10,570-10,920 ft
    10,920-11,020 ft
    11,000-11,400 ft
    11,400-11,800 ft
    11,800-12,200 ft
    12,200-12,600 ft
    12,600-13,000 ft
    13,000-13,400 ft
    13,400-13,800 ft
    13,800-14,200 ft
    14,200-14,618 ft

ExLog
Anchorage, AK

Formation Evaluation Log
Drilling Data Pressure Log
Temperature Data Log
Pressure Evaluation Log
Mud Resistivity Log
Geochemical Evaluation Log
End of Well Report
Geochemical Final Well Report

Core Laboratories
Dallas, TX

Correlation Coregraphs
Thin Sections 2 Boxes
Core Analysis Report 2 Sections
Special Core Analysis Study

AGAT Consultants
Denver, CO

Reservoir Quality Study 5 Volumes

ARCO Alaska Inc.
Anchorage, AK

Lithology Log
Core Descriptions Cores 1-17
Sidewall Sample Descriptions 4900-14,560 ft

Robertson Research
Houston, TX

Geochemical Analysis Final Report

Woodward-Clyde Consultants
San Francisco, CA

Paleomagnetic Data 3 Volumes

ARCO Exploration Company

Verticle Seismic Profile 2.5 s/in
Verticle Seismic Profile 5 s/in

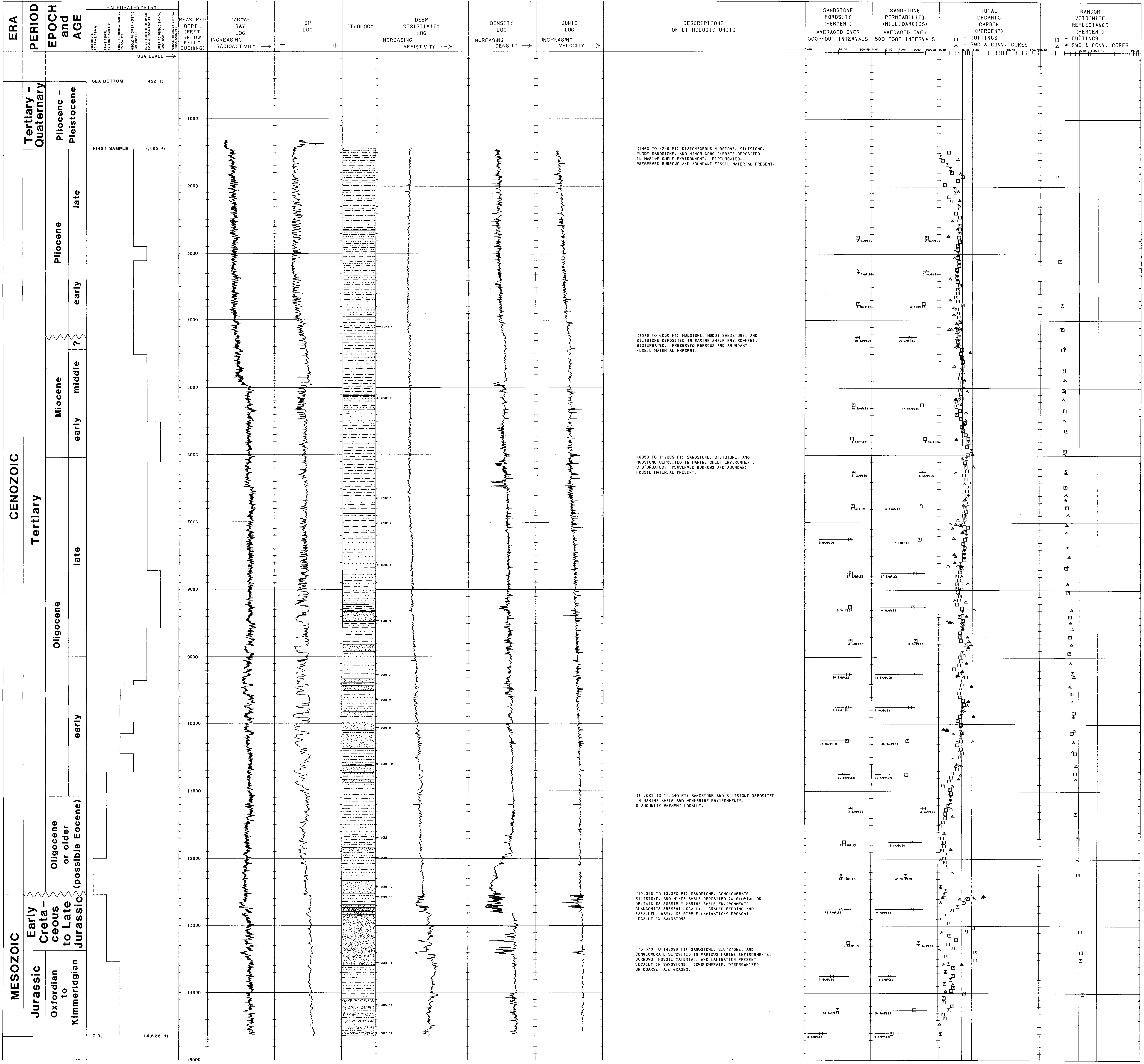
Biostratigraphics
San Diego, CA

- Biostratigraphic Summary
- Siliceous Microfossil Report
- Calcareous Nannofossil Report
- Radiolaria Report
- Palynology Report
- Foraminifera Report

PLATE 1. STRATIGRAPHIC COLUMN AND SUMMARY CHART OF GEOLOGIC DATA, ST. GEORGE BASIN COST NO. 2 WELL, BERING SEA, ALASKA

DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

OCS REPORT MMS 84-0018
PLATE 1 OF 2



(1460 TO 4246 FT) DIATOMACEOUS MUDSTONE, SILTSTONE, MUDDY SANDSTONE, AND MINOR CONGLOMERATE DEPOSITED IN MARINE SHELF ENVIRONMENT. BIOTURBATED. PRESERVED BURROWS AND ABUNDANT FOSSIL MATERIAL PRESENT.

(4246 TO 6050 FT) MUDSTONE, MUDDY SANDSTONE, AND SILTSTONE DEPOSITED IN MARINE SHELF ENVIRONMENT. BIOTURBATED. PRESERVED BURROWS AND ABUNDANT FOSSIL MATERIAL PRESENT.

(6050 TO 11,085 FT) SANDSTONE, SILTSTONE, AND MUDSTONE DEPOSITED IN MARINE SHELF ENVIRONMENT. BIOTURBATED. PERSERVED BURROWS AND ABUNDANT FOSSIL MATERIAL PRESENT.

(11,085 TO 12,540 FT) SANDSTONE AND SILTSTONE DEPOSITED IN MARINE SHELF AND NONMARINE ENVIRONMENTS. GLAUCONITE PRESENT LOCALLY.

(12,540 TO 13,370 FT) SANDSTONE, CONGLOMERATE, SILTSTONE, AND MINOR SHALE DEPOSITED IN FLUVIAL OR DELTAIC OR POSSIBLY MARINE SHELF ENVIRONMENTS. GLAUCONITE PRESENT LOCALLY. GRADED BEDDING AND PARALLEL, WAVY, OR RIPPLE LAMINATIONS PRESENT LOCALLY IN SANDSTONE.

(13,370 TO 14,626 FT) SANDSTONE, SILTSTONE, AND CONGLOMERATE DEPOSITED IN VARIOUS MARINE ENVIRONMENTS. BURROWS, FOSSIL MATERIAL, AND LAMINATION PRESENT LOCALLY IN SANDSTONE. CONGLOMERATE, DISORGANIZED OR COARSE-TAIL GRADED.

*U.S. GOVERNMENT PRINTING OFFICE: 1985–691-209

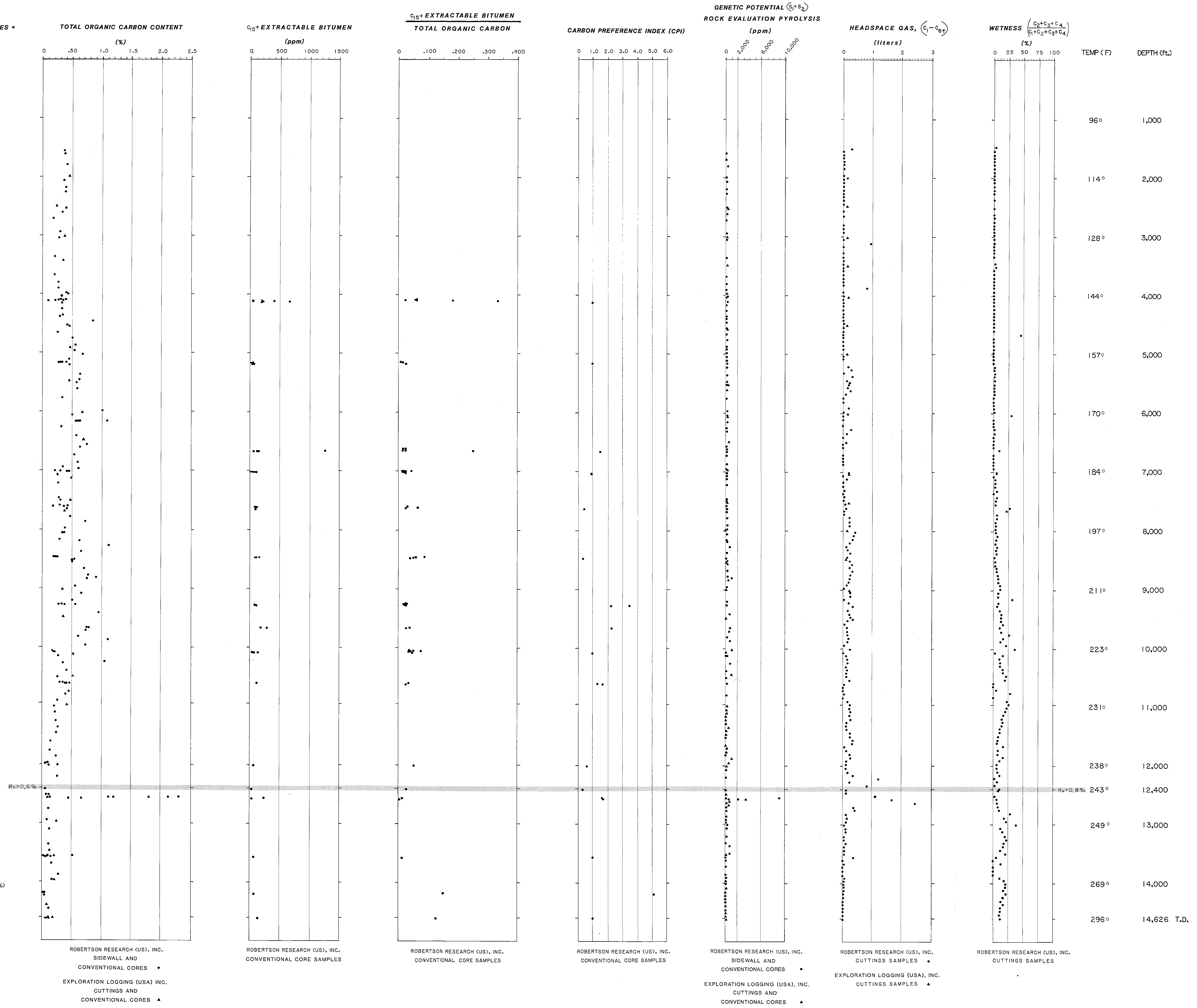
DEPARTMENT OF THE INTERIOR
MINERALS MANAGEMENT SERVICE

PLATE 2. ORGANIC RICHNESS AND HYDROCARBON POTENTIAL, ST. GEORGE BASIN COST NO. 2 WELL, BERING SEA, ALASKA

OCS REPORT MMS 84-0018
PLATE 2 OF 2

DEPTH (ft.)	TEMP (F)	DESCRIPTION OF SELECTED CUTTINGS, SIDEWALL, AND CONVENTIONAL CORE SAMPLES *
1,000	96°	IG CGL, GY-BRN, (45%), SLTST, DK GY, (40 %), S.S., M TO CRS, LT BRN, CALC, (10%), SHELL, (5%)
		SLST, (85%), IGN CGL, (10%), SHELL, (5%), CMT CONTAMINATION
2,000	114°	SLTST, (60%), IGN CGL, (20%), QTZ SND, (10%), S.S., F TO M, WH BRN, (10%)
		S.S., (80%), IGN CGL, (10%), QTZ. SND, (5%), SLTST, (5%)
		S.S., (80%), SLTS, (20%)
		CGL, SNDY, F TO M, GY-BRN, (70%), SLTST, (30%)
		SLTST, (80%), S.S., F TO CRS, GY WH, (20%)
3,000	128°	SLTST, (95%), QTZ SND, (5%)
		SLTST, (100%)
		SS, F TO M, LT BRN, SLTY, SL CALC
4,000	144°	SLTST, (100%), PIPE GREASE (?)
		SS, F TO M, SLTY, LT GY-BRN, (50%), SLTST, (40%), QTZ. SND, (10%)
		SLTST, (80%), QTZ SND, (20%)
		SS, (50%), SLTST, (40%), QTZ. SND, (10%)
5,000	157°	SLTST, LT GY-WH, SL CALC, (100%)
		SS, M TO CRS, LT BRN, QTZ. FRAGS, CLY MTX, (80%), QTZ SND, (20%)
		SLTST, (80%), QTZ SND, (20%)
6,000	170°	SLTST, LT GY-BRN, SNDY, (60%), SS, F TO M, LT GY-BRN, SLTY, (40%)
		SLTST (80%), SS, (20%)
		SLTST, GRY CARB FRAGS
7,000	184°	SLTST (90%), SS, (10%)
		SLTST, CARB, (85%), S.S., (15%)
8,000	197°	SS, F TO M, LT GY, SLTY, CALC, GLAU, (75%), SLTST, (25%)
		SS, F TO M, LT GY-BRN, SLTY, GLAUC (65%), SLTST (25%), QTZ SND, M, (10%)
		SLTST, GY-BRN, SNDY, CALC, TR CARB, (70%), SS, F TO M, LT GY-BRN, SLTY, GLAUC, (30%)
		SS, F TO M, GRY, SLTY, GLAUC, SL CALC, (70%), SLTST, (30%)
		SLTST, LT GY-BRN, CALC, TR CARB
9,000	211°	SS, SLTY, (50%), SLTST, DK GRY, (50%)
		SLST, GRY BRN, SNDY, (60%), SS, (40%), COAL, (TR)
		SLTST, GRY-BRN, SNDY, COAL
		SLTST, CALC, (80%), SS, (20%)
		SS, F TO CRS, GRY-WH, GLAUC, SL CALC, (90%), SLTST, CALC, (10%), VOLC, GRY, (TR)
		SLTST, DK GRY-BRN, SNDY, CALC, (75%), SS, F TO M, GRY-WH, (25%)
10,000	223°	SS, (90%), SLTST, 10%
		SS, (90%), SLTST, (10%)
		SLTST, DK GRY, TR CARB, (60%), SS, (40%)
		SS, (85%), SLTST, (15%)
11,000	231°	SS, F TO M, WH TO DK GRY, TR GLAUC AND PYR, (90%), SLTST, (10%)
		SS, F, GRY-WH TO DK GRY, (100%)
		SS, F TO M, GRAY-WH TO DK GRY, GLAUC, (100%)
12,000	238°	SS, F TO CRS, GRY, DIESEL OIL CONTAMINATION (?)
		SS, F TO CRS, GRY-WH TO DK GRY, WALNUT SHELLS
12,400	243°	SS, F TO CRS, GRY, DIESEL OIL CONTAMINATION (?)
		SS, F TO CRS, GRY-WH, COAL FRAGS, (95%), SH, DK GRY, (5%)
		VOLC, TUF, DK GRY GN, (40%), SS, M TO CRS, GRY-WH, COAL FRAGS, (30%), SH, (30%)
		SS, M TO CRS, GRY-BRN, (70%), VOLC, TUF, (20%), SH, (10%)
13,000	249°	SS, CGL, F TO CRS, GRY-BRN, MICA, TR CARB, (90%), SLTST, (10%)
		SS, CGL, GLAUC, (90%), SLTST, (10%)
		SS AND SLTST, VF, GRY, MICA, PIPE GREASE AND DIESEL OIL (?)
		SS, F TO CRS, GRY-WH TO BLK, SL CALC, MICA, (90%), SLTST, GRY-BRN, SL CALC, (10%)
14,000	269°	SS, (65%), SLTST, (20%), VOLC, TUF, GRY-WH AND DK GRY LAM, (10%), VOLC, GRN BLK, GL, (5%)
		IG, RED, YEL, GRN, PIPE GREASE AND DIESEL OIL (?)
		SS, SL META, (50%), VOLC, (30%), VOLC, TUF, (20%)
		IG, META, DK GRY-GRN, (90%), SS, F TO M, GRY-WH, (10%)
14,626 T.D.	296°	IG, GRY, MICA, PIPE GREASE AND DIESEL OIL (?)

* ABBREVIATIONS FROM AAPG BULLETIN, V. 49, NO. 9, p. 2103


TOTAL ORGANIC CARBON CONTENT

ROBERTSON RESEARCH (US), INC.
SIDEWALL AND
CONVENTIONAL CORES ●

EXPLORATION LOGGING (USA) INC.
CUTTINGS AND
CONVENTIONAL CORES ▲

$C_{15}+$ EXTRACTABLE BITUMEN

ROBERTSON RESEARCH (US), INC.
CONVENTIONAL CORE SAMPLES

$\frac{C_{15}+\text{ EXTRACTABLE BITUMEN}}{\text{TOTAL ORGANIC CARBON}}$

ROBERTSON RESEARCH (US), INC.
CONVENTIONAL CORE SAMPLES

CARBON PREFERENCE INDEX (CPI)

ROBERTSON RESEARCH (US), INC.
CONVENTIONAL CORE SAMPLES

GENETIC POTENTIAL (S_1+S_2)
ROCK EVALUATION PYROLYSIS

ROBERTSON RESEARCH (US), INC.
SIDEWALL AND
CONVENTIONAL CORES ●

EXPLORATION LOGGING (USA), INC.
CUTTINGS AND
CONVENTIONAL CORES ▲

HEADSPACE GAS, (C_1-C_{6+})

ROBERTSON RESEARCH (US), INC.
CUTTINGS SAMPLES ●

EXPLORATION LOGGING (USA), INC.
CUTTINGS SAMPLES ▲

WETNESS $\left(\frac{C_2+C_3+C_4}{C_1+C_2+C_3+C_4}\right)$

ROBERTSON RESEARCH (US), INC.
CUTTINGS SAMPLES