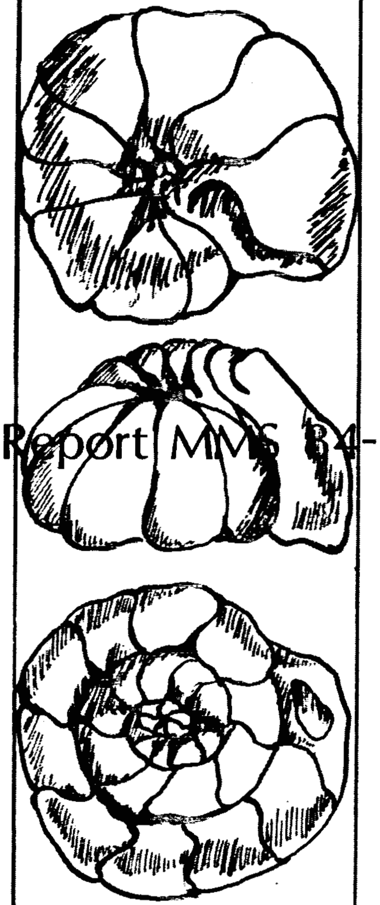
Geological and Operational Summary
ST. GEORGE BASIN COST NO. 1 WELL

Bering Sea, Alaska



OCS Report MMS 84-0016

United States Department of the Interior
Minerals Management Service

GEOLOGICAL AND OPERATIONAL SUMMARY

ST. GEORGE BASIN COST NO. 1 WELL

BERING SEA, ALASKA

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (cont.)

PLATES

Page

TABLES

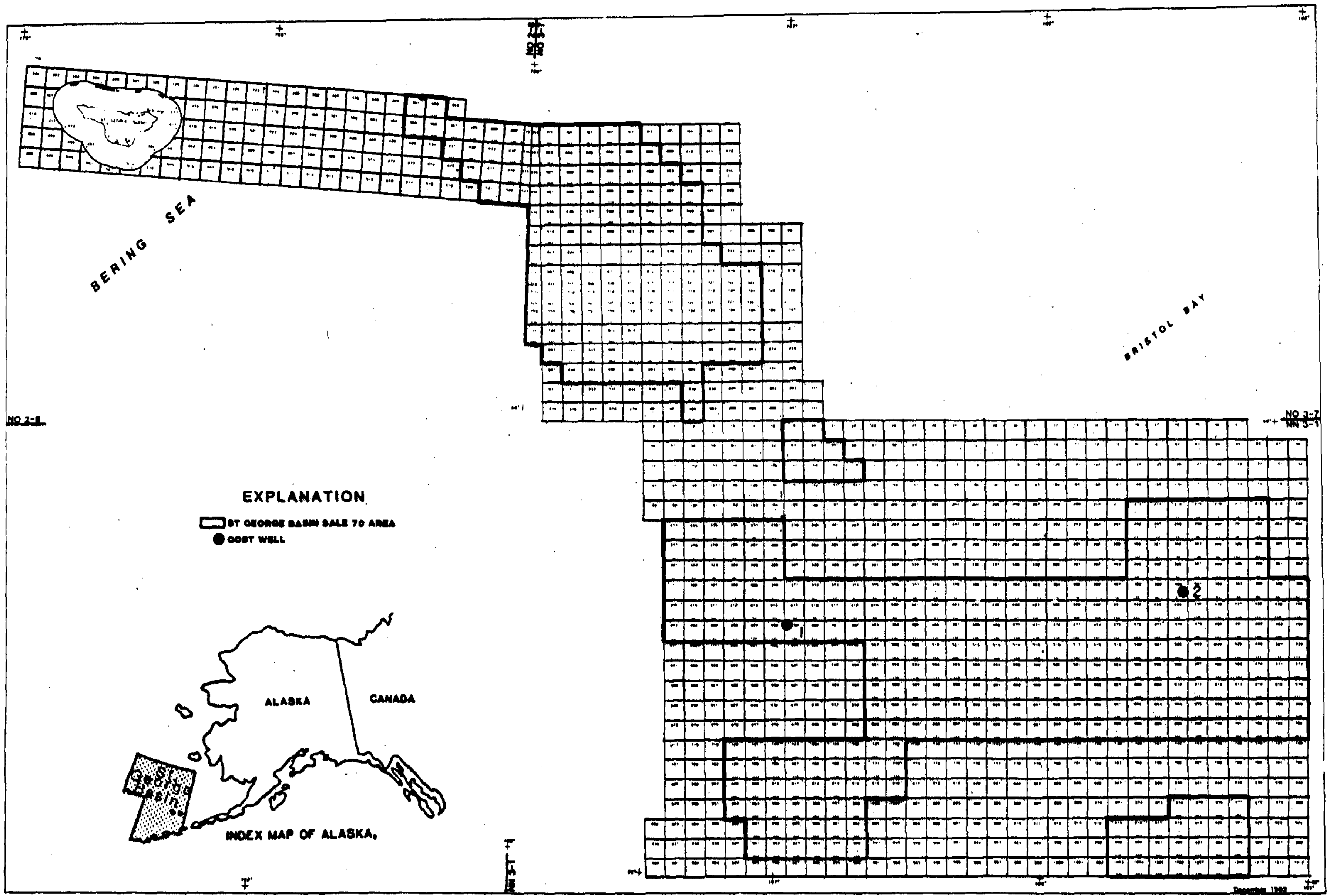


Figure 1. Location map showing St. George Basin Sale 70 area and COST No. 1 and No. 2 Wells.

Geological and Operational Summary
St. George Basin COST No. 1 Well
Bering Sea, Alaska

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 first St. George Basin Deep Stratigraphic Test well (designated the ARCO St. George Basin COST No. 1 Well by the operator and hereafter referred to as the well or the No. 1 well) were offered for lease in Sale 70 on April 12, 1983. One hundred-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 St. George Basin COST No. 1 well was completed on September 22, 1976, in Block 459, located approximately 105 miles southeast of St. George Island, Alaska (fig. 1). The well data listed in the appendix are available for public inspection at Minerals Management Service, Field Operations, located at 800 "A" Street, Anchorage, Alaska 99501.

All depths are measured in feet from the Kelly Bushing (KB), which was 98 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. 1 well was drilled by the Ocean Ranger, a self-propelled semisubmersible drilling rig. The Ocean Ranger, owned by ODECO, Inc., was built in 1976 by MHI Hiroshima Shipyard and Engine Works and was given the classification ABS - AMS + A - 1 (M), column-stabilized mobile drilling unit. The rig was designed for drilling in water up to 3000 feet deep, 100-knot winds, and 110-foot waves with a corresponding wave period of 15 seconds and a surface current of 3 knots. The Ocean Ranger was inspected before drilling began, and operations were observed by U.S. Geological Survey (USGS, now Minerals Management Service) personnel throughout the drilling period to ensure compliance with Department of Interior regulations and orders.

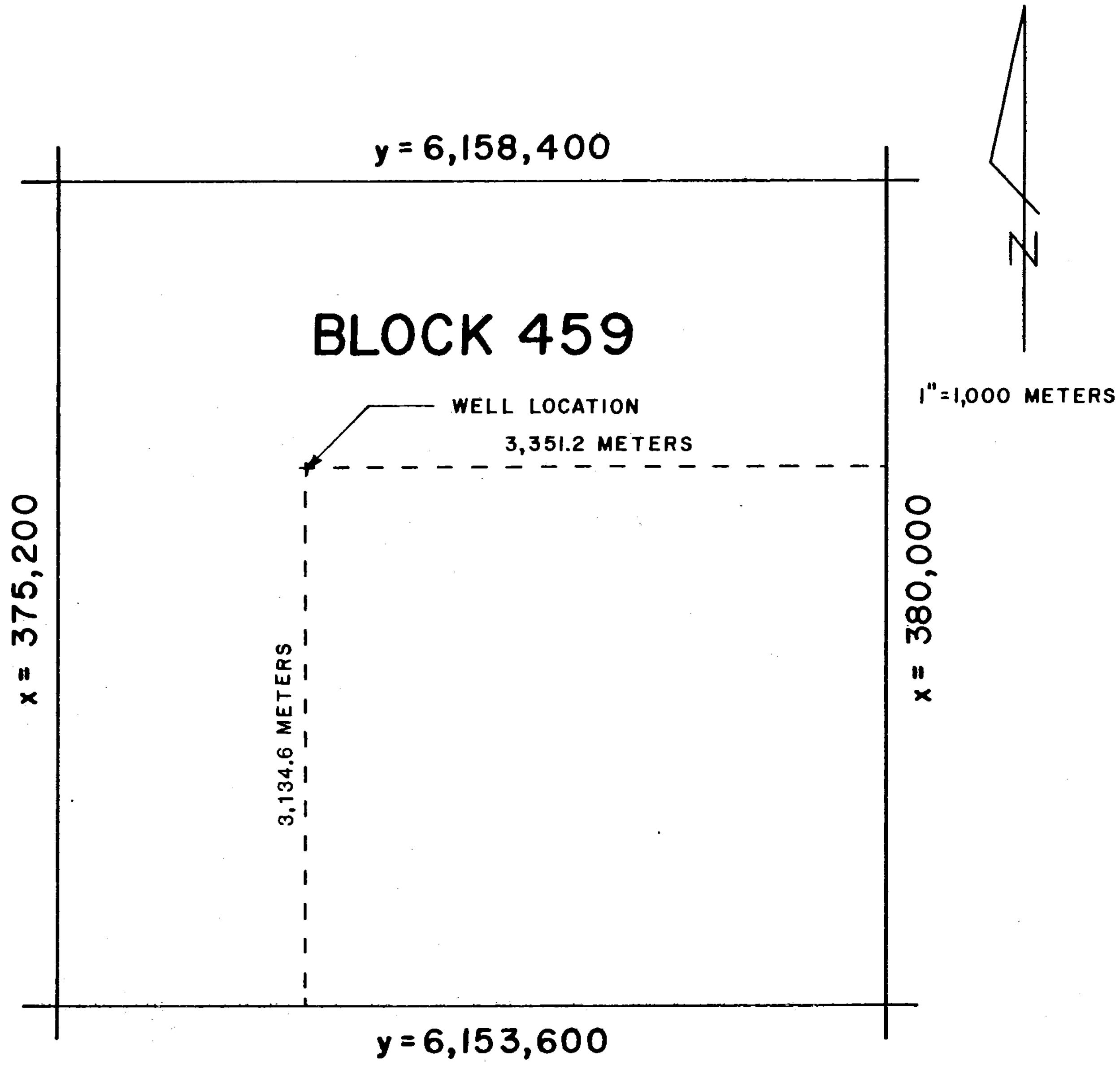
Cold Bay and Dutch Harbor, Alaska, were used as operational bases. Cold Bay, approximately 170 miles from the well location, was the air base. Two seagoing supply vessels transported drilling materials and supplies, including fuel, from Dutch Harbor to the rig. At least one standby vessel was within a 1-mile radius of the rig at all times. The supply vessels were also used for towing and anchor handling. Depending on weather, timing, and availability, materials and equipment were transported between Dutch Harbor and the Alaska mainland by these supply boats, barges, or other suitable vessels.

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 both chartered and commercial air carriers.

The No. 1 well was spudded at 1630 hours Alaska Standard Time, July 2, 1976. Drilling was completed 83 days later on September 22, 1976, at a total depth (TD) of 13,771 feet. After logging and coring operations were completed, the well was plugged and abandoned on October 2, 1976, and the rig was released.

Atlantic Richfield Company (ARCO) acted as the operator for itself and the following nineteen petroleum companies that shared expenses for the well:

Amerada Hess Corporation
AMOCO Production Company
British Petroleum, Inc.
Cities Service Company
Continental Oil Company
Exxon Company, U.S.A.
Getty Oil Company
Gulf Energy and Minerals Company, U.S.A.
Marathon Oil Company
Mobil Oil Corporation
Pennzoil Company
Phillips Petroleum Company



GEODETIC POSITION	UNIVERSAL TRANSVERSE MERCATOR COORDINATES, ZONE 3, in METERS.
LAT. 55°32' 34.64"N.	y = 6,156,734.6
LONG. 166°57' 17.50"W.	x = 376,648.8

Figure 2. Final location plat showing the position of the COST No. 1 Well, St. George Basin, Alaska

Shell Oil Company
Skelly Oil Company
Standard Oil of California
Sun Oil Company
Tenneco Oil Company
Texaco, Inc.
Union Oil Company of California

The No. 1 well was located at lat 55°32'34.6437" N., long 166°57'17.5001" W., or UTM coordinates (zone 3) X = 376,648.83 m and Y = 6,156,734.57 m. The final well site is shown in figure 2. Water depth at the location is 442 feet. All measurements were made from the Kelly Bushing, which was 98 feet above the water line and 540 feet above the mud line. The maximum deviation from vertical was 2 3/4 degrees, and the well was drilled, for the most part, with less than 1 degree deviation.

Drilling stipulations required the operator to provide the Minerals Management Service (formerly USGS) with all well logs, samples, core slabs, geologic information, and operational reports.

DRILLING PROGRAM

The No. 1 well was drilled using two 17 1/2-inch drill bits to a depth of 1600 feet, and deepened with twenty-seven 8 1/2-inch bits to TD. Additional bits were used for hole opening, to drill through cement, for clean-out trips, and for the conventional coring program. Drilling rates ranged from 3 to 2700 feet/hour. The rate gradually decreased from an average of 1600 feet/hour at 2600 feet to 100 feet/hour at 5700 feet. At this depth softer sediments were encountered and the drilling rate increased to 200 feet/hour down to 6500 feet. From this depth, the rate again gradually decreased to an average of 10 feet/hour at TD. The daily drilling progress is shown in figure 3.

Three strings of casing were set in the well as shown in figure 4. The 30-inch casing was set at 642 feet with 776 sacks of cement; the 20-inch casing was set at 1556 feet with 1950 sacks of cement; the 13 3/8-inch casing was set at 4833 feet with 1900 sacks of cement. Class G cement was used for all casings. While cementing the 13 3/8-inch casing, loss of circulation problems were encountered. Permission was received from the USGS to drill out the 13 3/8-inch casing shoe, and two Cement Bond Logs were run with no indication of cement bonding. After squeeze cementing to ensure proper bonding of the casing with the formation, and running a leak-off test, drilling was continued with no further problems.

The abandonment procedure is also shown in figure 4. A cement retainer was set between 4,730 and 4,780 feet with cement 70 feet above and 200 feet below the retainer. The 13 3/8-inch casing was cut at 740 feet; both the 30-inch and 20-inch casings were cut at 555 feet. At the surface, a cement plug was set between 630 and 840 feet.

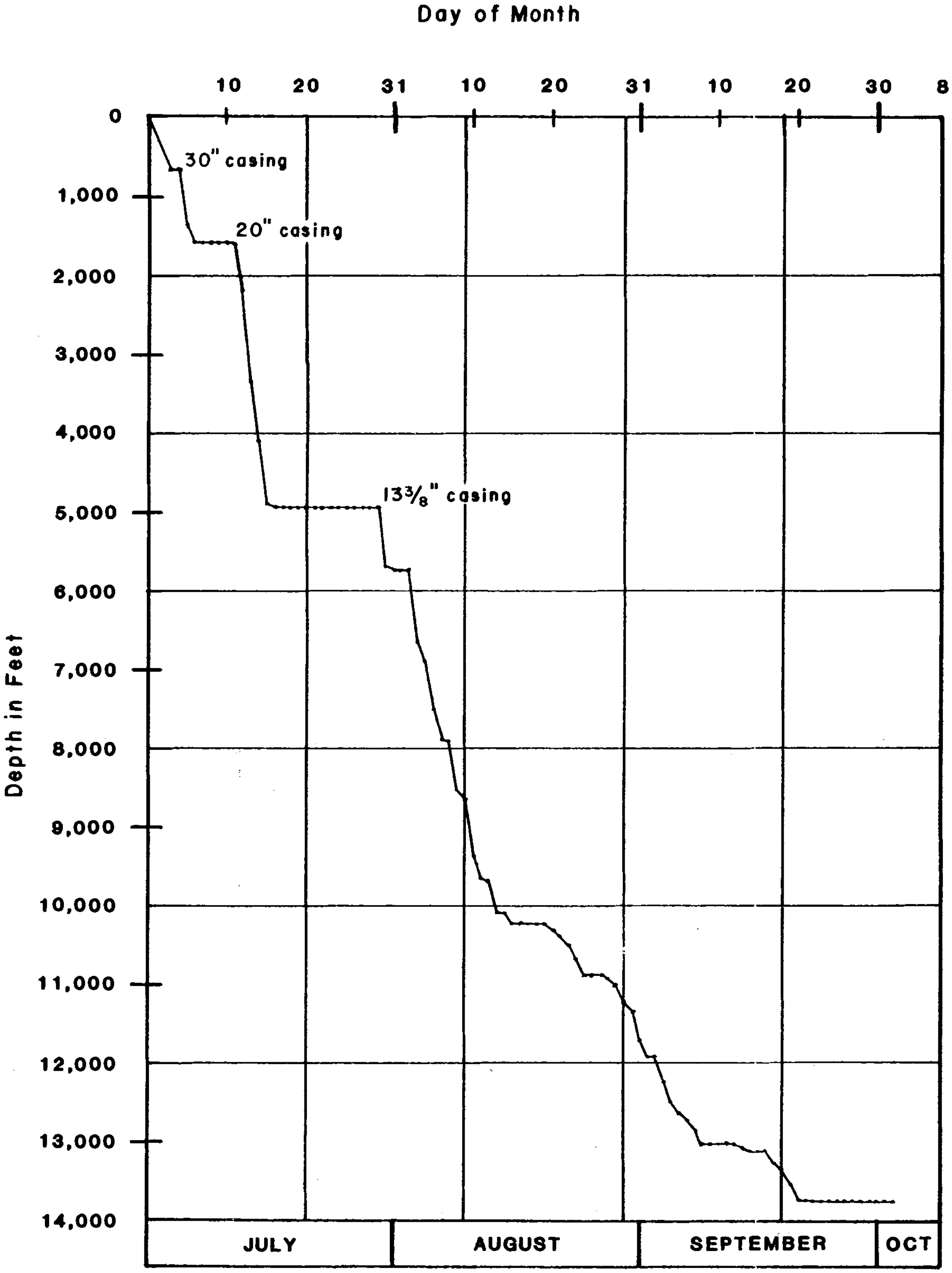


Figure 3. Graph showing daily drilling progress for the St. George Basin COST No. 1 Well.

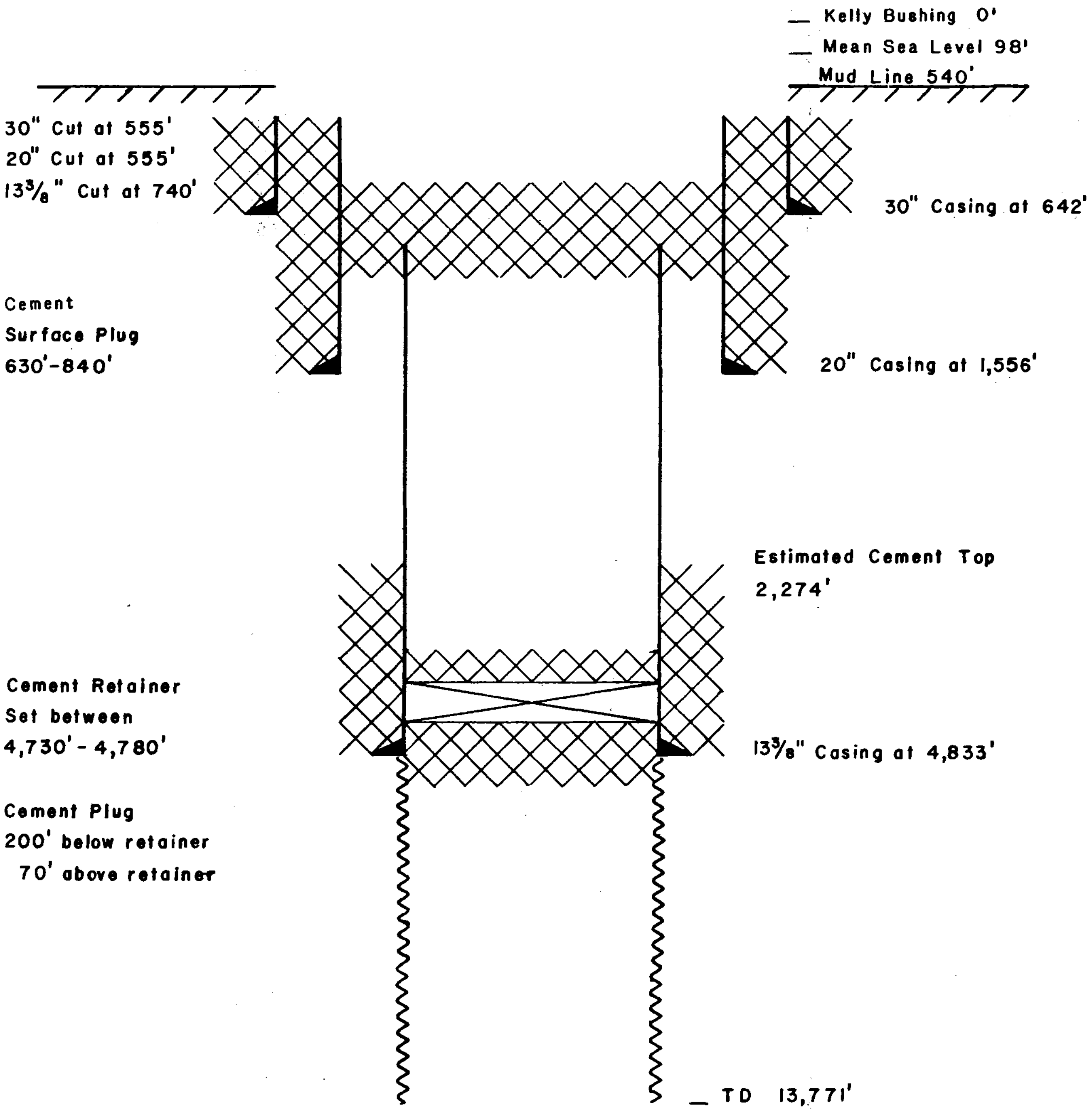


Figure 4. Schematic diagram showing casing strings, plugging, and abandonment program, St. George Basin COST No. 1 Well.

DRILLING MUD

Changes in selected drilling mud properties are shown in figure 5. Seawater and spotted viscous gel pills were used as drilling fluid down to 1580 feet. At this depth, fresh-water drilling mud with a weight of 8.6 pounds/gallon and a viscosity of 43 seconds displaced the seawater. Mud weight was increased to 9.0 pounds/gallon at 4200 feet, reached 9.6 pounds/gallon at 10,300 feet, and remained at that weight to TD. The viscosity of the mud fluctuated between 35 and 60 seconds in the first 5400 feet and averaged about 45 seconds for the remainder of the well. Mud pH averaged 11.0 with minor fluctuations. Chloride concentrations began with 3200 ppm, decreased to 1400 ppm at 8950 feet, and 2000 ppm at TD. Mud logging services were provided by The Analysts.

SAMPLES AND TESTS

Thirteen conventional cores were obtained and analyzed for porosity, permeability, grain density, paleontology, depositional environment, and lithology.

Table 1. Conventional Cores

Core No.	Interval (feet)	Recovered (feet)
1	3370-3420	47
2	4105-4151	30
3	4880-4921	0
4	5669-5726	30
5	5726-5746	18.5
6	6848-6868	18
7	7876-7924	41
8	9646-9694	45
9	10,323-10,356	12
10	10,356-10,395	21
11	10,905-10,947	42
12	13,080-13,120	39
13	13,760-13,771	9

Three series of sidewall cores were taken. At 4921 feet, 150 cores were recovered in four runs with 12 misfires, 11 empty bullets, and one lost bullet. At 10,217 feet, 363 cores were recovered in 435 attempts, leaving 16 bullets in the hole. At 13,006 feet, 49 cores were attempted, 37 recovered, and 12 bullets were lost. Five hundred and fifty successful cores were obtained.

There were no drill stem tests made on this well.

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

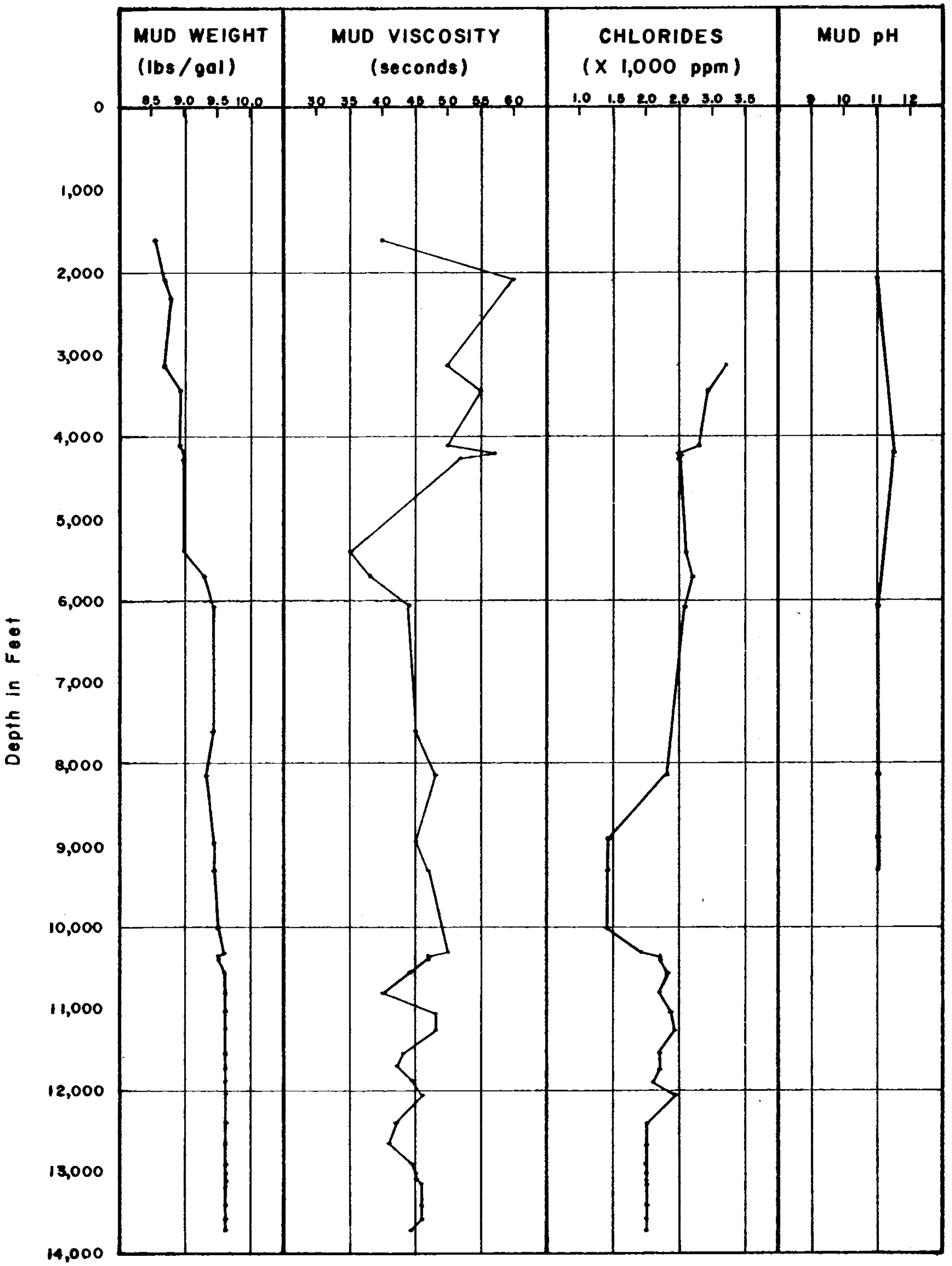


Figure 5. Changes with depth of drilling mud properties, including mud weight, viscosity, total chlorides, and pH, St. George Basin COST No. 1 Well.

4921 feet to 1553 feet

Dual Induction Laterolog/Spontaneous Potential
Compensated Formation Density Sonic Log/Neutron Gamma Ray
Micro-Lateral Log/Caliper and Spontaneous Potential
Velocity Survey
High Resolution Continuous Dipmeter
Repeat Formation Tester
High Resolution Temperature Survey
Cement Bond Log

10,217 feet to 4921 feet

Dual Induction Laterolog/Spontaneous Potential
Borehole Compensated Sonic Log
Sonic Log
Density Neutron Log
Velocity Survey
Long-Spaced Sonic Log
Micro-Lateral Log
Cement Bond Log
High Resolution Continuous Dipmeter/Caliper
High Resolution Temperature Log
Repeat Formation Tester

13,006 feet to 10,217 feet

Dual Induction Laterolog
Borehole Compensated Sonic Log
Velocity Survey
Compensated Neutron Log - Compensated Formation Density Log/Gamma Ray/Caliper
Long-Spaced Sonic Log
Micro-Lateral Log
High Resolution Continuous Dipmeter
Temperature Survey
Repeat Formation Tester

13,771 feet to 13,006 feet

Dual Induction Laterolog
Borehole Compensated Sonic/Gamma Ray/Caliper
Velocity Survey
High Resolution Temperature Survey

WEATHER

Weather conditions were monitored from late June through the end of September 1976. During this period, waves of 10 feet or more occurred on 10 days, with a maximum wave height of 16 feet in September. Wind speeds reached 53 miles per hour on August 30, but were not above 40 miles per hour on any other day. The temperature was never below 40° F or higher than 53° F.

SHALLOW GEOLOGIC SETTING
by
C. Drew Comer

The shallow geologic characteristics of the drill site were identified by a high-resolution geophysical survey (BBN-Geomarine Services Company, 1976) and a 236-foot-deep geotechnical corehole (Woodward-Clyde Consultants, 1976a). These studies evaluated potential shallow drilling hazards. A more detailed discussion of the regional environmental geology may be found 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 low concentrations 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 seen on high-resolution seismic 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 in the basin is the St. George graben, a large, fault-bounded depression located north of the No. 1 well. 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 the 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 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 shallow 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 abnormal pressure.

SITE-SPECIFIC ENVIRONMENTAL GEOLOGY

The site survey performed by BBN-Geomarine Services Company indicated that the sea floor at the well site is smooth and gently slopes to the southwest. It is underlain by flat-lying strata and is free of faulting. Acoustic anomalies on seismic reflection profiles suggest the presence of shallow gas, and a geotechnical corehole did encounter dispersed gas in the sediments from 67 to 236 feet below mudline. This gas was normally pressured and apparently not in communication with a deeper, high-pressured reservoir. The gas was probably generated in situ by biogenic processes. The cored sediments ranged from silty clays to fine silty sands and were Pleistocene in age except for a thin veneer of Holocene sediments at the surface. Shallow gas did not prove to be a problem during drilling operations.

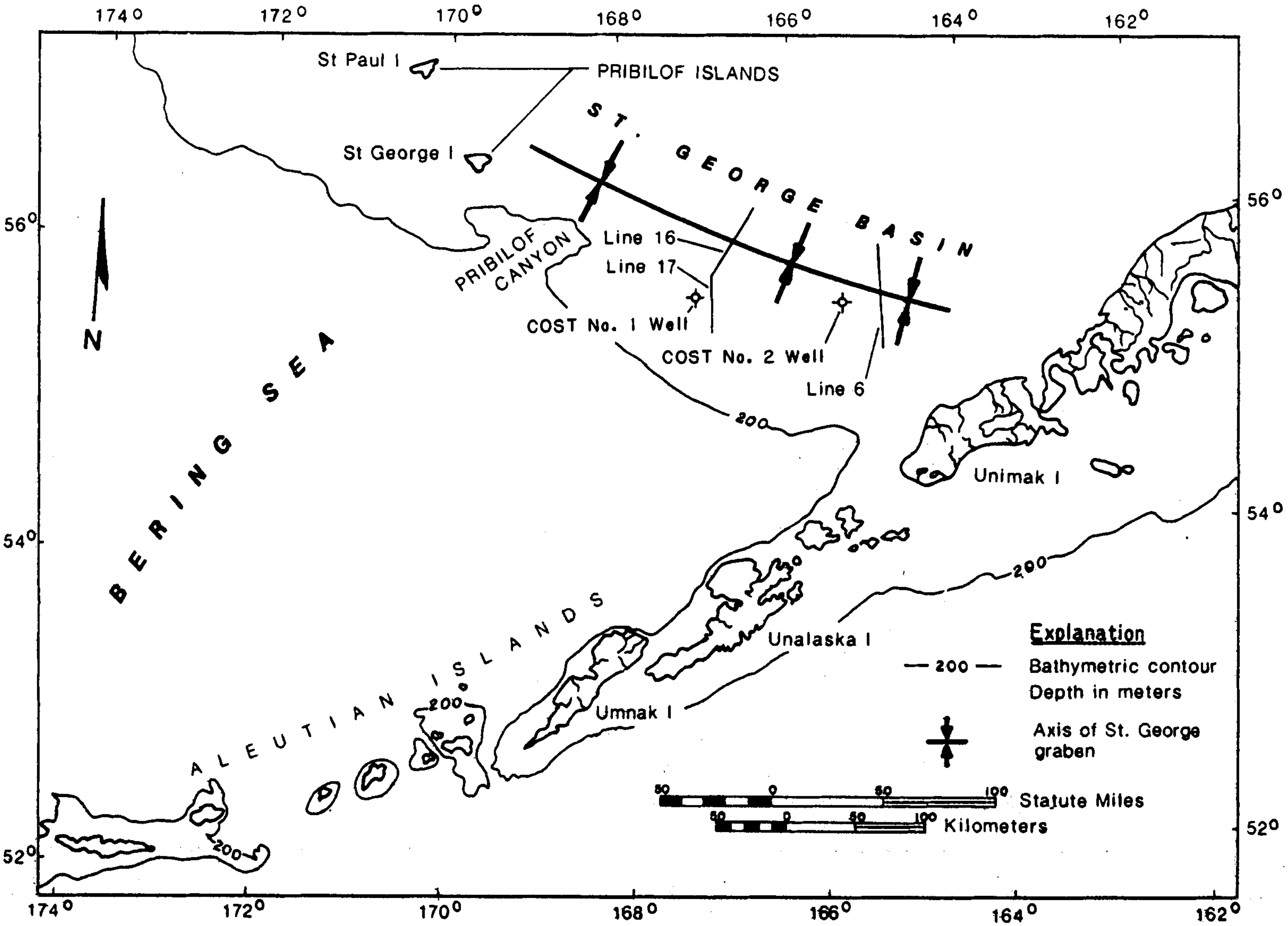


FIGURE 6. Location map of St. George Basin, COST wells, and U.S. Geological Survey seismic lines.

SEISMIC REFLECTION CORRELATION AND VELOCITY ANALYSIS

by

C. Drew Comer

The seismic stratigraphy of the No. 1 well was developed from reflection data collected in 1976 by the USGS, 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, 1975 Seiscom Delta lines 173 and 226, were also utilized. Velocity data from the No. 1 well were compared with the No. 2 well. The locations of the wells and the USGS lines in relation to the axis of the 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 Hertz. The synthetic seismogram is displayed in both normal and reverse polarity. The seismic reflection profile displayed with the synthetic seismogram is Seiscom Delta line 226. Figure 8 is a time-stratigraphic column of the No. 1 well based on the Paleontology and Biostratigraphy chapter of this report.

VELOCITY ANALYSIS

Interval velocities and a time-depth curve (fig. 9) were calculated from the sonic log. The interval velocities increase gradually with depth, as expected, except for some minor reversals such as the one seen from 8000 to 8400 feet. This interval is an interbedded sandstone and siltstone sequence that underlies a zone of pebbly sandstone and conglomerate within the lower Oligocene section. The interval velocity increases from 11,500 to 16,000 feet/second at about 10,600 feet, which is near the contact of the Tertiary sediments with the volcanic basement. Basalt was encountered at 10,380 feet underlying a basal Eocene conglomerate. The apparent acoustic basement on the synthetic seismogram occurs approximately 100 milliseconds below the acoustic basement on the Seiscom Delta profile (fig. 7). The greater travel time to basement in the synthetic seismogram may have been caused by anomalously low interval velocities measured by the sonic tool in a rugose or washed-out zone. The caliper log indicates that caving occurred in the basal 200 feet of the Tertiary sediments, which could explain the apparently low interval velocities.

Figure 10 is a comparison of time-depth curves generated from the sonic logs for the Nos. 1 and 2 wells. The curve for 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 than in the No. 1 well at comparable levels. The major exception is the high velocity interval in the No. 1 well from 10,600 to 11,400 feet, which corresponds to the volcanic basement.

It should be pointed out that velocities derived from sonic logs are subject to drift error due to irregularities within the borehole (Tucker, 1982). Also, since the shallowest part of the borehole 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 reflection lines 16 and 17, which are 24-channel common-depth-point (CDP) profiles. Line 17 passes within 4.5 miles of the No. 1 well, and line 16 crosses the St. George graben northeast of the well (fig. 6). The horizons marked on the profiles are age dates based on paleontology. They were correlated from the well to line 17 using 1975 Seiscom Delta seismic reflection lines 173 and 226. The top of the Eocene is not marked as a separate horizon in the Tertiary section on figure 12 because it onlaps the basement between the well and the USGS line.

The No. 1 well is located in a local basement depression south of the St. George graben. The lowermost Tertiary strata onlap a basement high near shotpoint 1400 a few miles northeast of the drill site (fig. 12). This high may be genetically related to the Pribilof Ridge to the northwest and the Black Hills Ridge to the southeast, as it is aligned with the trend of these structures as mapped by Cooper and others (1979) and Marlow and others (1979).

The basement horizon on figure 12 is an angular unconformity between Cenozoic strata and the underlying Mesozoic (?) rocks. The basement is basalt at the drill site, but sedimentary rocks probably occur in the basement throughout much of St. George basin. A sedimentary section with well-defined bedding is apparent on USGS line 16 along the margin of the graben northeast of the No. 1 well. The No. 2 well, which was drilled along the margin of the graben, encountered Lower Cretaceous and Upper Jurassic sedimentary rocks in the basement. Upper Cretaceous sedimentary rocks were dredged from the Bering Shelf margin in the Pribilof Canyon (Hopkins and others, 1969). Upper Jurassic sedimentary rocks were dredged from Pribilof Ridge where the basement shoals to the surface near St. George Island (Vallier and others, 1980).

Lower Oligocene pebbly sandstone and conglomerate (7600 to 7860 feet) occur near the top of the seismic sequence that onlaps the basement high. The overlying Oligocene and younger strata can be correlated beyond the basement high and into the graben. Seismic and lithologic evidence suggests an unconformity within the lower Oligocene section, but no distinct hiatus could be defined on the basis of paleontological evidence.

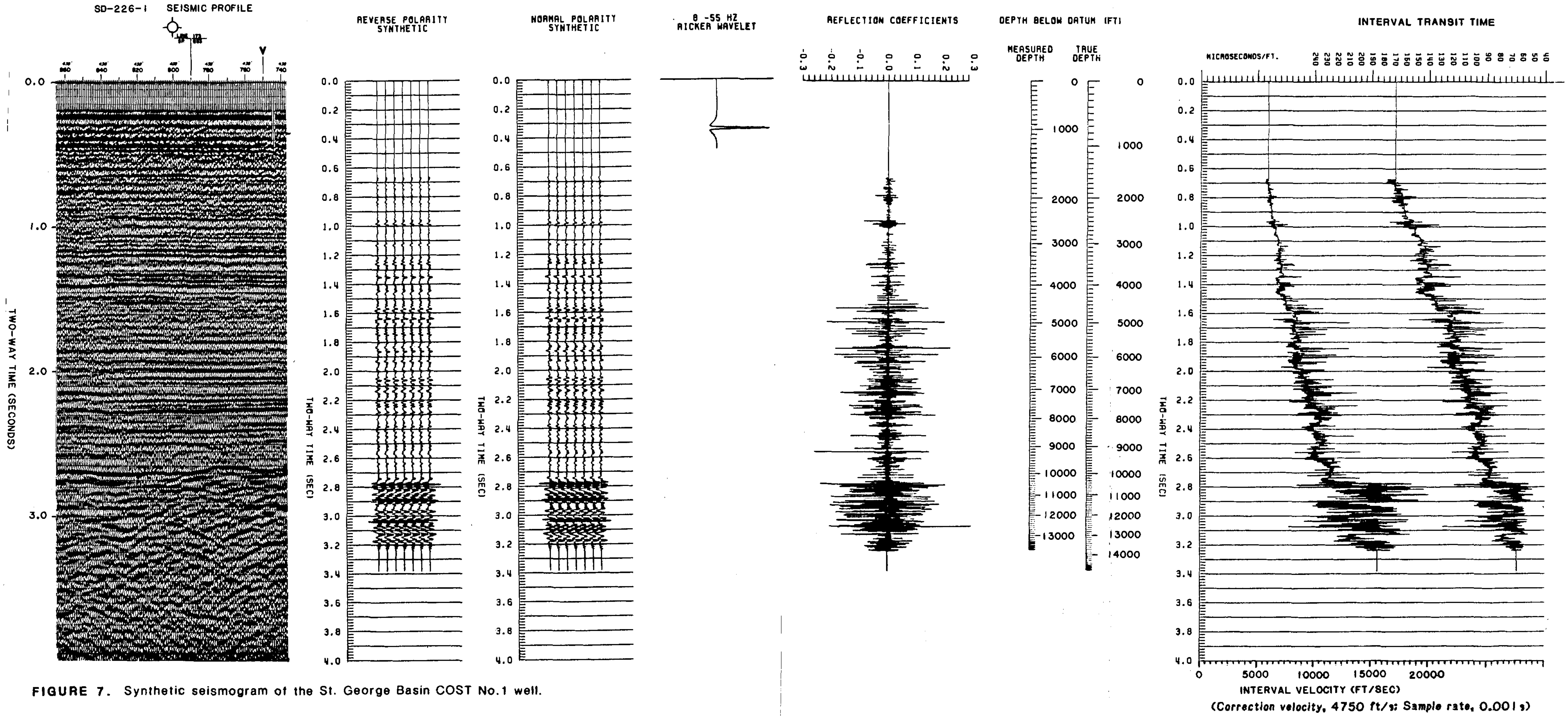


FIGURE 7. Synthetic seismogram of the St. George Basin COST No.1 well.

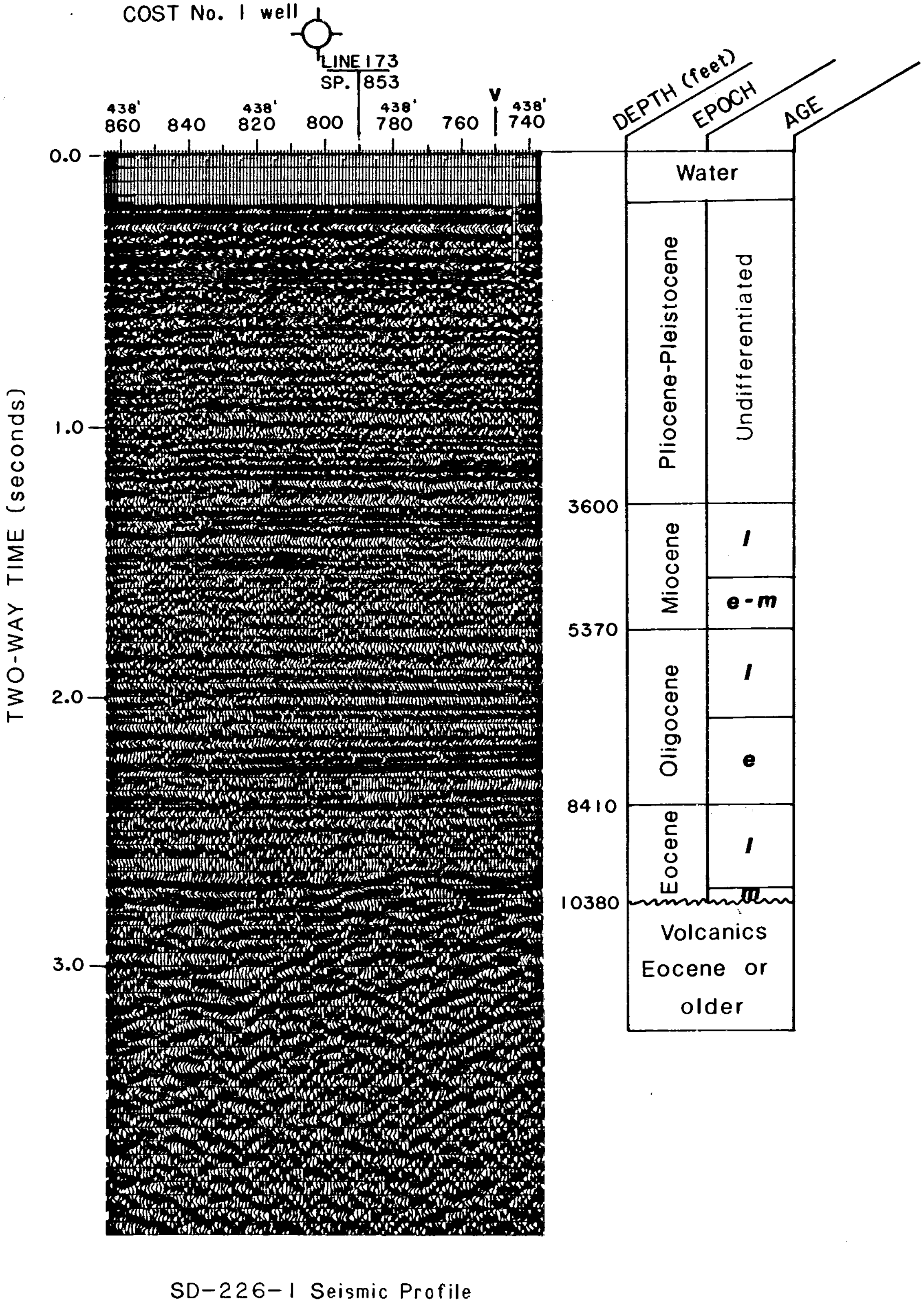


FIGURE 8. Time-stratigraphic column and seismic profile of the St. George Basin COST No.1 well.

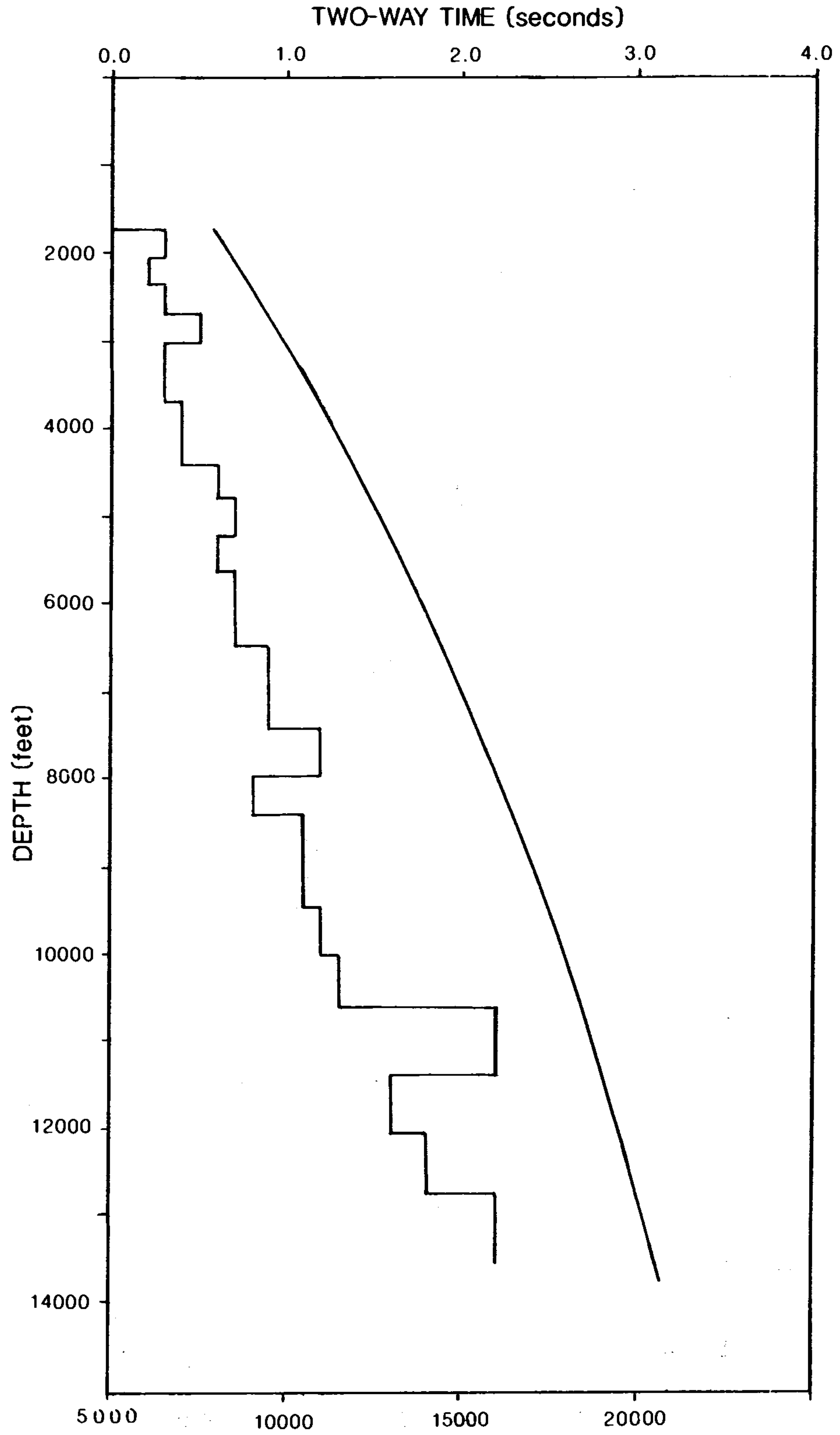


FIGURE 9. Interval velocities and time-depth curve from the sonic log of St. George Basin COST No. 1 well.

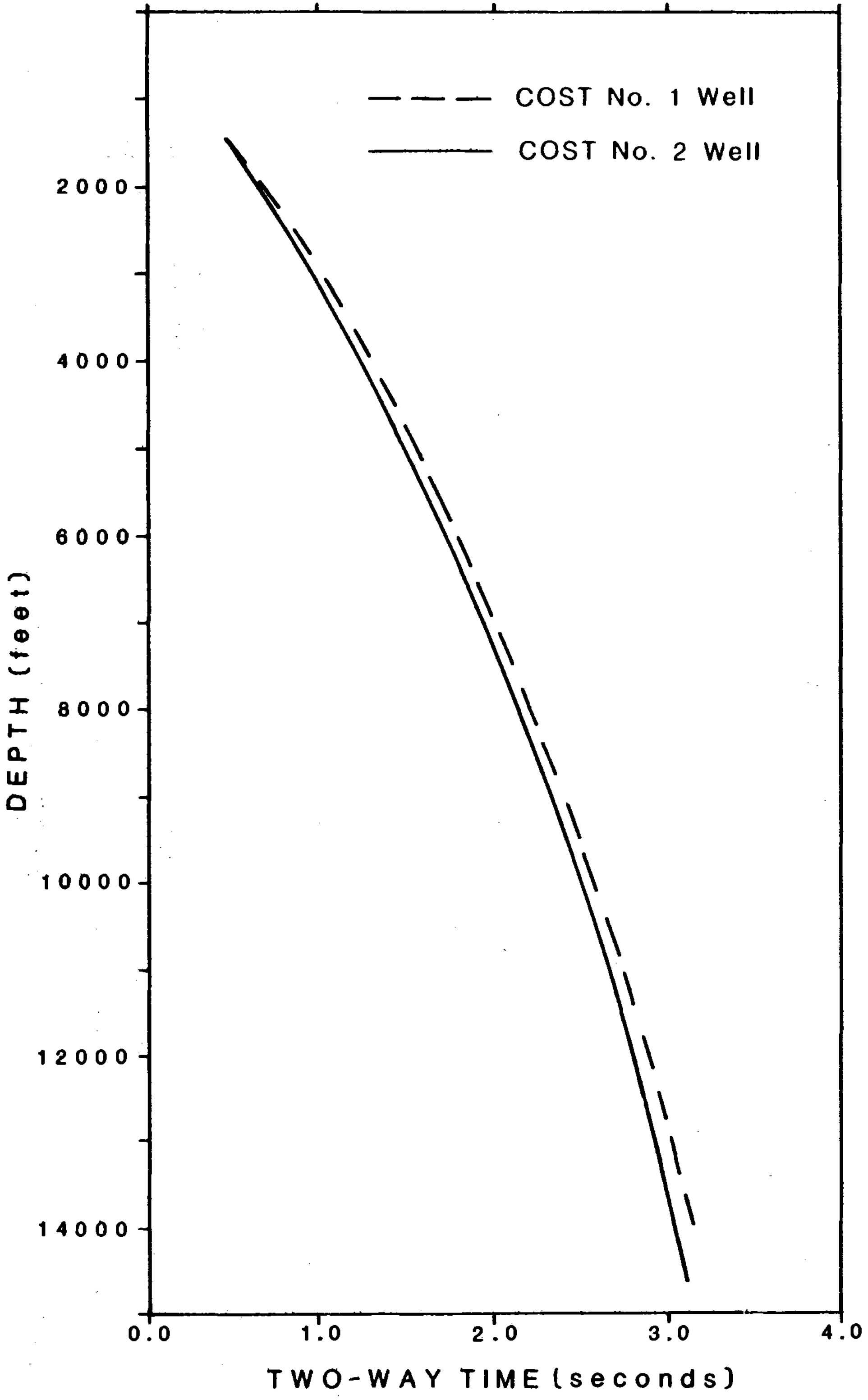


FIGURE 10. Comparison between time-depth curves for the St. George Basin COST No.1 and No.2 wells.

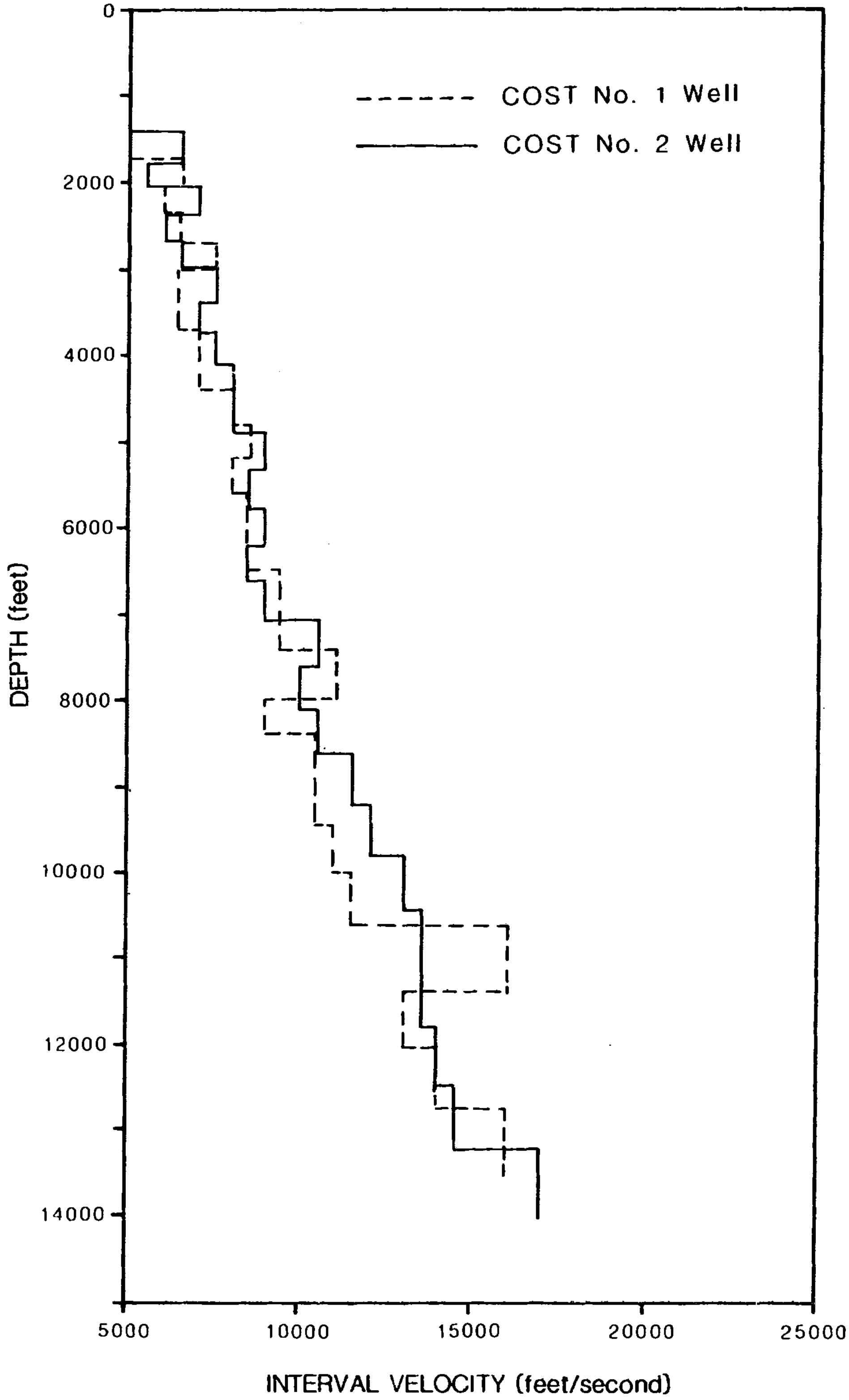
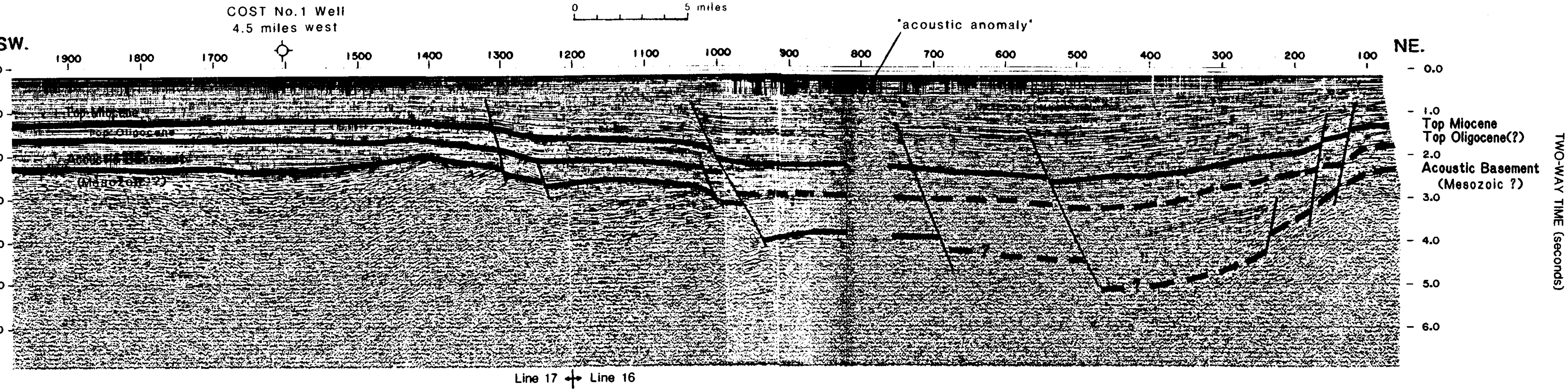


FIGURE 11. Comparison between interval velocities for the St. George Basin COST No. 1 and No. 2 wells.



URE 12. U.S. Geological Survey seismic lines 16 and 17. .

The offset of the 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 acoustic basement is obscure in the graben on USGS line 16 and may be deeper than is indicated in figure 12. The Oligocene top is also somewhat uncertain in the graben. The relatively high proportion of Neogene to Paleogene (and possibly Upper Cretaceous) section implies relatively rapid subsidence during the Neogene.

Strata equivalent in age to the basal Tertiary section of the No. 1 well are certain to occur in the graben, although they cannot be correlated beyond the basement high. Marlow and Cooper (1980) suggest that basin subsidence may have begun in the Late Cretaceous, so Cretaceous as well as lower Tertiary sediments may occur in the graben. The basal sediments in the graben probably have no age equivalents in the No. 1 well. This has important implications for both source rock and reservoir rock potential of the graben sediments. The area outside of the graben was apparently subaerially exposed in the Late Cretaceous and early Tertiary. If this is the case, then the lowermost graben sediments probably 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. Thus, the reservoir rock potential in the graben may be better than that of the rocks encountered in the No. 1 well.

PALEONTOLOGY AND BIOSTRATIGRAPHY

by

John A. Larson

Paleoecology and biostratigraphy for the St. George Basin COST No. 1 well were determined by detailed analyses of microfossil assemblages recovered from rotary drill bit cuttings (ditch samples), sidewall cores, and conventional core samples. Ditch samples were taken at 30-foot intervals between the uppermost sample at 1600 feet and the lowermost sample at 13,755 feet. Numerous sidewall cores (SWC) and 12 conventional cores were taken over this interval. The microfossil assemblages examined include Foraminifera, diatoms and silicoflagellates, Radiolaria, calcareous nannoplankton, pollen and spores, and dinocysts (dinoflagellate cysts). The principal sources of data for microfossil identification, abundance, distribution, and environmental implications are the consultant reports on the well and a nearby shallow core hole (Anderson, Warren, and Associates, Inc., 1976 a, b). Foraminifera from significant stratigraphic intervals of the well and from dredge samples collected near the well site were analyzed by Minerals Management Service personnel. Identification and analysis of siliceous microfossils from slides provided by ARCO were also utilized. Discrepancies between this report and the consultant's conclusions regarding the zoning of the upper part of the well result from information made available subsequent to the consultant's report regarding the biostratigraphic zonation of high latitude North Pacific diatoms (Barron, 1980), and from additional biostratigraphic information in the consultant's report on the biostratigraphy of the more recent ARCO St. George Basin COST No. 2 well (Biostratigraphics, 1982). Analysis and evaluation of foraminiferal data, interpretation of data, and synthesis were done by the author. Analysis of Foraminifera in the grab samples was done by Ronald F. Turner. Siliceous microfossil analysis was done by Donald L. Olson.

The biostratigraphy of the well is discussed in the order that the strata were penetrated. Following the conventional practice for subsurface biostratigraphy, fossil occurrences are listed as highest and lowest occurrences because references to first and last occurrences are potentially confusing. Samples from cores are given somewhat more weight than those from cuttings because core depths can be more precisely located and cores are less subject to downhole contamination. The well is correlated with the No. 2 well at the conclusion of this chapter.

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. Below the Miocene, dinocysts and calcareous nannofossils are most important. Foraminifera corroborate the biostratigraphy developed from these microfossil groups. Paleoenvironments referred to as continental (non-marine) include fluvial, lacustrine, and paludal. Transitional environments include brackish estuaries and hypersaline 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 bathymetric 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 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 principally on pollen and spore assemblages, and to a lesser extent on diatom assemblages.

PLEISTOCENE TO HOLOCENE

Prior to the drilling of the No. 1 well, a shallow core hole was drilled to a depth of 236 feet below sea bottom in the vicinity of the well site (Anderson, Warren, and Associates, Inc., 1976a). Diatom species present in the shallow core hole indicate that only the top 9 feet of sediment are of late Pleistocene to Holocene age.

Although the diatom population in the upper 9 feet of the core hole is very similar to that of underlying Pleistocene age samples, an abundant population of *Biddulphia aurita* seems to indicate a Holocene age. Other diatom species present include *Actinocyclus divisus*, *Actinoptychus undulatus*, *Arachnoidiscus ehrenbergii*, *Coscinodiscus africanus*, *Coscinodiscus asteromphalus*, *Coscinodiscus excentricus*, *Coscinodiscus marginatus*, *Coscinodiscus nodulifer*, *Coscinodiscus oculus-iridus*, *Denticulopsis seminae*, *Melosira sulcata*, *Porosira glacialis*, *Rhaphoneis amphiceros*, *Rhizosolenia hebetata*, *Stephanopyxis turris*, *Thalassionema nitzschioides*, *Thalassiosira* cf. *T. convexa*, *Thalassiosira decipiens*, *Thalassiosira gravida*, *Thalassiosira lineata*, *Thalassiosira oestrupii*, and *Thalassiothrix longissima*. Silicoflagellates present include *Distephanus octangulatus*, *Distephanus speculum*, and *Distephanus strauracanthus*. Radiolarians include *Sphaeropyle langii*, *Spongiodiscus* sp., and *Spongotrochus glacialis*. Siliceous endoskeletal dinoflagellates were also present, including *Actiniscus pentasterias* and *Actiniscus elongatus*.

Foraminifera present in this interval include *Cassidulina* cf. *C. laevigata*, *Elphidium clavatum*, *Eggerella advena*, *Epistominella exigua*, *Nonionella labradorica*, *Trifarina angulosa*, *Trifarina fluens*, *Trochammina* cf. *T. pacifica*, *Uvigerina cushmani*, and *Uvigerina* cf. *U. peregrina*.

Additional Holocene Foraminifera were recovered from dredge samples gathered from the same area by Minerals Management Service personnel in conjunction with a Tetra Tech site-specific biological survey. In addition to many of the previously mentioned species, the dredge samples contained *Adercotrema glomerata*, *Cassidulina norcrossi*, *Elphidium batialis*, and *Uvigerina juncea*, along with *Cassidulina delicata*, *Cibicides fletcheri*, *Cribrostomoides crassimargo*, *Globobulimina auriculata*, *Nonionella auricula*, *Reophax scorpiurus*, *Reophax micaceous*, *Silicosigmoilina groenlandica*, and *Trochammina nana*.

Pollen and spores in the Pleistocene to Holocene portion of the shallow core hole include *Abiespollenites* sp., *Alnipollenites* sp., *Betulapollenites* sp., *Myriophyllumpollenites* sp., *Piceapollenites* sp., *Pinuspollenites* sp., Compositae, Ericaceae tetrads, Onagraceae, *Laevigatosporites* sp., and *Lycopodiumsporites* sp. Dinocysts include *Baltisphaeridium* sp. and *Spiniferites* sp. Specimens of Tasmanaceae are also present.

No calcareous nannofossils were observed in the late Pleistocene to Holocene interval.

Environment

The foraminiferal assemblages in both the shallow core hole and grab samples are indicative of middle to outer neritic environments, although the measured water depths of the grab samples are somewhat shallower (210 to 260 feet). Rare specimens of *Cassidulina delicata*, generally considered a deep-water form, also occur in the grab samples.

PLEISTOCENE

The interval from 9 to 187 feet in the shallow core hole is late Pleistocene in age, on the basis of the diatoms present. The siliceous microfossil assemblage is similar to that found in the upper 9 feet, except that the abundance of the diatom species *Biddulphia aurita* is greatly reduced, and the species *Coscinodiscus radiatus*, *Navicula optima*, *Fragilariopsis* sp., *Rhizosolenia styliformis*, and *Roperia tesselata* appear. The highest occurrence of *Thalassiosira nidulus* is at 145 feet. The radiolarian *Dictyophimus criciae* is present in one sample. Pollen and spore populations are similar to those in the upper 9 feet. The most noticeable change in the assemblage is the addition of *Acerpollenites* sp., *Castaneapollenites* sp., *Ilexpollenites* sp., *Juglanspollenites* sp., *Liquidambarpollenites* sp., and *Quercuspollenites* sp. in the interval between 46 and 116 feet. Below 116 feet, these forms are again scarce or absent. Other palynomorphs present are rare specimens of the dinocyst *Spiniferites* sp. and specimens of Tasmanaceae.

One non-age-diagnostic calcareous nannofossil, *Coccolithus pelagicus*, was seen at 10 feet. Foraminiferal species present include most of those seen in the Holocene section from 0 to 9 feet, as well as *Bolivina decussata*, *Bolivina pacifia*, *Buccella frigida*, *Buccella* cf. *B. tenerrima*, *Buliminella elegantissima*, *Cassidulina minuta*, *Dentalina* cf. *D. baggi*, *Elphidium bartletti*, *Elphidium* cf. *E. discoidale*, *Protoelphidium orbiculare*, *Globigerina bulloides*, *Globigerina parabulloides*, *Globigerina quinqueloba*, *Neogloboquadrina pachyderma*, *Nonionella miocenica?*, and *Virgulinella bramletti*.

There is no paleontologic information from the interval between 167 and 187 feet.

The section from 187 feet to the base of the core is middle Pleistocene in age, on the basis of the highest occurrence of the diatom *Rhizosolenia curvirostris* at 187 feet. The remainder of the siliceous microfossil population is similar to that observed in the late Pleistocene, with the exception of the silicoflagellate Distephanus octonarius, which does not appear above 195 feet, and frequent occurrence of the diatom Denticulopsis seminae var. fossilis, which does not occur above 226 feet.

Pollen and spore assemblages are similar to the late Pleistocene assemblages. The only dinocyst present is Baltisphaeridum sp. at 226 feet.

No calcareous nannofossils were observed in this interval.

The foraminiferal assemblage is similar to that of the late Pleistocene, with the addition of Cibicides cf. C. perlucidus and Quinqueloculina seminulum.

Environment

The Foraminifera indicate inner to middle neritic paleodepths from 9 to 46 feet and middle to outer neritic paleodepths from 46 to 167 feet. Below the data gap (167 to 187 feet) the Foraminifera indicate continued middle to outer neritic conditions to 236 feet.

The pollen assemblage from 9 to 46 feet indicates cool conditions. Between 46 and 116 feet a slight late Pleistocene (interglacial?) warming trend is indicated, with a return to cool conditions from 116 to 167 feet. The pollen indicates another slight (interglacial?) warming trend from 195 to 217 feet, followed by a cooling trend to 236 feet.

Because the ocean bottom was at a measured depth of 540 feet in the No. 1 well, the 236 feet of sediment in the shallow core hole corresponds to the measured interval of 540 to 776 feet in the well. The equivalent well depths for intervals in the core hole are as follows: the Holocene section corresponds to the interval from 540 to 549 feet; the late Pleistocene extends from 549 to 727 feet, with an apparent slight warming trend from 586 to 656 feet; the basal or middle Pleistocene part of the core hole corresponds to well depths of 727 to 776 feet, with another apparent slight warming trend from 735 to 757 feet.

There are no biostratigraphic data available from the base of the shallow core hole to the highest well sample at 1600 feet. The interval from 776 to 1600 feet in the well is therefore referred to as Pliocene-Pleistocene in age.

PLIOCENE

The first sample recovered was at a measured depth of 1600 feet. Analysis of the microfossils present, particularly diatoms, indicates that from this sample to 3600 feet the sediments are Pliocene in age. There are problems in defining the diatom biostratigraphy because of mixing and reworking of older diatoms, along with possible reworking of Pliocene forms. Some of this may be related to uplift and erosion of Tertiary sediments (principally Miocene) somewhere in the area (St. George Arch?, Alaska Peninsula?) during the Pliocene. Geochemical evidence for the presence of reworked materials in sediments above

3600 feet supports this interpetation. A further complication is downhole caving of diatom-bearing sediments, which was probably aggravated in the upper parts of the well by very high rates of drilling. There are scattered occurrences of Pleistocene diatoms in the Pliocene section, and some Pliocene forms appear to have been caved down into the Miocene section of the well. Despite these problems, a zonation of the Pliocene and Miocene was made following the zones established by Barron (1980). Several key diatom species are missing and some appear to be out of place, so that a complete zonation was not possible. Data from the consultants' more recent experience regarding the ranges of less diagnostic diatom species in the Bering Sea were utilized (Biostratigraphics, 1982).

The interval from 1600 to 1780 feet is probably late Pliocene in age, possibly part of the *Denticulopsis seminae* var. *fossilis* Zone. This age assignment is based on several diagnostic forms that are present in the top sample, including *Denticulopsis seminae* var. *fossilis*, *Stephanopyxis horridus*, *Thalassiosira nidulus*, *Thalassiosira antiqua*, and *Thalassiosira gravida*. Also present are *Actinocyclus* cf. *A. oculatus* and *Rhaphoneis sachalinensis*. Other siliceous microfossils include the silicoflagellate *Distephanus speculum* and the ebridian *Ammodochium rectangulare*.

The interval from 1780 to 2109 feet is probably early late Pliocene, possibly in the *Denticulopsis seminae* var. *fossilis* - *Denticulopsis kamtschatica* Zone. The top of this zone is defined here by the highest occurrence of frequent *Denticulopsis kamtschatica* (1780 feet). The base is defined by the lowest occurrence of *Denticulopsis seminae* var. *fossilis* in conjunction with the highest occurrence of *Cladogramma californica* at 2109 feet (SWC). Other siliceous microfossils present include those occurring in the overlying interval, along with the silicoflagellate *Distephanus speculum elongatus*, the ebridian *Ebriopsis antiqua*, and the radiolarians *Spongodiscus* sp. and *Sphaeropyle robusta*.

From 2109 to 3600 feet the diatom stratigraphy is difficult to determine because of caving and reworking. The lowest common occurrence of *Thalassiosira usatchevii*, indicative of earliest Pliocene, is in the sidewall core at 3500 feet. The base of the Pliocene is tentatively placed at 3600 feet, based on silicoflagellate occurrences. The interval from 2109 to 3600 feet is assigned to the lower Pliocene *Denticula kamtschatica* b and c Subzones.

The silicoflagellate assemblage is similar to that of the late Pliocene, but also contains *Distephanus boliviensis jimlingii*. *Distephanus* cf. *D. minutus*, which first appears in the early Pliocene or latest Miocene, occurs at 3600 feet (SWC) and marks the lowest probable Pliocene in the well. Additional siliceous taxa in the interval include the ebridians *Ebriopsis crenulata* and *Parathranium tenuipes*. The Radiolaria present are similar to those of the late Pliocene, with the addition of *?Prunopyle* sp.

Foraminifera in the upper part of the late Pliocene section (1600 to 1780 feet) include *Bolivina* cf. *B. numerosa*, *Buccella tenerrima*, *Cassidulina californica*, *Cassidulina minuta*, *Cassidulina yabei*, *Cibicides* cf. *C. perlucidus*, *Dentalina* cf. *D. baggi*, *Elphidium bartletti*, *Elphidium clavatum*, *Elphidium* cf. *E. discoidale*, *Elphidium incertum*, *Protoelphidium orbiculare*, *Epistominella* bradyana, Epistominella exigua, Epistominella cf. E. pacifica, Glandulina laevigata, Melonis aff. M. pompilioides, Nonionella labradorica, Pseudoglandulina inflata, Trifarina angulosa, Uvigerina cushmani, Uvigerina hootsi, and Virgulina bramletti, along with the planktonic species Globigerina aff. G. nepenthes and Globigerina parabulloides.

The early late Pliocene (1780 to 2109 feet) contains a similar assemblage, with the addition of Buccella mansfieldi, Buccella frigida, Cassidulina nakamurai, Marginulina sp., Plectofrondicularia sp., Rotalia cf. R. garveyensis, Trifarina fluens, Uvigerina juncea, and Uvigerina cf. U. modeloensis. Virgulinella pertusa is present below 1900 feet. Additional planktonic species are Globigerina cf. G. minutissma and Globigerina praebulloides.

Most of the above species are present in the lower part of the Pliocene section (2109 to 3600 feet). Additional species include Astacolus cf. A. planatus, Bolivina pacifica?, Cassidulina cf. C. laevigata, Cassidulina cf. C. punctata, Cassidulina cf. C. teretis, Cibicides cf. C. perlucidus, Cibicides cf. C. suppressus, Eilohedra levicula, Fissurina sp., Haplophragmoides sp., Haplophragmoides cf. H. crassus, Haplophragmoides deformes, Haplophragmoides cf. H. trulissata, Nodosaria sp., and Nonionella digitata. Anomalina glabrata is present below 3100 feet. Species indicative of deeper water deposition include Bolivina decussata, Nonion cf. N. barleeanum, Pullenia salisburyi, Sigmoilina sp., Textularia sp., and Uvigerina cf. U. peregrina. Additional planktonic species include Globigerina bulloides, Globigerina cf. G. quadrilatera, Globigerina quinqueloba, Globigerina cf. G. umbilicata, Globoquadrina cf. G. eggeri, Globorotalia cf. G. acostaensis, Globorotalia cf. G. minutissima, Globorotalia cf. G. pseudopima, and Neogloboquadrina cf. N. pachyderma. All of the planktonic species present from 1600 to 3600 feet are known to occur in the Pliocene, with the possible exception of Globigerina praebulloides, which may not have ranged higher than the late Miocene. This form may intergrade morphologically with Globigerina bulloides.

Dinocysts present in the Pliocene section include Baltisphaeridium spp. and Operculodinim sp. (2?), a form previously observed in the Pliocene of southern Alaska. Several specimens of reworked older species are present throughout the Pliocene section. Tasmanaceae are also present.

The Pliocene pollen and spore assemblage is dominated by land-derived forms, including Alnipollenites sp., Tsugaepollenites sp., Betulaceae, Laevigatosporites, and Sphagnumsporites. Less common but persistent are Boisduvaliapollenites sp., Pterocaryapollenites sp., Compositae, Ericaceae, Malvaceae, and Onagraceae, with sporadic Caryapollenites sp., Juglanspollenites sp., Nyssapollenites sp., Rugaepollis sp., Tiliaepollenites sp., Ulmipollenites sp., Caryophyllaceae, and Polemoniacae. Pediastriumsporites sp., a fresh-water algal spore, is also present. Juglanspollenites sp. and Ericaceae are more common below 3490 feet.

Calcareous nannofossils are very scarce in the Pliocene interval, with only two non-age diagnostic species, Coccolithus dormicoides and Coccolithus pelagicus, appearing below 3000 feet.

Environment

The foraminiferal populations present indicate middle to outer neritic conditions from 1600 to 1720 feet. From 1720 to 3070 feet, paleoenvironments are mostly outer neritic to upper bathyal, with middle to lower bathyal conditions present between 2200 and 2380 feet. Upper to middle bathyal conditions are indicated from 3070 feet to the base of the Pliocene at 3600 feet.

The pollen and spore assemblages indicate temperate conditions throughout the Pliocene interval. Abundance-weighted percentages of warm-water versus cold-water diatoms (modified from Schrader, 1973) also indicate relatively warm conditions (possibly temperate) with sporadic, short cooler intervals.

MIOCENE

The sediments between 3600 and 5370 feet are of probable Miocene age. The zonation of the upper part of this interval, based primarily on the diatom zonation of Barron (1980), is provisional. The base of the interval is defined by calcareous nannofossil occurrences.

The interval from 3600 to 3716 feet (SWC) is tentatively assigned to the *Denticulopsis kamtschatica* Subzone a (late late Miocene) on the basis of the lowest sidewall occurrence of *Denticulopsis kamtschatica*. Other siliceous microfossils in this interval include the silicoflagellates *Dictyocha pseudofibula* and *Distephanus speculum*, the ebridians *Ebriopsis antiqua*, *Ebriopsis crenulata*, *Ammodochium rectangulare*, and *Parathranium tenuipes*, and the radiolarians *Spongodiscus* sp. and *Sphaeropyle* cf. *S. robusta*.

The interval from 3716 (SWC) to 4120 feet is assigned to the *Denticulopsis hustedtii* Subzone b (middle late Miocene). The base of this interval is defined by the highest occurrence of *Coscinodiscus yabei*. The assemblage of silicoflagellates and ebridians is similar to that of the overlying interval. Additional silicoflagellates include *Distephanus boliviensis major*, *Dictyocha* sp., and *Mesocena circulus*. Additional Radiolaria include *Larnacantha* sp., *Phacodiscus* sp., and *Spongodiscus* sp.

The interval from 4120 to 4390 feet is possible middle late Miocene in age (*Denticulopsis hustedtii* Subzone a). This assessment is made on the basis of the highest occurrence of continuous *Denticulopsis dimorpha* at 4390 feet. (The lower boundary of this zone may be as high as 4210 feet, the highest isolated ditch sample occurrence of *Denticulopsis lauta*, but it is likely that this higher sample contains reworked material.) Siliceous microfossils present in addition to diatoms are similar to those of the 3716 to 4120 foot interval, but are joined by an ebridian, *Praebriopsis* cf. *P. fallax*, and the radiolarian *Xiphospira circularis*.

The section from 4390 to 4600 feet is placed in the upper part (Subzone d) of the *Denticulopsis hustedtii* - *Denticulopsis lauta* Zone (early late Miocene). Present in this interval are *Actinocyclus ingens*, *Denticulopsis dimorpha*, *Denticulopsis hustedtii*, and *Denticulopsis lauta*. The assemblage is similar to that observed from 4120 to 4390 feet, with the addition of the silicoflagellates Corbisema triacantha, Distephanus crux, Distephanus cf. D. hannai, Distephanus minutus, Distephanus speculum cf. pentagonus, and Distephanus speculum cf. pseudocrux, along with the ebridian Hermesinum cf. H. geminum, and the radiolarians Spongodiscus gigas and Theocorys cf. T. redondoensis.

The interval from 4600 to 5370 feet is early to middle Miocene in age. Well-preserved siliceous microfossils are scarce in this interval, possibly because of destructive diagenetic changes, or possibly marking a disconformable (paraconformable?) surface. The sidewall cores below 4600 feet are barren or contain poorly preserved diatoms, and ditch samples below this depth appear to contain a high proportion of caved material. Diatom zonation below 4600 feet is therefore very tentative. The lowest occurrence of infrequent Denticulopsis hustedtii at 4840 feet may mark the base of the Denticulopsis hustedtii - Denticulopsis lauta Zone (earliest middle Miocene). The lowest occurrence of infrequent Denticulopsis lauta at 5100 feet may indicate the base of the Denticulopsis lauta Zone (late early Miocene), and the lowest occurrence of infrequent Actinocyclus ingens at 5190 feet may mark the base of the Actinocyclus ingens Zone (middle early Miocene).

In the late Miocene section (3600 to 4600 feet), calcareous nannofossils are relatively sparse. In the interval from 3600 to 3716 (SWC) feet, species present include Coccolithus doronicoides, Coccolithus pelagicus, and Gephyrocapsa cf. G. caribbeanica. The interval from 3716 to 4120 feet contains a similar assemblage, with the addition of Reticulofenestra pseudoumbilica. Similar calcareous nannofossils are also present from 4120 to 4390 feet, with the addition of Cyclicargolithus sp. and Braarudosphaera bigelowi. Cyclococcolithina leptopora appears in the 4390 to 4600 foot interval. From 4600 to 5370 feet (early to middle Miocene), the calcareous nannoplankton assemblage is similar to that seen in the late Miocene section, with the addition of Dictyococcites sp.

The Miocene pollen and spore assemblage is similar to the Pliocene assemblage, but there is an increase in Pterocaryapollenites sp. and a more consistent presence of Ulmipollenites sp. and Nyssapollenites sp.

Dinocysts increase in diversity in the Miocene section (3600 to 5370 feet). Lejeunia hyalina-fallax, Lejeunia paratenella var., Leptodinium sp., Nematosphaeropsis cf. N. balcombiana, Spiniferites spp., and Spiniferites cingulatus all appear in this interval. Also present are Cordosphaeridium inodes and specimens of the Desmidiaceae, an order of flagellate green algae. Reworked Mesozoic dinocysts are also relatively common elements.

The foraminiferal assemblage from 3600 to 3716 feet (possible latest Miocene) is similar to the Pliocene fauna. It includes Anomalina glabrata, Bolivina cf. B. numerosa, Cassidulina californica, Cassidulina aff. C. laevigata, Cassidulina laticamerata, Cassidulina minuta, Cibicides cf. C. perlucidus, Cyclammina pacifica, Elphidium bartletti, Epistominella bradyana, Epistominella pacifica, Haplophragmoides deformes, Melonis pompilioides, Trifarina cf. T. angulosa, Uvigerina cf. U. cushmani, and Uvigerina cf. U. hootsi.

A similar assemblage occurs in the 3716 to 4120 foot interval, where these species are joined by *Buccella* cf. *B. tenerrima*, *Cassidulina* cf. *C. nakamurai*, *Cassidulina* cf. *C. norvangi*, *Cassidulina* cf. *C. yabei*, *Cibicides* cf. *C. mckennai*, *Dentalina* sp., *Epistominella exigua*, *Epistominella* cf. *E. parva*, *Nonion* cf. *N. barleeanum*, *Rotalia* cf. *R. beccarii*, *Uvigerina* cf. *U. hispidocostata*, *Uvigerina* cf. *U. peregrina*, *Valvulineria araucana*, *Virgulina* sp., and *Virgulinella pertusa*.

A similar assemblage appears in the 4120 to 4390 foot interval. Additional Foraminifera present include *Buccella frigida*, *Fissurina* sp., *Haplophragmoides* spp., *Sphaeroidina* sp., and *Uvigerina* cf. *U. senticosa*.

A similar but sparse foraminiferal fauna occurs from 4390 to 4600 feet, with *Quinqueloculina* sp. being the only new form observed.

Foraminifera are more frequent in the 4600 to 5370 foot interval (early to middle Miocene), where the assemblage also contains *Cassidulina* cf. *C. limbata*, *Elphidium* sp., *Nonion barleeanum inflatum*, *Nonionella* sp., *Pullenia* sp., *Trifarina* cf. *T. fluens*, *Trifarina* sp., *Uvigerina* aff. *U. montesanensis*, and *Globigerina quadrilatera*.

Environment

The foraminiferal assemblages suggest that deposition in the 3600 to 4840 foot interval took place in an upper to middle bathyal environment. From 4840 to 4980 feet, middle to lower bathyal depositional conditions are indicated, and from 4980 feet to the base of the Miocene (5370 feet), deposition took place in upper to middle bathyal depths.

The spore-pollen assemblages present indicate a warmer, more temperate climate in the Miocene than in the overlying Pliocene. Diatom data indicate that except for an uppermost Miocene cool interval (3600 to 3670 feet), conditions were generally warm, possibly warm-temperate. Indicated warming reaches a maximum between 4030 and 4120 feet.

OLIGOCENE

Sediments of probable Oligocene age are present from 5370 to 8410 feet. The top of the Oligocene and the subdivision of that interval into late and early portions are based on calcareous nannofossil data. The base of the Oligocene was based on the first occurrences of Eocene dinoflagellates.

The top of the late Oligocene is defined by the first occurrence of the calcareous nannofossils *Cyclicargolithus floridanus* and *Dictyococcites* cf. *D. scrippsae* at 5370 feet, and by *Dictyococcites* cf. *D. bisectus* at 5374 feet (SWC). The base of the late Oligocene is placed at 6810 feet. Other species present in the interval include *Coccolithus doronicoides*, *Coccolithus* cf. *C. miopelagicus*, *Coccolithus pelagicus*, *Cyclicargolithus* sp., *Cyclococcolithus* sp., *Cyclococcolithina* cf. *C. neogammation*, *Dictyococcites* sp., *Discolithina* cf. *D. vagintiforata*, *Helicopontosphaera* sp., *Reticulofenestra* sp., and *Reticulofenestra pseudoumbilica*.

Possible early Oligocene sediments are present from 6810 to 8410 feet. The top of this interval is indicated by the first occurrence of a large calcareous nannofossil, Reticulofenestra sp., which strongly resembles Reticulofenestra umbilica. Additional species include Discolithina sp., Helicopontisphaera cf. H. intermedia, and Sphenolithus sp. Calcareous nannofossils are sparse below 8070 feet.

Dinocysts show a significant increase in diversity and abundance in the Oligocene interval. Several reworked Jurassic forms are also present between 6750 and 7980 feet. Indigenous species in the late Oligocene (5370 to 6810 feet) include Achomosphaera alcicornu, Deflandria spp. (spiny forms), Nematosphaeropsis sp., Operculodinium centrocarpum, Paralecaniella indentata, Spiniferites crassipellis, Thalassiphora cf. T. velata, Tuberculodinium rosignole, and Tuberculodinium vancampoae. Additional species appearing in the early Oligocene (6810 to 8410 feet) include Cyclonephelium exuberans-pastielsi and Deflandria cf. D. wetzelii.

The Oligocene pollen assemblage includes more consistent occurrences of Caryapollenites sp., Ulmipollenites sp., and possibly Tiliaepollenites sp. There are sporadic occurrences of Acerpollenites sp. and Liquidambarpollenites sp. The Compositae are absent in this interval, and Malvaciae are very rare.

The Oligocene foraminiferal fauna is somewhat more diverse than that of the overlying Miocene section. Species present in the late Oligocene interval include Anomalina glabrata, Bathysiphon sp., Bolivina aff. B. numerosa, Bolivina sp., Buccella sp., Buccella frigida, Buccella cf. B. mansfieldi oregonense, Buccella cf. B. tenerrima, Cassidulina cf. C. carinata, Cassidulina crassipunctata, Cassidulina cf. C. globosa, Cassidulina cf. C. laevigata, Cassidulina cf. C. laticamerata, Cassidulina aff. C. minuta, Cibicides sp., Cibicides aff. C. evolutus, Cibicides aff. C. perlucidus, Cyclammina pacifica, Dentalina sp., Elphidium cf. E. bartletti, Elphidium cf. E. clavatum, Elphidium cf. E. subnodosum, Elphidiella sp., Epistominella bradyana, Fissurina sp., Globobulimina sp., Gyroidina sp., Haplophragmoides sp., Haplophragmoides aff. H. excavata, Lagena sp., Marginulina sp., Nonion barleeanum, Nonionella sp., Polymorphina? sp., Polymorphina cf. P. ligua, Pseudoglandulina? sp., Pseudoglandulina inflata, Pullenia sp., Pyrgo sp., Quinqueloculina sp., Robertina sp., Robulus sp., Rotalia cf. R. beccarii, Triloculina sp., Uvigerina aff. U. cushmani, Uvigerina aff. U. hispidocostata, Uvigerina aff. U. hootsi, Uvigerina aff. U. modeloensis, Uvigerina aff. U. montesanensis, Uvigerina aff. U. subperegrina, Valvulineria menloensis, Virgulina? sp., and Globigerina sp. The first occurrence of Gaudryina alazanensis, which has been considered to be Oligocene or older in the Pacific Northwest, is at 5400 feet.

The early Oligocene foraminiferal fauna is similar to that of the late Oligocene, with the addition of Cassidulina aff. C. limbata, Cassidulina aff. C. tortuosa, Cibicides aff. C. fletcheri, Cyclogyra? sp., Elphidium sp., Gaudryina sp., Melonis sp. (large), Melonis pompilioides, Nonion sp., Rosalina? sp., and Textularia sp. The deep-water form Gyroidina cf. G. soldani appears at 7879 feet (SWC).

Environment

The Foraminifera in the Oligocene section indicate that conditions from 5370 to 6960 feet were probably upper to middle bathyal. Foraminifera are rare from 5940 to 6510 feet, but infrequent to abundant dinocysts and rare calcareous nannofossils indicate open marine conditions. Paleoenvironments from 6960 to 7140 feet are outer neritic to upper bathyal. Probable upper to middle bathyal paleodepths are indicated from 7140 to 8310 feet. Although Foraminifera are rare from 7290 to 7950 feet and from 8010 to 8310 feet, infrequent but diverse dinocyst assemblages in these intervals indicate open marine conditions. An interval of conglomeratic sands between 7720 and 7870 feet, including a poorly sorted conglomerate from 7800 to 7830 feet, may indicate slump conditions, shallow-water deposition, or an unconformity. For the remainder of the Oligocene section, inner to middle neritic depths are indicated. Conclusions concerning paleoenvironments from 5940 to 6510 feet and from 7290 to 7950 feet are provisional because of the sparse foraminiferal faunas.

The Oligocene pollen and spore assemblage suggests a temperate to warm-temperate climate.

EOCENE

Sediments of Eocene age are present from 8410 to 10,380 feet. The top of the Eocene is based on the first occurrence of an age-diagnostic dinocyst assemblage. The base of the interval is placed at the top of a sequence of basaltic rocks of undefined age.

A diverse assemblage of dinocysts occurs in the Eocene section of the well. The absence of older dinocysts from this assemblage indicates that it is no older than middle Eocene. Dinoflagellate species include *Adnatosphaeridium reticulense*, *Comasphaeridium* cf. *C. cometes*, *Cordosphaeridium* sp., *Cordosphaeridium fibrospinosum*, *Cordosphaeridium* cf. *C. biarmatum*, *?Impletosphaeridium* cf. *I. transfodum*, *?Lanternosphaeridium* sp., *Phthanoperidinium amoenum*, *Phthanoperidinium conatum*, *Spiniferites* cf. *S. incertus*, and *Wetzeliella articulata*.

The section can be provisionally subdivided into late and late middle Eocene on the basis of calcareous nannofossil distributions. A very large form of *Braarudosphaera bigelowi* at 8790 feet and *Discolithina* cf. *D. plana* at 9608 feet support a late Eocene age for the upper part of the interval. Other species present include ?*Coccolithus* sp., *Cyclicargolithus* sp., *Cyclicargolithus* cf. *C. floridanus*, *Dictyococcites* cf. *D. scrippsae*, ?*Dictyococcites* sp., *Helicopontosphaera* sp., *Helicopontosphaera* cf. *H. intermedia*, *Reticulofenestra* sp., and ?*Sphenolithys* sp. The top of the middle Eocene is placed at 10,050 feet, coinciding with the appearance of *Transversopontis* sp. and *Transversopontis* cf. *T. pulcher*. The latter species, along with a variant of *Braarudosphaera bigelowi*, suggests a late middle Eocene age.

Both diversity and abundance decrease in the Eocene pollen and spore assemblage. Forms that are present include rare *Alnipollenites* sp., *Caryapollenites* sp., *Momipites* sp., Betulaceae, and Pinaceae. Polypodiaceae are rare in the late Eocene and rare to frequent in the middle Eocene.

The dominant lithology from 10,280 to 10,380 feet is volcanic pebble conglomerate. Microfossils of Eocene age were recovered from this interval. Age and environmental interpretations below 10,280 feet should be considered provisional, however, because of possible downhole contamination.

The Foraminifera in the late Eocene part of the section include *Anomalina* cf. *A. glabrata*, *Bathysiphon* cf. *B. eocenica*, *Bolivina* aff. *B. numerosa*, *Buccella* sp., *Caucasina* sp., *Cibicides* sp., *Cribrononion* cf. *C. roemeri*, *Cyclammina pacifica*, *Elphidium* sp., *Elphidium* cf. *E. bartletti*, *Elphidiella* sp., *Glandulina* sp., *Globobulimina* sp., *Globobulimina pacifica oregonense*, *Gyroidina* sp., *Haplophragmoides* spp., *Melonis* sp. (large), *Melonis pompiliodes*, *Nonion* sp., *Nonion* aff. *N. barleeanum*, *Nonionella* sp., *Pseudoglandulina inflata*, *Pseudoglandulina* cf. *P. nallpeensis*, *Quinqueloculina* sp., and *Trochammina* sp. Abundant *Caucasina eocaenica kamchatica* appear at 9540 feet. Additional species appearing in the middle Eocene (below 10,050 feet) include *Guttulina* sp. and *Pullenia*? spp.

Environment

An inner to middle neritic environment is indicated by the foraminiferal assemblages between 8410 and 9000 feet. Several occurrences of *Melonis* sp. (large form) in this interval may indicate slightly deeper environments, however. Between 9000 and 10,380 feet, outer neritic to upper bathyal depths are indicated, with a short interval of upper to middle bathyal depths between 9450 and 9660 feet. Because the Foraminifera in the conglomerates from 10,280 to 10,380 feet may be caved, the environmental assignment for this interval is provisional. A slight difference in preservation of some of the Foraminifera from this interval, however, indicates that some are in place.

The sparse pollen assemblage does not give a clear indication of the paleoclimate, but suggests that the late to middle Eocene may have been temperate to warm-temperate. This is consistent with paleobotanical evidence from the Eocene of the Gulf of Alaska region, where plant fossil and pollen assemblages (Wolfe, 1977; Wolfe and Poore, 1982) indicate that the climate was temperate in the late Eocene and warm-temperate in the middle Eocene.

MIDDLE EOCENE OR OLDER

The interval from 10,380 to 13,771 feet consists of a sequence of nonfossiliferous basaltic rocks for which radiometric dating has thus far proved inconclusive. This interval is assigned a middle Eocene or older (indeterminate) age. The depositional environment has not yet been determined.

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 core hole 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 core hole 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 sample interval (1600 feet in the No. 1 well and 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 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.

Miocene 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 strata comprise the thickest section in the 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 well 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 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.

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 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

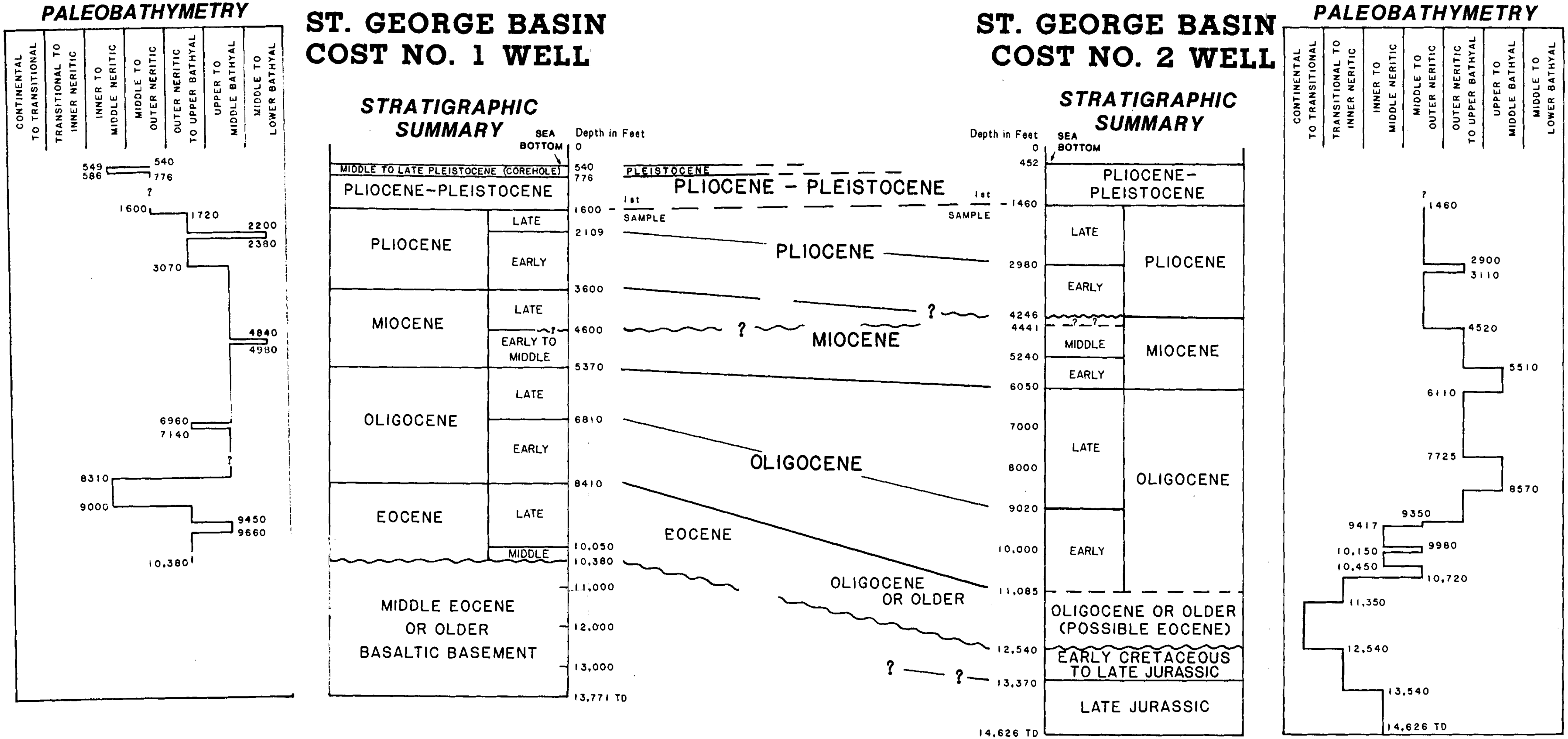
Early Cretaceous to Late Jurassic age rocks are present in the No. 2 well from 12,540 to 13,370 feet. Paleoenvironments are transitional to inner neritic. No equivalent units were encountered in the No. 1 well.

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.

ST. GEORGE BASIN COST NO. 1 WELL

ST. GEORGE BASIN COST NO. 2 WELL



LITHOLOGY AND WELL LOG INTERPRETATION

by

J. G. Bolm

The analysis of lithology and reservoir characteristics in the No. 1 well is based on examination of samples, well logs, and consultants' reports. The sample material consists of cuttings, conventional cores, and thin sections of material from sidewall and conventional cores, all of which are from below 1600 feet in the well. Well logs cover the interval from 1553 to 13,771 feet.

The well was drilled with a fresh-water mud system, and log responses were normal. The well penetrated sedimentary rocks down to 10,380 feet and volcanic rocks below that depth. Although the identification of lithology is not a problem in the sedimentary section of the well, the strata are not easily grouped into meaningful units based on lithology. The volcanic section of the well is treated as a unit and the sedimentary section is discussed in terms of biostratigraphic units. Biostratigraphic data and data pertaining to reservoir and source rock quality are presented graphically together with the gamma-ray, spontaneous potential (SP), deep resistivity, density, and sonic logs in plate 1.

PLIOCENE (1600 to 3600 feet)

The uppermost 2000 feet from which samples were obtained consists of sandstone, siltstone, and mudstone deposited in neritic and bathyal environments. The mudstone is locally sandy or pebbly, and some of the sandstone is muddy. The sandstone is very friable where it is not muddy. Many of these rocks are diatomaceous and commonly contain glauconite. The sand fraction is dominated by volcanic rock fragments, monocrystalline quartz, and less abundant plagioclase feldspar. Most of the volcanic rock fragments are holo- or hypocrystalline and of basaltic or andesitic composition. Nonvolcanic rock fragments present in the sand fraction include limestone, mudstone, slate, schist, and quartzite. A small amount of the sand fraction consists of biotite, muscovite, chlorite, hornblende, augite, diopside, epidote, garnet, zircon, chert, and iron oxide. A single grain of crossite is present in a sandstone sample from 3406 feet.

Detrital matrix is common in the sandstone. Authigenic smectitic clay and analcime are common as cements in those sandstones without abundant detrital matrix. Core 1 (fig. 14) is an extensively bioturbated, sandy, diatomaceous, glauconitic mudstone with preserved lamination and ripple lamination.

Porosity measurements of sandstone from 14 sidewall cores taken in the interval range from 34.4 to 41.9 percent. Permeabilities of these same samples range from 3.2 to 51 mD. No sandstone was recovered in core 1.

The SP log indicates about 1125 feet of porous siltstone and sandstone in the Pliocene section. These strata range from less than 5 to approximately 200 feet thick. Most of the porous beds range from 10 to 50 feet thick. Comparison of the gamma-ray log with the SP log indicates that the gamma-ray log is a reliable indicator of porous rock in this section.

The deep resistivity curve is flat. The shallow curve shows resistivities between 0.5 and 1 ohm-m greater than the deep curve. The density curve is jagged, probably in response to undercompaction of the sediments. The extreme density range over the interval is from 1.60 to 2.25 g/cm^3, but locally the difference between high and low values seldom exceeds 0.20 g/cm^3. There is a general increase in average density downward through the section. The density log indicates a minimum porosity of 26 percent for sandstone based on the highest densities recorded, but density-derived porosities exceed 40 percent for most of the porous rock delineated by the SP log. The sonic log records a gradual decrease in interval transit time from an average of 170 µs/foot at the top of the Pliocene section to an average of 142 µs/foot at the bottom. The sonic log indicates porosities of 40 percent or more for the sandstones in this section.

MIOCENE (3600 to 5370 feet)

The interval from 3600 to 5370 feet consists of interbedded mudstone, siltstone, and sandstone deposited in a bathyal environment. The sand fraction is dominated by volcanic rock fragments. Quartz and plagioclase feldspar are less abundant. Pyrite is more abundant than iron oxide below 4130 feet.

Ductile sand grains have undergone deformation by compaction wherever there is insufficient detrital matrix for cushioning. Authigenic smectitic clay and analcime are present as cements in sandstone samples without abundant detrital matrix. The glauconitic, bioturbated, muddy sandstone and weakly laminated mudstone containing fossil bivalves and well-preserved burrows seen in core 2 (fig. 15) are typical of marine shelf deposition. An attempt was made to cut core 3 from 4880 to 4921 feet, but no rock was recovered.

Porosity measurements of sandstone from 20 sidewall cores range from 26.7 to 44.7 percent. Permeabilities of these same samples range from 2.2 to 128 mD. The average porosity for 14 sandstone samples from core 2 is 37 percent. The average permeability of these same samples is 78 mD.

The SP log indicates about 775 feet of porous sandstone and siltstone in 5- to 90-foot-thick beds. Most of these beds are under 30 feet thick. Comparison of the gamma-ray and SP logs shows that the gamma-ray log is a reliable indicator of porous rock above 4870 feet, but not below that depth. This probably reflects a greater abundance of clay-rich matrix in the bottom part of the interval. The deep resistivity curve is flat. The shallow resistivity curve displays resistivities between 0.5 and 1 ohm-m greater than the deep curve. The density log records a general increase in average density with depth from about 1.8 to about 2.2 g/cm^3, with an extreme density range of 1.76 to 2.43 g/cm^3. The range of average densities indicates that sandstone porosities should generally exceed 28 percent in this interval. The sonic log records a general decrease in average interval transit time from 150 to 120 µs/foot downward. The sonic log indicates that sandstone porosities decrease from 44 to 30 percent downward through the interval.

OLIGOCENE (5370 to 8410 feet)

The interval from 5370 to 8410 feet consists of interbedded sandstone, siltstone, and mudstone. Conglomerate is present from 7710 to 7860 feet, and the sandstone above the conglomerate is pebbly up to 7600 feet. These rocks were deposited in neritic to bathyal environments. The sand fraction is compositionally similar to that of the overlying Miocene section, but volcanic rock fragments are even more dominant over quartz and feldspar. Ductile grains in the sandstone have been deformed by compaction wherever there is insufficient detrital matrix for cushioning. Intergranular pore spaces are visible in some thin sections of sandstone. Calcite, smectitic clay, and analcime are present as authigenic cements. Cores 4, 5, 6, and 7 from this interval are described in figures 16, 17, 18, and 19. Some of the glauconitic sandstone contains well-preserved burrows and fossil material indicative of marine shelf deposition. The thin, pebbly layers in core 7 are interpreted as material deposited by currents generated in major storms.

Porosity measurements of sandstone from 63 sidewall cores from this interval range from 16.7 to 34.2 percent. Permeabilities of unfractured samples range from 1.5 to 732 mD. Permeabilities of most samples are less than 100 mD, and most of the samples with permeabilities greater than 100 mD are from between 5900 and 6500 feet. Average porosities of sandstone samples from conventional cores range from 21.1 to 27.6 percent. There is a clearly defined decrease of porosity with depth. Average permeabilities of sandstone samples from conventional cores range from 0.66 to 127 mD. There is no discernable relationship between average permeability and depth or average porosity.

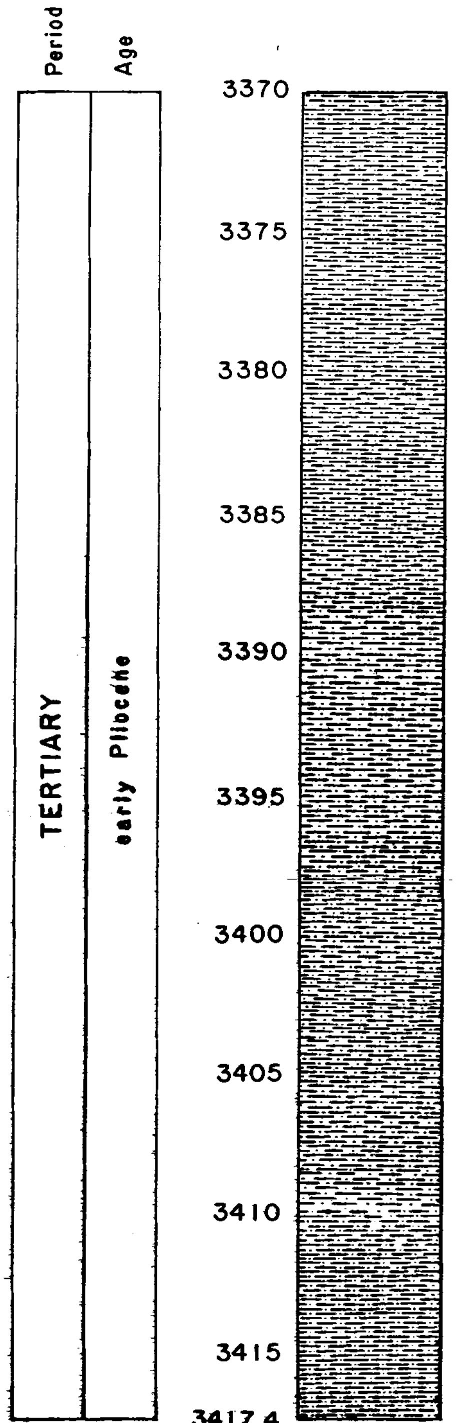
The SP log indicates about 1650 feet of porous sandstone in 5- to 350-foot-thick beds. Twelve hundred feet of this sandstone is in beds more than 150 feet thick. Comparison of the SP and gamma-ray logs indicates that the gamma-ray log is not a reliable indicator of porous rock in this interval. The deep resistivity curve is generally flat through the interval; the shallow curve shows resistivities between 0.5 and 2 ohm-m greater than the deep curve. The density curve is moderately irregular above 7950 feet, where the caliper log shows the presence of numerous washouts. Average densities from the parts of the upper portion of the interval that were not affected by caving range from 2.1 to 2.2 g/cm^3. In the bottom portion of the interval, where caving was not a problem, densities generally increase downward from about 2.25 g/cm^3 at 7950 feet to 2.35 g/cm^3 at the bottom of the interval. The density log suggests that sandstone porosities may be as high as 35 percent in the upper part of the interval, but may be expected to decrease downward to an average value of about 20 percent near the bottom of the interval. The sonic log was not as greatly affected by caving as was the density log. A general decrease in average transit time from 123 to 100 μs/foot is recorded on the sonic log. This indicates a generally downward-decreasing range of sandstone porosities from about 32 percent near the top of the interval to about 24 percent near the bottom.

EOCENE (8410 to 10,380 feet)

The interval from 8410 to 10,380 feet consists of siltstone, sandstone, mudstone, and conglomerate deposited in neritic to bathyal environments. Minor amounts of limestone in cuttings from 9240 to 9600 feet probably represent calcareous concretions. Conglomerate is the predominant lithology in the bottom 100 feet of the interval, and the sandstone is pebbly from 10,100 feet down to the top of the conglomerate. The sand fraction is compositionally similar to that of the Oligocene section above. Volcanic rock fragments predominate over quartz and feldspar. The feldspar is predominantly plagioclase. Ductile sandstone grains have been deformed by compaction wherever sufficient detrital matrix for cushioning is not present, and intergranular spaces not occupied by matrix are filled with authigenic smectitic clay, analcime, or zeolite cement. Cores 8, 9, and 10 from this interval are described in figures 20, 21, and 22. The burrowed, glauconitic sandstone seen in core 8 is indicative of deposition in a marine shelf environment. The disorganized conglomerate seen in cores 9 and 10 may represent channel deposition in a submarine valley or marine shelf deposition.

Porosity measurements of sandstone from 15 sidewall cores range from 20.3 to 27.9 percent. Permeabilities for these same samples range from 1.8 to 57 mD. Average porosities of sandstone samples from conventional cores range from 11.9 to 17.4 percent and decrease downward through the interval. Average permeabilities for sandstone samples from conventional cores range from 0.07 to 17 mD. There is no discernable relationship between average permeability and depth or average porosity.

The SP log indicates about 450 feet of porous sandstone and conglomerate in 5- to 100-foot-thick beds. Comparison of the SP and gamma-ray logs indicates that the gamma-ray log is a reliable indicator of porous rock in this interval. The deep resistivity curve is flat with local variations of up to 1 ohm-m. The shallow curve follows the deep curve and displays from 0 to 1 ohm-m greater resistivity. Extensive caving makes the density log unreliable in the bottom 200 feet of the interval. In the upper part of the interval, densities generally range from 2.35 to 2.4 g/cm^3 and indicate sandstone porosities of 17 to 20 percent. The sonic log records a general downward decrease in interval transit time from about 100 μs/foot down to 90 μs/foot and indicates sandstone porosities of 18 to 24 percent.



<u>Mudstone</u>, olive-gray (5 Y 4/1), finely mottled, scattered very fine to fine sand grains, local iron oxide stains, diatomaceous locally, glauconitic; massive to weakly laminated or ripple laminated.

Porosity * (Percent)	Permeability * (Millidarcies)	Random Vitrinite Reflectance (Percent)
33.6	0.48	
		0.49
33	.59	
33.4	.41	
32.8	.47	
36.5	.56	
24.7	.09	
30.7	.27	
31.9	1.5	
31.8	1.4	
36.1	.33	
30.5	.31	
31.6	.22	
31.6	.25	
32.3	.66	
32.3	2.5	
31.6	2.8	
32.2	.59	
30.8	.28	
32.1	.22	
32.6	3.4	
34.9	3.4	
33.2	.39	
33.6	.91	
33.2	3.6	
34.7	.43	
33.6	.29	
33.6	.41	
35.7	.45	
34.8	.83	
33.8	1.4	
35.9	.29	
42.5	.25	
43	.36	
44.5	3.0	
41.6	5.6	
40.8	1.5	
42.1	6.9	
47.1	4.6	
42.4	2.0	
42.2	2.	
43.9	3.0	

Explanation

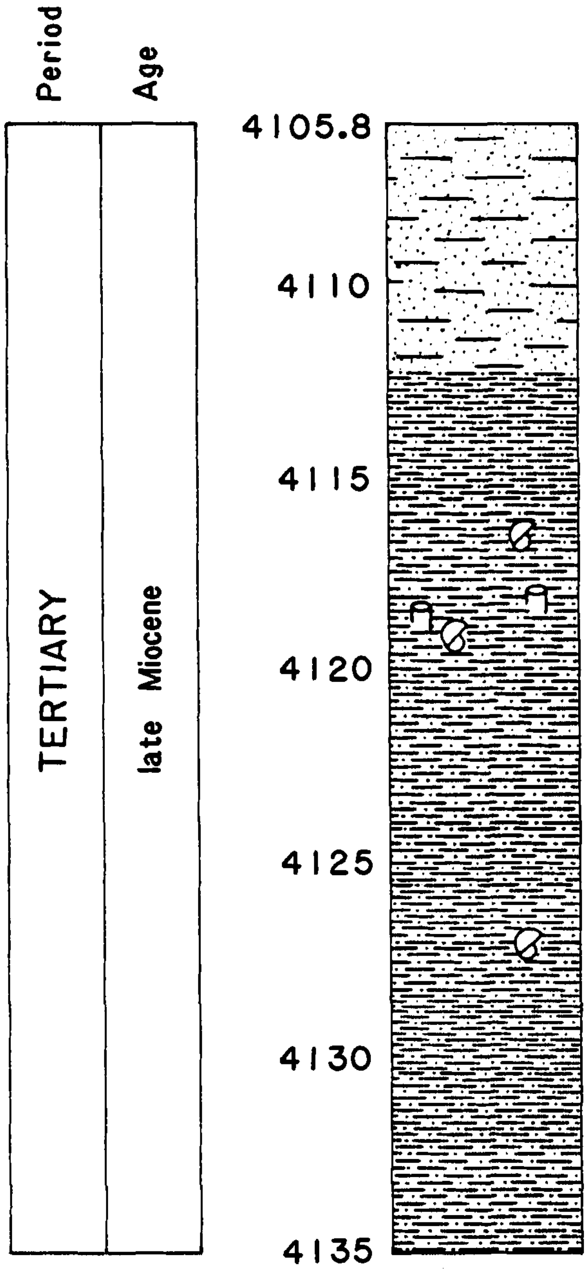
- ⋂ - burrow
- ⊘ - bivalve
- ๑ - gastropod
- ⋏ - cross-bedding

FIGURE 14.

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

Porosity and permeability data from Core Laboratories Inc.
Random vitrinite reflectance data from Atlantic Richfield Co.

* ADDITIONAL DATA IN TABLE 4



Sandstone, olive-gray (5 Y 4/1), mottled, very fine grained, very muddy, glauconitic, bioturbated; bottom 2 feet gradational to unit below.

Mudstone, olive-gray (5 Y 4/1), mottled, whole bivalves and bivalve fragments, abundant coaly and carbonaceous debris; massive to weakly laminated; well-preserved burrows locally.

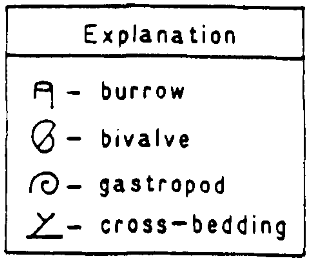
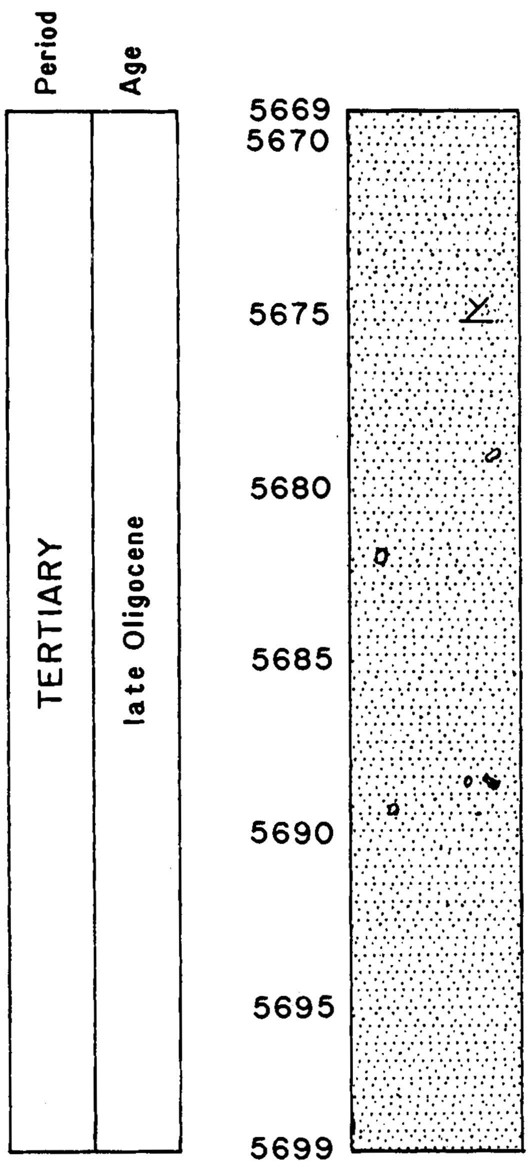


Figure 15.
Description of conventional core 2,
St. George Basin COST No. 1 well.

Porosity and permeability data from Core Laboratories, Inc.
Random vitrinite reflectance data from Atlantic Richfield Co.
* Additional data in table 4.

Porosity * (Percent)	Permeability * (Millidarcies)	Random Vitrinite Reflectance (Percent)
36.7	79	
36.5	24	
37.0	136	
37.0	126	
36.0	84	
38.0	10	
39.0	2.5	
40.3	5.6	
39.1	.71	
43.4	.57	
43.3	.63	
41.7	2.0	
42.0	.78	
42.5	3.4	
43.6	.50	
43.1	.63	
44.1	.71	
43.5	.98	
43.9	.60	
43.2	.07	
39.7	2.8	
37.1	6.0	
39.0	3.1	
42.3	1.7	
42.4	10	
43.0	.50	
43.3	.29	
43.0	.33	0.54
43.5	.53	
44.1	.29	



Sandstone, olive-black (5 Y 2/1), very fine grained, glauconitic; scattered bivalve fragments, coaly debris, and volcanic pebbles; massive with locally well-developed ripple lamination; small laminae of coarse sand lie along many cross-stratification slip faces.

Porosity * (Percent)	Permeability * (Millidarcies)
26.3	0.88
26.3	.39
25.0	.12
27.3	.79
25.9	.28
29.3	.94
25.5	.14
24.7	.28
25.0	.91
25.8	.23
24.3	.11
26.8	.29
28.6	.45
26.4	.78
25.8	1.3
26.1	1.3
27.4	1.9
25.7	1.7
24.4	1.3
26.2	14
26.1	18
28.0	35
27.3	17
31.7	84
29.9	63
28.5	29
30.2	68
28.0	36
31.3	91
30.1	55
26.2	4.6
27.5	11
29.1	47
29.2	65

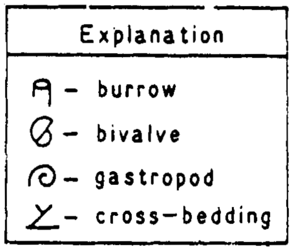
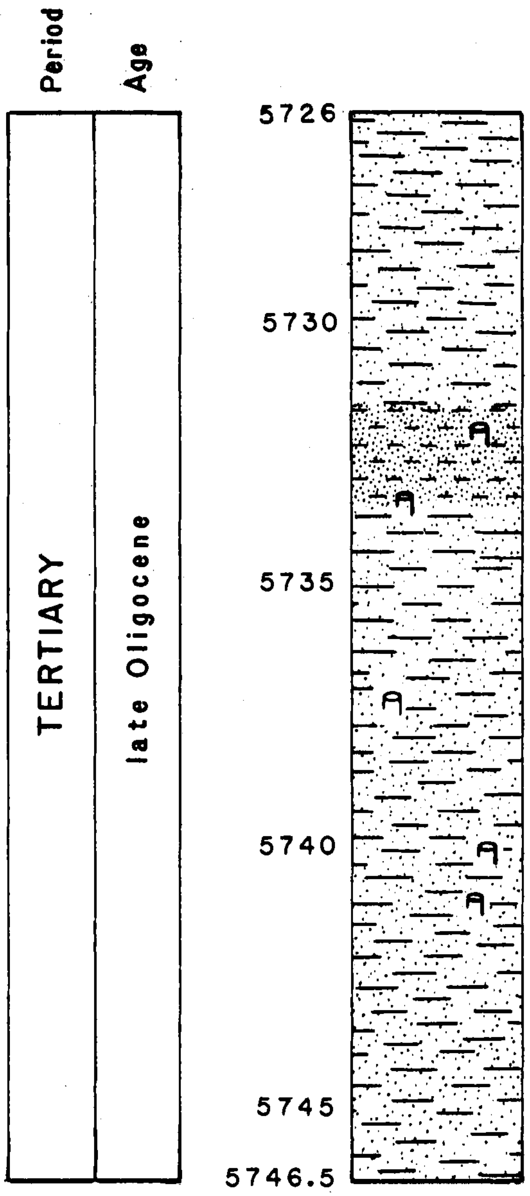


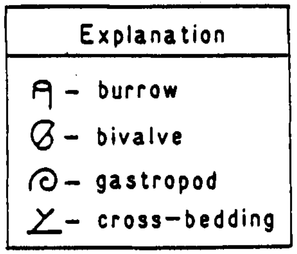
FIGURE 16. DESCRIPTION OF CONVENTIONAL CORE 4, ST. GEORGE BASIN COST NO. 1 WELL

Porosity and permeability data from Core Laboratories, Inc.

* Additional data in table 4.



<u>Sandstone</u>, olive-gray (5 Y 4/1), very fine to fine-grained, glauconitic, calcareous between 5731.3 and 5733.4 feet, massive with many preserved burrows.

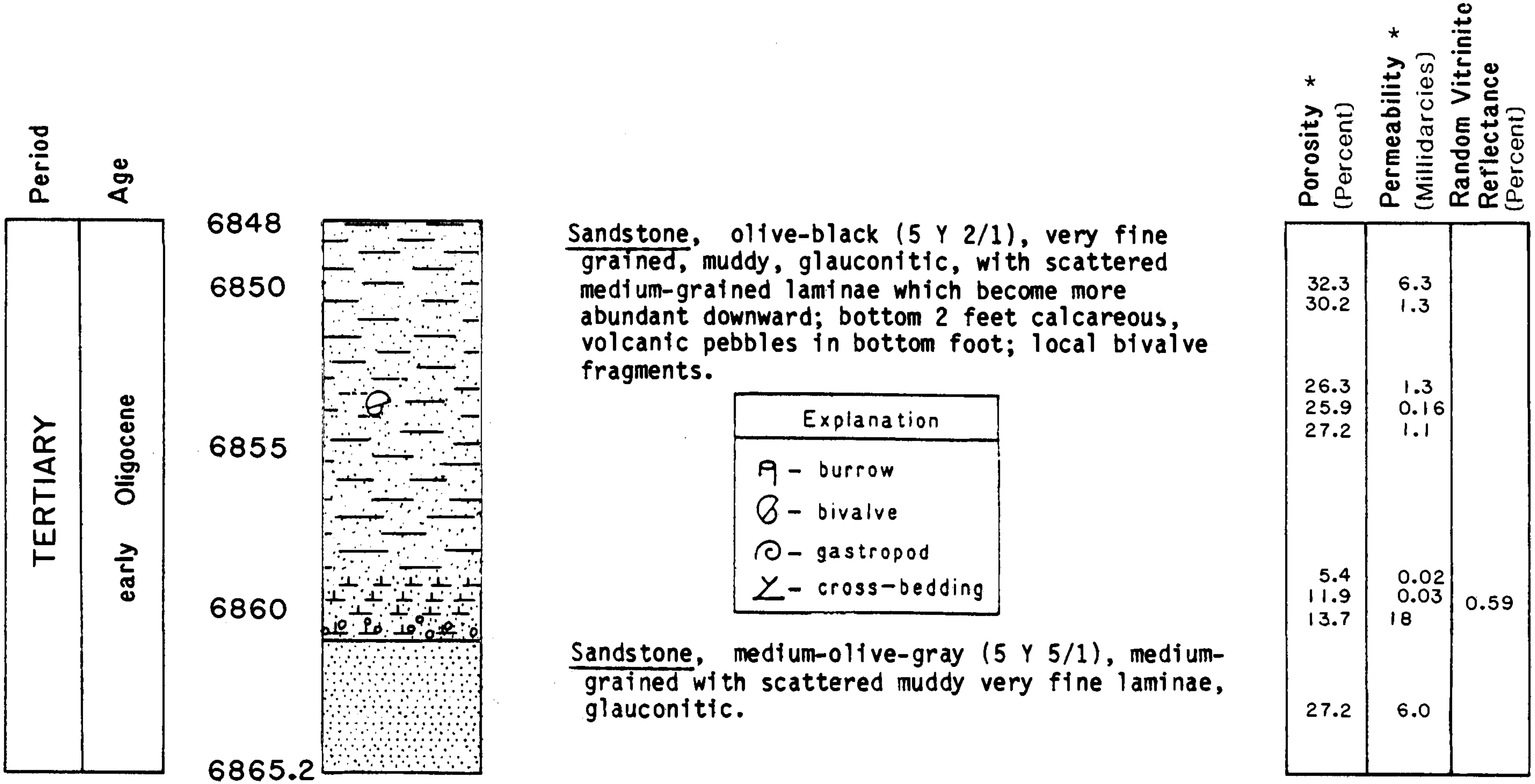


Porosity * (Percent)	Permeability * (Millidarcies)
29.8	64
30.8	58
29.6	44
27.6	45
27.9	60
27.9	67
29.1	64
26.7	54
8.5	0.02
8.5	0.01
9.5	0.01
9.7	0.04
28.2	19
29.6	23
29.2	25
29.0	17
30.7	25
30.0	20
29.5	30
30.9	23
30.3	31
31.8	34
29.6	24
30.0	21
31.6	65
29.7	22
31.9	67
30.8	29
32.1	25
30.9	22
31.2	47
29.8	36
31.2	13
30.6	21
31.2	21
28.5	6.9
30.0	13

FIGURE 17.
DESCRIPTION OF CONVENTIONAL CORE 5,
ST. GEORGE BASIN COST NO. 1 WELL

Porosity and permeability data from Core Laboratories, Inc.

* Additional data in table 4.



Sandstone, olive-black (5 Y 2/1), very fine grained, muddy, glauconitic, with scattered medium-grained laminae which become more abundant downward; bottom 2 feet calcareous, volcanic pebbles in bottom foot; local bivalve fragments.

Sandstone, medium-olive-gray (5 Y 5/1), medium-grained with scattered muddy very fine laminae, glauconitic.

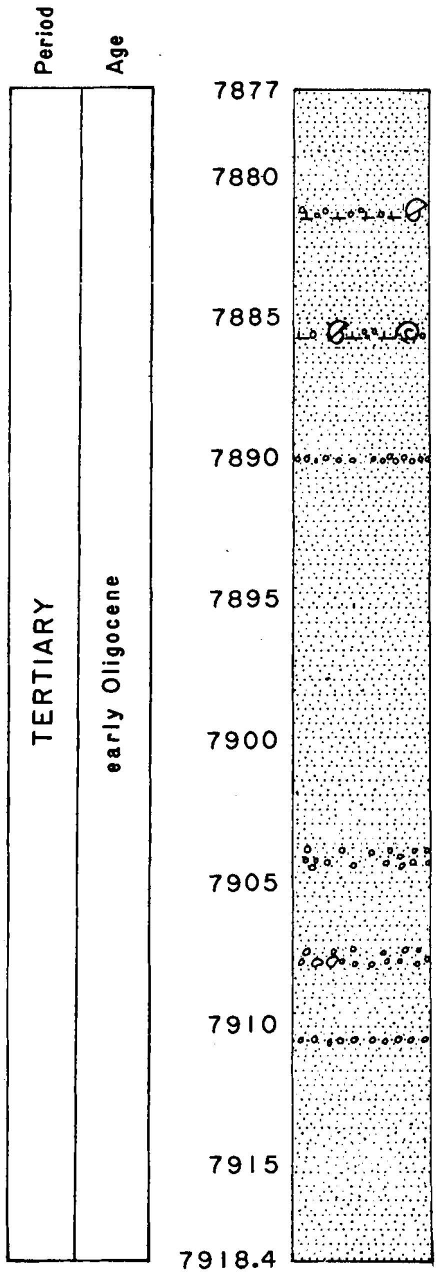
Porosity * (Percent)	Permeability * (Millidarcies)	Random Vitrinite Reflectance (Percent)
32.3	6.3	
30.2	1.3	
26.3	1.3	
25.9	0.16	
27.2	1.1	
5.4	0.02	
11.9	0.03	0.59
13.7	18	
27.2	6.0	

FIGURE 18. DESCRIPTION OF CONVENTIONAL CORE 6, ST. GEORGE BASIN COST NO. 1 WELL

Porosity and permeability data from Core Laboratories, Inc.

Random vitrinite reflectance data from Atlantic Richfield Co.

* Additional data in table 4.



Sandstone, greenish-black (5 G 2/1), very fine to fine-grained, with coarse sand grains scattered and in laminae that grade up into very fine to fine sand grade, glauconitic, abundant volcanic pebbles in thin layers, calcareous from 7881.1 to 7881.6 and from 7885.4 to 7885.8 feet; contains scattered carbonaceous debris and fossil fragments with whole bivalves and gastropods in some pebbly layers; generally massive.

Porosity * (Percent)	Permeability * (Millidarcies)	Random Vitrinite Reflectance (Percent)
22.1	0.41	
22.8	.42	
22.3	2.5	
20.4	.58	
22.5	.69	
21.9	.83	
9.3	.14	
23.8	.99	
24.2	1.2	
24.1	.70	
23.2	1.1	
20.6	.65	
22.1	.69	
21.4	.94	
19.1	.60	
19.8	.35	
18.9	.29	
22.4	.69	
21.5	.71	
21.3	.52	
22.8	.55	
22.3	.53	
21.6	.44	
18.3	.59	
15.5	.35	0.60
16.1	.42	
16.4	.37	
16.4	1.21	
15.1	.67	
16.2	.18	
17.6	.31	
20.3	.49	
17.6	.64	
24.	.67	
22.9	.91	
18.2	.50	
17.7	.45	
17.4	.58	
17.9	.53	
17.8	.58	
16.2	.60	

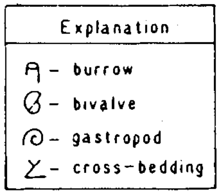
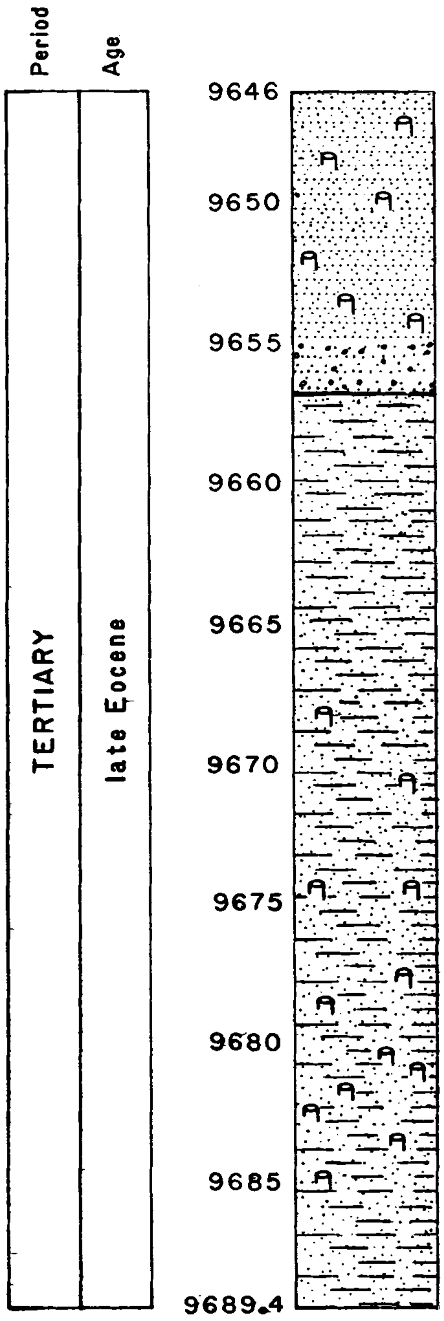


FIGURE 19.

DESCRIPTION OF CONVENTIONAL CORE 7, ST. GEORGE BASIN COST NO. 1 WELL

Porosity and permeability data from Core Laboratories Inc.
Random vitrinite reflectance data from Atlantic Richfield Co.

* ADDITIONAL DATA IN TABLE 4



Sandstone, olive-black (5 Y 2/1), very fine grained, glauconitic, burrowed.

Sandstone, medium-olive-gray (5 Y 5/1), medium- to coarse-grained, glauconitic, pebbly.

Sandstone, olive-black (5 Y 2/1), very fine grained; laminated, with shale partings; burrowed, with burrows increasing in abundance downward.

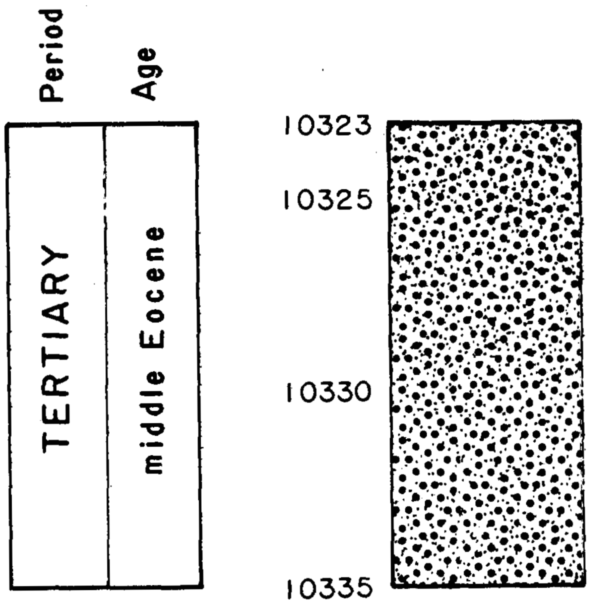
Explanation

- burrow
- bivalve
- gastropod
- cross-bedding

Porosity (Percent)	Permeability (Millidarcies)	Random Vitrinite Reflectance (Percent)
14.8	0.15	0.63
18.3	.04	
17.5	.03	
17.6	.04	
18.0	.03	
16.7	.03	
17.8	.03	
15.5	.03	
19.9	.05	
19.8	.03	
20.6	.06	
19.9	.04	
22.7	.05	
19.9	.05	
15.7	.04	
16.0	.03	
17.7	.05	
20.8	.55	
16.2	.03	
14.8	.08	
20.6	.19	
15.6	.12	
18.4	.06	
18.2	.09	
21.8	.07	
17.9	.03	
21.0	.16	
17.1	.05	
15.0	.08	
18.9	.07	
14.6	.03	
20.0	.13	
17.4	.04	
17.6	.11	
19.2	.08	
18.7	.08	
18.3	.04	
13.8	.06	
15.8	.09	
16.6	.03	
12.1	.03	
14.9	.02	0.60
11.8	.03	
12.4	.02	
17.0	.04	
15.9	.04	
15.3	.02	
14.9	.03	
19.0	.06	
18.1	.06	

FIGURE 20.
DESCRIPTION OF CONVENTIONAL CORE 8,
ST. GEORGE BASIN COST NO. 1 WELL

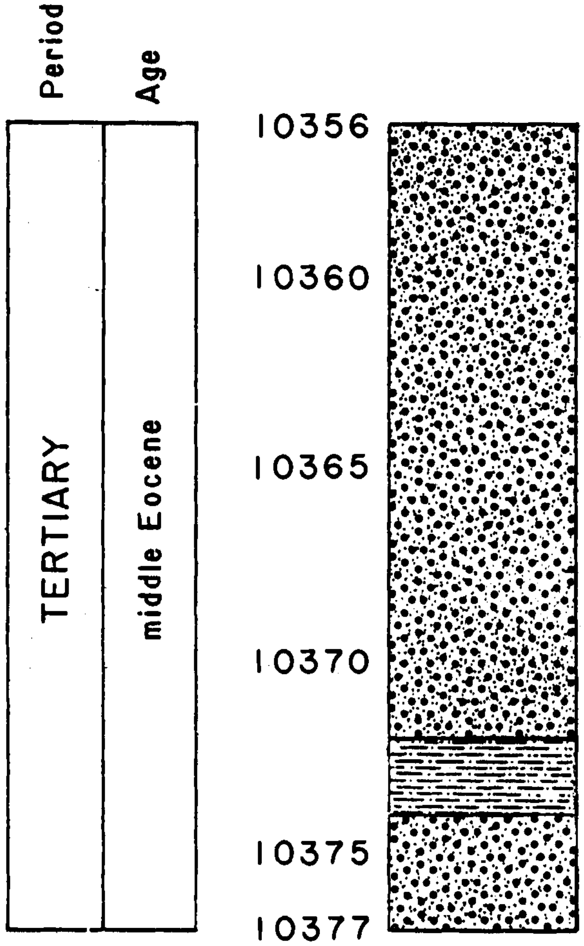
Porosity and permeability data from Core Laboratories, Inc.
Random vitrinite reflectance data from Atlantic Richfield Co.



Conglomerate, subangular to rounded volcanic coarse sand to boulders in chloritic mud matrix; clast-supported, largest boulder larger than 12 cm.

FIGURE 21.
DESCRIPTION OF CONVENTIONAL CORE 9,
ST. GEORGE BASIN COST NO. 1 WELL
Porosity and permeability data from Core Laboratories, Inc.

Porosity (Percent)	Permeability (Millidarcies)
21.3	83
25.0	2.1
9.2	0.03
10.6	0.02
13.1	0.09



Conglomerate, angular to rounded volcanic clasts to 8 cm in variably brownish-black (5 YR 2/1) or grayish-green (5 G 5/2) matrix; clast-supported.

Mudstone, sandy, laminated; plagioclase ranging to coarse sand size common in lower 6 inches.

Conglomerate, as at top of core.

Porosity (Percent)	Permeability (Millidarcies)	Random Vitrinite Reflectance (Percent)
14.6	15	
15.0	10.7	
13.3	1.0	
		0.65
3.7	0.03	
6.7	0.71	
18.0	2.4	

FIGURE 22. DESCRIPTION OF CONVENTIONAL CORE 10, ST. GEORGE BASIN COST NO. 1 WELL

Porosity and permeability data from Core Laboratories, Inc.
Random vitrinite reflectance data from Atlantic Richfield Co.

VOLCANIC ROCKS (10,380 to 13,769.5 feet)

The deepest sampled interval in the well (10,380 to 13,769.5 feet) consists of basalt, basaltic breccia, and tuff. These rocks comprise the acoustic basement in this area of the basin. Conventional cores 11, 12, and 13 are from this interval. Core 11 consists of massive basalt, and cores 12 and 13 consist of basaltic breccia. The basalt is commonly holocrystalline. Pilotaxitic, ophitic, and subophitic textures are present but not as common as intergranular. The mesostasis in these rocks consists of various mixtures of augite, olivine, chlorite, sphene, leucoxene, iron oxide, and pyrite. Some samples are felsophyric. Many samples are amygdaloidal. Quartz, albite, chlorite, calcite, sphene, leucoxene, pyrite, and laumontite and other zeolites commonly fill the amygdules. It could not be determined from the data available whether these rocks were emplaced in a submarine or subaerial environment.

Amoco Production Company obtained chemical analyses of five basalt samples from core 10. The results of these analyses expressed in oxide weight percent are presented in table 2. The samples are classified as alkali-olivine basalts on the basis of MacDonald and Katsura's (1964) plot of alkalis against silica.

Potassium-argon age determinations were performed by Teledyne Isotopes and the Mobil Research and Development Corporation, Field Research Laboratory. Two samples are from clasts from the conglomerate at the base of the Eocene section; the remainder are from the volcanic section. The ages obtained are presented in table 3. The reliability of the ages is suspect on two counts: there is considerable variation among ages of samples collected in close proximity to each other, and most of the radiometric dates are younger than the paleontological ages (Eocene or older).

The SP curve over the interval is generally flat above 11,400 feet and blocky below this depth. The gamma-ray log is blocky except for a long flat section from 10,470 to 11,300 feet. The deep resistivity curve is jagged to blocky with a range of recorded values from 0.5 to 42 ohm-m. The shallow curve generally follows the deep curve, but the values recorded by the two curves may vary by up to 15 ohm-m. The density curve is jagged throughout, and recorded densities range from 2.35 to 2.85 g/cm^3.

The sonic log records an average interval transit time of about 90 µs/foot from the top of the interval down to 10,350 feet. Below 10,350 feet, interval transit time is more variable, with values most commonly ranging from 50 to 75 µs/foot.

Table 2.--BASALT CHEMISTRY DATA

[COST Well Data from AMOCO Production Company]

	Chemical Compositions (Oxide Weight Percents)				
	10,906 ft COST Well	10,917 ft COST Well	10,927.5 ft COST Well	10,934 ft COST Well	10,941.5 ft COST Well
SiO_2	43.66	46.80	42.16	44.57	43.43
Al_2O_3	15.55	15.65	15.74	15.14	13.38
Fe_2O_3	4.09	4.73	3.89	3.96	3.71
FeO	7.53	8.66	6.80	7.22	7.06
MgO	12.57	12.08	9.75	11.15	11.42
CaO	9.77	3.66	15.84	11.54	15.18
Na_2O	2.97	3.45	2.76	2.90	2.61
K_2O	0.17	0.28	0.46	0.21	0.45
TiO_2	2.59	3.23	2.39	2.46	2.21
P_2O_5	N/A	N/A	N/A	N/A	N/A
MnO	N/A	N/A	N/A	N/A	N/A
Total	98.90	98.54	99.79	99.15	99.45

Table 2. (cont.)

Chemical Compositions (Oxide Weight Percents)					
Continental Tholeiitic Basalt*		Oceanic Tholeiitic Basalt*		Alkali Basalt*	
Average	Range	Average	Range	Average	Range
50.7	44.35-54.6	49.3	42.8 -52.56	47.1	41.04-51.4
14.4	12.48-16.32	15.2	7.3 -22.3	15.3	10.11-26.26
3.2	0.95- 7.56	2.4	0.69- 7.90	4.3	0.53-15.85
9.8	4.18-13.60	8.0	2.87-13.58	8.3	0.48-13.63
6.2	3.52-11.16	8.3	4.59-26.0	7.0	2.66-17.87
9.4	7.45-11.8	10.8	6.69-14.1	9.0	6.81-14.46
2.6	1.8 - 3.47	2.6	0.90- 4.45	3.4	1.35- 4.8
1.0	0.19- 1.74	0.24	0.04- 0.70	1.2	0.13- 2.5
2.78	0.9 - 3.99	1.8	0.35- 3.69	2.7	0.92- 4.52
	0.09- 0.81	0.21	0.06- 0.56	0.41	0.09- 0.93
0.16	0.10- 0.3	0.17	0.90- 0.44	0.17	0.06- 0.36
99.5		99.02		98.88	

*From Hyndman (1972, p. 171)

Table 3. Potassium-argon ages of basalt samples from St. George Basin COST No. 1 Well. Ages have been adjusted in accord with currently used decay and abundance constants (Dalrymple, 1979). The two shallowest samples are from clasts in conglomerate at the base of the sedimentary section. All other samples are from the bottommost volcanic part of the well.

Depth (ft)	Age ($x10^6$ yrs)	%K	Laboratory
10,333	120 ± 16	0.027	Teledyne Isotopes
10,375	27 ± 4	1.50	Same
10,907.2	25.7 ± 1.3	0.297	*Mobil Research and Development
10,907.2	22.9 ± 1.2	0.297	Same
10,925.3	35.5 ± 1.7	0.410	Same
10,925.3	35.1 ± 1.7	0.410	Same
10,930.2	31.7 ± 1.5	0.3859	Same
10,930.2	32.4 ± 1.6	0.3859	Same
10,934	38 ± 6	0.35	Teledyne Isotopes
10,942.6	29.2 ± 1.5	0.3719	*Mobil Research and Development
10,942.6	31.1 ± 1.5	0.3719	Same
13,080	33.7	0.589	Teledyne Isotopes
13,096	28.2	1.08	Same
13,110	27.3	0.298	Same
13,123	63.3	0.086	Same
13,760	30.2 ± 1.5	0.878	Same
13,768	136.4 ± 6.9	0.094	Same
13,769.5	52.2 ± 2.6	0.226	Same

*Mobil Research and Development Corporation, Field Research Laboratory

POROSITY AND PERMEABILITY

Porosity and permeability determinations for samples from sidewall and conventional cores are presented in table 4. Above 6000 feet, there is good agreement between the porosities of sandstone samples from conventional cores and those of sandstone samples from nearby sidewall cores. Below 6000 feet, sandstones from sidewall cores generally have higher porosities than do those from nearby conventional cores. Figure 23 presents a plot of average porosity against depth for sandstone samples from conventional cores. Figure 24 presents a plot of average porosity against average permeability for the same samples. Porosity and permeability data from sandstones from both conventional and sidewall cores are presented graphically on plate 1. On the plate, 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 values plotted in the plate do not correspond with actual depths. The number of sandstone samples in each interval is given under the applicable symbol. Figure 23 shows a general decrease in porosity with depth, but average sandstone porosity exceeds 20 percent down to 8000 feet and remains above 10 percent to the base of the sedimentary section. There is no apparent relationship between sandstone porosities and permeabilities from conventional cores (fig. 24). The great variability of permeability with respect to porosity is probably due to variability in the abundance of matrix. Porosity and permeability have been reduced by compaction, ductile grain deformation, and cementation. Clay, analcime, and zeolites are the most abundant authigenic cements. Diagenesis has probably had a greater influence on sandstone permeability than on sandstone porosity. Cementation also played an important role in postdepositional permeability reduction.

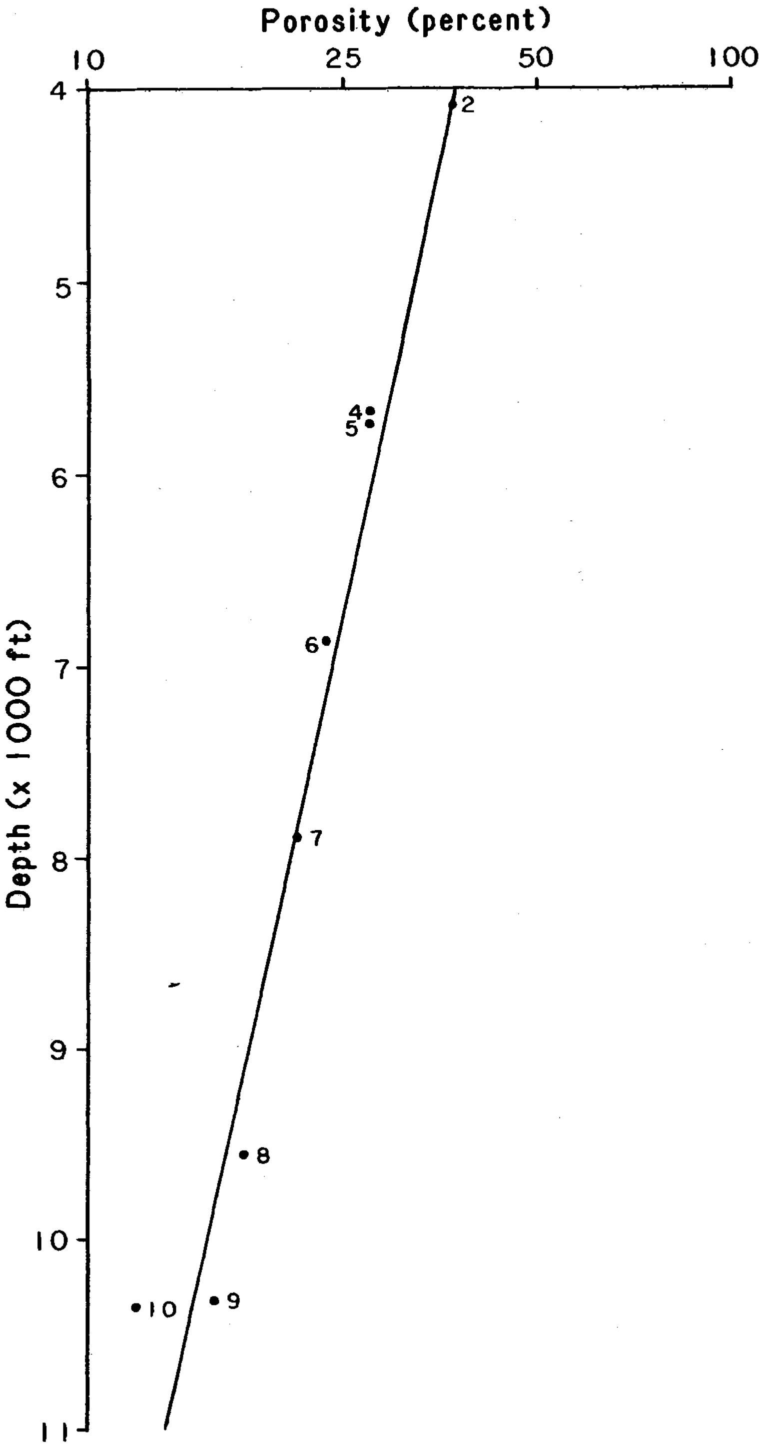


FIGURE 23. Plot of average porosity against depth for sandstone samples from conventional cores, St. George Basin COST No. 1 well.

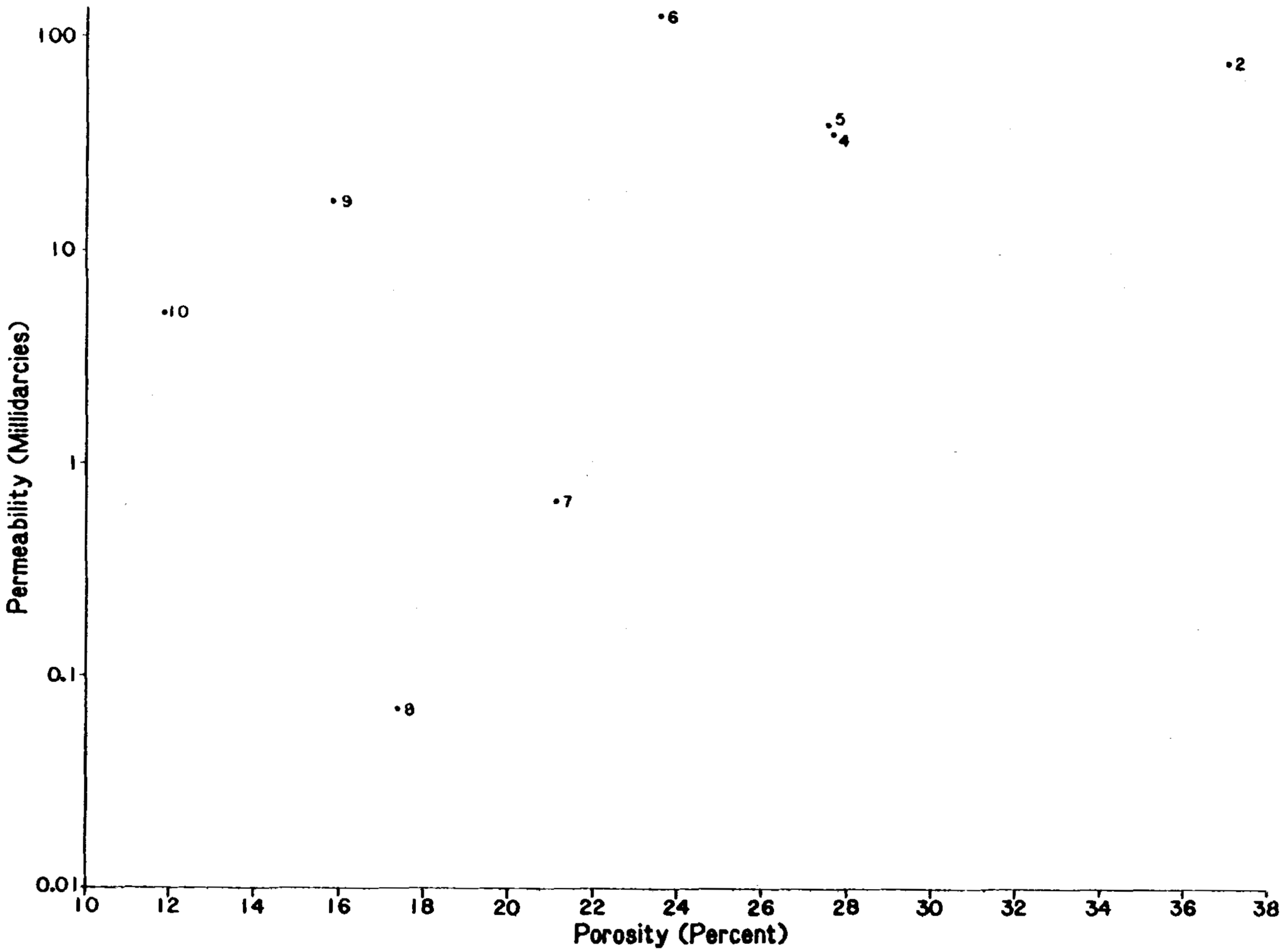


FIGURE 24. Plot of average porosity against average permeability for sandstone samples from conventional cores, St. George Basin COST No.1 well.

Table 4. Porosity and Permeability, St. George Basin COST No. 1 Well. (From Core Laboratories, Inc.)

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
1660	ss,vfg, v slty, cly	41.2	22	Sidewall
1724	ss,vf-fg, slty	35.5	51	Sidewall
1730	slt,ss,vfg,cly	43.3	1.7	Sidewall
1824	slt,cly,cly	44.5	0.9	Sidewall
1862	same	41.8	0.4	Sidewall
1870	ss,vf-fg,v slty	35.6	8.6	Sidewall
1903	slt,cly	41.8	0.2	Sidewall
1950	same	42.7	0.1	Sidewall
2000	ss,vfg,v slty, cly	36.3	3.2	Sidewall
2090	slt,v cly	42.3	1.1	Sidewall
2144	ss,vfg,v slty	38.3	4.9	Sidewall
2151	cly, slty	31.3	0.2	Sidewall
2225	slt,v cly	43.1	0.4	Sidewall
2302	slt,v cly	36.1	0.7	Sidewall
2410	ss,vfg,slty,cly	41.9	14	Sidewall
2451	same	38.8	46	Sidewall
2500	same	39.9	13	Sidewall
2554	slt,cly,sdy	35.8	4.4	Sidewall
2602				Sidewall
2650	slt,cly,sdy	36.0	6.5	Sidewall
2700	slt,v sdy,cly	31.0	12	Sidewall
2752	ss,vf-mg,slty	36.3	39	Sidewall
2810	slt,v cly	40.1	0.6	Sidewall
2852	slt,sdy,cly	38.4	3.2	Sidewall
2910	same	32.0	0.8	Sidewall
2955	ss,vfg,v slty,cly	34.4	33	Sidewall
3010	slt,cly	39.5	1.2	Sidewall
3036	same	37.1	2.1	Sidewall
3051	same	30.9	0.9	Sidewall
3090	same	41.7	1.4	Sidewall
3100	ss,vfg,v slty,cly	36.4	6.7	Sidewall
3160	cly,slty	32.9	0.2	Sidewall
3192	slt,sdy,cly	38.9	4.5	Sidewall
3210	same	39.2	4.7	Sidewall
3250	ss,vfg,v slty,cly	39.1	24	Sidewall

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
3294	slt,sdy,vfg,cly	39.7	5.1	Sidewall
3356	same	36.6	3.2	Sidewall
3370.1	sltst,v cly	33.6	0.48	Core 1
3371.4	same	29.7	0.50	Core 1
3372.2	same	33.0	0.59	Core 1
3373.2	same	33.4	0.41	Core 1
3374.5	same	32.8	0.47	Core 1
3375.3	same	36.5	0.56	Core 1
3376.4	same	24.7	0.09	Core 1
3377.4	same	30.7	0.27	Core 1
3378.2	same	31.9	1.5	Core 1
3380.7	same	31.8	1.4	Core 1
3383.4	same	36.1	0.33	Core 1
3385.7	same	30.5	0.31	Core 1
3386.3	same	31.6	0.22	Core 1
3387.1	same	31.6	0.25	Core 1
3388.4	same	32.3	0.66	Core 1
3390.6	same	32.3	2.5	Core 1
3391.9	same	31.6	2.8	Core 1
3392.7	same	32.2	0.59	Core 1
3393.6	same	30.8	0.28	Core 1
3394.1	same	32.1	0.22	Core 1
3395.1	same	32.6	3.4	Core 1
3396.3	same	34.9	3.4	Core 1
3398.6	same	33.2	0.39	Core 1
3399.4	same	33.6	0.91	Core 1
3400.3	same	33.2	3.6	Core 1
3401.7	same	34.7	0.43	Core 1
3402.5	same	33.6	0.29	Core 1
3403.6	same	33.6	0.41	Core 1
3404.2	same	35.7	0.45	Core 1
3405.4	same	34.8	0.83	Core 1
3406.1	same	33.8	1.4	Core 1
3407.3	same	35.9	0.29	Core 1
3408.2	same	42.5	0.25	Core 1
3409.5	same	43.0	0.36	Core 1
3410.1	same	42.7	205	Core 1
3410.6	same	44.5	3.0	Core 1
3411.3	same	41.6	5.6	Core 1
3411.7	same	44.2	65	Core 1

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
3412.1	sltst,v cly	40.8	1.5	Core 1
3412.9	same	44.5	1.7	Core 1
3413.3	same	42.1	6.9	Core 1
3413.9	same	43.4	2.8	Core 1
3414.3	same	47.1	4.6	Core 1
3414.9	same	44.6	3.7	Core 1
3415.6	same	42.4	2.0	Core 1
3416.2	same	42.2	2.0	Core 1
3416.5	same	43.8	2.0	Core 1
3417.1	same	43.9	3.0	Core 1
3456	ss,vfg,v slty,cly	34.8	22	Sidewall
3494	slt,v cly	29.6	1.3	Sidewall
3504	cly,slty	30.3	0.4	Sidewall
3543	slt,cly nod	43.5	18	Sidewall
3590	ss,vfg,v slty	37.3	49	Sidewall
3615	slt,v sdy	36.6	19	Sidewall
3650	cly, slty	39.4	4.1	Sidewall
3702	ss,vfg,v slty, cly	37.3	49	Sidewall
3774	ss,vfg,slty	37.1	128	Sidewall
3808	cly	42.5	0.5	Sidewall
3844	slt,cly,sdy	37.6	0.9	Sidewall
3903	slt,sl sdy,v cly	44.2	15	Sidewall
3910	slt,v sdy,v cly	38.9	3.6	Sidewall
3943	slt,sl sdy,v cly	40.5	0.9	Sidewall
3953	slt,v cly	43.0	3.2	Sidewall
3999	slt,v sdy, cly	35.8	23	Sidewall
4013	ss,vfg,v slty,cly	35.8	78	Siedwall
4040	same	44.7	21	Sidewall
4094	same	37.0	16	Sidewall
4096	same	36.6	24	Sidewall
4098	slt,sdy,cly	36.8	19	Sidewall
4104	ss,vfg,v slty,cly	36.3	35	Sidewall
4105.2	ss,vfg, v cly	37.2	144	Core 2
4105.5	same			
4105.8	same	36.7	79	Core 2
4106.3	same	34.3	150	Core 2
4106.6	same	36.5	24	Core 2
4106.8	same	36.7	45	Core 2
4107.0	same	37.0	136	Core 2
4107.2	same			

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
4107.4	ss, vfg, v cly	37.0	126	Core 2
4107.6	same	36.0	143	Core 2
4108	slt,v cly	40.8	2.4	Sidewall
4108.1	ss, vfg, v cly	36.0	84	Core 2
4108.3	same			
4108.7	same	35.9	91	Core 2
4109.1	same	37.0	61	Core 2
4109.7	same	38.0	10	Core 2
4110.3	same	40.8	2.5	Core 2
4110.7	same	39.0	2.5	Core 2
4111.0	mdst	40.3	5.6	Core 2
4111.4	same	39.7	13.2	Core 2
4112.5	same	39.1	0.71	Core 2
4113.8	same	43.4	0.57	Core 2
4114.4	same	43.3	0.63	Core 2
4115.7	same	41.7	2.0	Core 2
4116.3	same	41.5	5.0	Core 2
4117.5	same	42.0	0.78	Core 2
4118.4	same	42.5	3.4	Core 2
4119.5	same	43.6	0.50	Core 2
4120.4	same	43.1	0.63	Core 2
4121.3	same	44.1	0.71	Core 2
4122.6	same	43.5	0.98	Core 2
4123.6	same	43.9	0.60	Core 2
4124.7	same	43.2	0.07	Core 2
4125.2	same	40.6	1.8	Core 2
4126.5	same	39.7	2.8	Core 2
4127.1	same	37.1	6.0	Core 2
4127.3	same	37.3	8.9	Core 2
4127.6	same	39.0	3.1	Core 2
4127.9	same	38.0	7.0	Core 2
4128.3	same	42.3	1.7	Core 2
4129.3	same	42.4	10	Core 2
4130.4	same	43.0	0.50	Core 2
4131.4	same	43.3	0.29	Core 2
4132.5	same	43.0	0.33	Core 2
4133.6	same	43.5	0.53	Core 2
4134.2	same	44.1	0.29	Core 2
4150	slt,v cly	40.3	2.6	Sidewall
4200	cly,slty	39.9	3.0	Sidewall

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
4250	slt,v cly,sl sdy	40.7	2.8	Sidewall
4309	ss,vfg,v slty	38.9	48	Sidewall
4397	ss,vfg,v slty cly	38.7	12	Sidewall
4432	same	37.1	43	Sidewall
4481	same	38.0	34	Sidewall
4495	cly,slty	39.2	3.1	Sidewall
4504	slt,v sdy,cly	38.8	27	Sidewall
4539	slt,sdy,cly	41.3	7.7	Sidewall
4578	ss,vfg,v slty,cly	38.4	12	Sidewall
4650	slt,sl sdy,v cly	29.3	3.5	Sidewall
4669	slt,v sdy,cly	31.0	36	Sidewall
4710	slt,sl sdy,v cly	27.5	2.7	Sidewall
4750	cly,slty	26.3	3.7	Sidewall
4800	same	26.3	1.5	Sidewall
4860	slt,v cly	26.1	3.8	Sidewall
4865	slt,v cly,sl sdy	28.9	4.6	Sidewall
4904	sltst,sdy,cly	31.8	3.1	Sidewall
4950	ss,vfg,slty,cly	30.4	2.2	Sidewall
4970	sltst,v cly	30.7	1.3	Sidewall
5000	sltst,v cly,sdy	30.4	2.9	Sidewall
5030	ss,vf-fg,slty	29.4	39	Sidewall
5048	ss,vf-fg,slty,cly	29.8	36	Sidewall
5102	same	28.3	25	Sidewall
5164	sltst,v cly	29.2	2.0	Sidewall
5198	ss,vf-fg,slty,cly	28.6	31	Sidewall
5230	ss,vfg,slty,cly	28.1	15	Sidewall
5252	ss,vfg,v slty,cly	28.2	5.6	Sidewall
5298	same	26.7	4.4	Sidewall
5320	sltst,cly,	31.1	88	Sidewall, frac.
5370	ss,vfg,slty,cly	30.4	92	Sidewall
5401	same	28.7	14	Sidewall
5460	ss	27.6	12	Sidewall
5496	ss,vf-fg.slty,v cly	25.7	11	Sidewall
5552	sltst,sdy,cly	29.4	2.2	Sidewall
5606	sltst,v cly	28.9	18	Sidewall
5646	sltst,v cly,	28.0	56	Sidewall, frac.
5669.3	ss	26.3	0.88	Core 4
5670.4	same	26.3	0.39	Core 4
5671.3	same	25.0	0.12	Core 4
5672.4	same	27.3	0.79	Core 4

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
5673.5	ss	25.9	0.28	Core 4
5674.5	same	29.3	0.94	Core 4
5675.3	same	25.5	0.14	Core 4
5676.4	same	24.7	0.28	Core 4
5677.5	same	25.0	0.91	Core 4
5678.6	same	25.8	0.23	Core 4
5679.4	same	24.3	0.11	Core 4
5680.3	same	26.8	0.29	Core 4
5681.3	same	28.6	0.45	Core 4
5681.6	same	27.3	0.96	Core 4
5682.4	same	27.2	0.72	Core 4
5682.5	same	26.4	0.78	Core 4
5683.3	same	26.2	1.4	Core 4
5683.8	same	25.8	1.3	Core 4
5684.2	same	27.9	1.4	Core 4
5684.8	same	26.1	1.3	Core 4
5685.3	same	31.6	1.7	Core 4
5685.5	same	27.4	1.9	Core 4
5686.4	same	28.5	1.8	Core 4
5686.5	same	25.7	1.7	Core 4
5687.4	same	24.3	1.8	Core 4
5687.5	same	24.4	1.3	Core 4
5688-89	same	26.2	14	Core 4
5689-90	same	26.1	14	Core 4
5689-90	same	26.1	18	Core 4
5689-90	same	26.2	16	Core 4
5690-91	same	28.0	35	Core 4
5690-91	same	36.6	248	Core 4
5691-92	same	27.3	17	Core 4
5691-92	same	28.4	36	Core 4
5692-93	same	31.7	84	Core 4
5692-93	same	29.9	78	Core 4
5692-93	same	29.9	63	Core 4
5693-94	same	28.5	29	Core 4
5693-94	same	29.6	65	Core 4
5693-94	same	30.2	68	Core 4
5694-95	same	28.6	46	Core 4
5694-95	same	28.0	36	Core 4
5694-95	same	28.2	29	Core 4
5695-96	same	30.7	116	Core 4

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
5695-96	ss	31.3	91	Core 4
5695-96	same	34.9	228	Core 4
5696-97	same	30.1	55	Core 4
5696-97	same	29.3	58	Core 4
5696-97	same	26.2	4.6	Core 4
5697-98	same	16.9	216	Core 4
5697-98	same	27.6	23	Core 4
5697-98	same	27.5	11	Core 4
5698-99	same	28.3	60	Core 4
5698-99	same	29.1	47	Core 4
5698-99	same	29.2	65	Core 4
5720	ss,vfg,slty,cly	31.6	41	Sidewall
5726.3	ss	29.0	58	Core 5
5726.4	same	29.8	64	Core 5
5726.5	same	30.8	58	Core 5
5727.1	same	31.8	56	Core 5
5727.2	same	29.6	44	Core 5
5727.4	same	28.0	49	Core 5
5727.6	same	27.6	45	Core 5
5727.7	same	29.7	107	Core 5
5727.9	same	27.9	60	Core 5
5730.1	same	31.2	87	Core 5
5730.2	same	26.7	86	Core 5
5730.3	same	27.9	67	Core 5
5730.5	same	29.1	64	Core 5
5730.6	same	25.6	48	Core 5
5730.8	same	26.7	54	Core 5
5731.4	same	9.3	0.02	Core 5
5731.5	same	8.5	0.02	Core 5
5732.2	same	8.5	0.01	Core 5
5732.4	same	9.5	0.01	Core 5
5733.3	same	9.7	0.04	Core 5
5733.8	same	28.2	19	Core 5
5734.4	same	29.6	23	Core 5
5734.7	same	29.2	25	Core 5
5735.1	same	29.0	17	Core 5
5735.9	same	29.9	22	Core 5
5736.4	same	30.7	25	Core 5
5736.8	same	30.0	20	Core 5
5737.5	same	29.5	30	Core 5

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
5737.6	ss	30.9	23	Core 5
5738.3	same	30.3	31	Core 5
5738.8	same	31.8	34	Core 5
5739.3	same	29.6	24	Core 5
5739.6	same	30.0	21	Core 5
5740.1	same	31.6	65	Core 5
5740.2	same	29.7	22	Core 5
5741.2	same	31.9	67	Core 5
5741.8	same	30.8	29	Core 5
5742.3	same	32.1	25	Core 5
5742.4	same	30.9	22	Core 5
5743.1	same	31.2	47	Core 5
5743.9	same	29.8	36	Core 5
5744.3	same	31.2	13	Core 5
5744.6	same	30.6	21	Core 5
5745.2	same	31.2	21	Core 5
5745.8	same	28.5	6.9	Core 5
5746.3	same	30.0	13	Core 5
5790	sltst,v sdy,vfg,cly	28.6	49	Sidewall
5854	ss,vf-fg,slty,cly	30.4	31	Sidewall
5922	same	31.7	279	Sidewall
6002	ss,fg,slty	34.2	704	Sidewall
6002	ss,f-mg	32.7	534	Sidewall
6048	ss,fg,slty	34.0	664	Sidewall
6048	ss,f-mg	32.2	413	Sidewall
6092	ss,fg.slty	33.8	596	Sidewall
6140	ss,vfg,slty,cly	33.4	451	Sidewall
6140	ss,mg	31.2	670	Sidewall
6200	ss,vf-fg,slty	32.9	347	Sidewall
6250	same	33.4	323	Sidewall
6298	same	32.9	596	Sidewall
6298	ss,f-mg	31.9	368	Sidewall
6352	ss,vf-fg,slty	33.5	517	Sidewall
6352	ss,mg	31.5	732	Sidewall
6398	ss,vf-fg,slty,cly	28.5	142	Sidewall
6450	same	30.8	181	Sidewall
6500	ss,vf-fg,slty	21.3	9.9	Sidewall
6550	same	30.3	253	Sidewall
6610	ss,vf-mg	31.3	283	Sidewall
6640	ss,vf-mg,v slty,cly	24.4	2.2	Sidewall

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
6700	ss,vfg,v slty,cly	24.4	31	Sidewall
6736	ss,vfg,v slty	29.2	138	Sidewall
6750	ss,vf-fg,liq.	16.7	4808	Sidewall, frac.
6750	ss,f-mg	28.0	60	Sidewall
6802	ss,f-mg,slty	31.5	367	Sidewall
6802	ss,fg	29.2	49	Sidewall
6847-50	same	NA		Core 6
6847-50	same	20.4	0.30	Core 6
6847-50	same	33.8	234	Core 6
6847-50		30.9	331	Core 6
6847-50	same	31.0	340	Core 6
6847-50	same	N/A		
6850	ss,vfg, slty	29.1	45	Sidewall
6850-53	ss	32.3	6.3	Core 6
6850-53	same	30.9	2.1	Core 6
6850-53	same	30.2	1.3	Core 6
6850-53	same	31.1	2.2	Core 6
6850-53	same			Core 6
6850-53	same	30.1	2.9	Core 6
6853-56	same	26.3	1.3	Core 6
6853-56	same			Core 6
6853-56	same	25.9	0.16	Core 6
6853-56	same	27.2	1.1	Core 6
6853-56	same	30.7	173	Core 6
6853-56	same	29.1	586	Core 6
6859-60	same	5.4	0.02	Core 6
6859-60	same	9.7	0.02	Core 6
6859-60	same	11.9	0.03	Core 6
6860-61	same	13.7	18	Core 6
6860-61	same	4.6	0.03	Core 6
6860-61	same	5.2	0.01	Core 6
6863-64	same	27.2	6.0	Core 6
6864-65	same			Core 6
6864-65	same	30.1	1080	Core 6
6900	ss,vfg,slty	30.5	7.6	Sidewall
6967	ss,f-mg,slty,cly lam	28.5	128	Sidewall
6998	ss,vf-fg,slty	25.8	38	Sidewall
7036	ss,vf-fg,slty,cly	33.8	222	Sidewall
7036	ss,fg	25.6	17	Sidewall
7052	ss,vf-fg,slty	24.8	26	Sidewall

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
7078	sltst,sdy,cly	24.1	3.2	Sidewall
7132	ss,vfg,v slty,cly	22.9	4.9	Sidewall
7148	ss,vf-mg,slty,cly	23.9	26	Sidewall
7190	ss,vfg,v slty,cly	26.3	7.6	Sidewall
7216	ss,vf-fg,slty,cly	27.0	31	Sidewall
7242	ss,vf-cg,slty,cly	24.8	15	Sidewall
7298	ss,vf-fg,slty,cly	33.2	74	Sidewall
7334	sltst,cly	21.3	--	Sidewall
7340	ss,vf-fg,slty,cly	26.5	13	Sidewall
7400	same	31.9	29	Sidewall
7446	same	24.8	7.0	Sidewall
7510	same	28.2	18	Sidewall
7529	ss,vfg,cly,inbd	24.1	26	Sidewall
7570	same	23.8	25	Sidewall
7630	sltst,sdy,cly	23.7	5.1	Sidewall
7660	sltst,cly	19.7	30	Sidewall
7708	ss,vfg,v slty,cly	22.9	4.9	Sidewall
7749	same	24.1	11	Sidewall
7800	same	21.5	1.5	Sidewall
7849	same	22.6	2.7	Sidewall
7877.1	ss	22.1	0.41	Core 7
7878.1	same	22.8	0.42	Core 7
7878.6	same	22.3	2.5	Core 7
7879.2	same	22.3	0.98	Core 7
7879.9	same	20.4	0.58	Core 7
7880.7	same	22.5	0.69	Core 7
7881.3	same	21.9	0.83	Core 7
7881.8	same	9.3	0.14	Core 7
7882.9	same	23.8	0.99	Core 7
7883.3	same	24.2	1.2	Core 7
7883.8	same	24.5	0.66	Core 7
7884.2	same	24.1	0.70	Core 7
7884.6	same	23.2	0.85	Core 7
7885.1	same	23.2	1.1	Core 7
7885.4	same	21.1	0.95	Core 7
7885.9	ss	19.9	1.18	Core 7
7886.9	same	20.6	0.65	Core 7
7888.0	same	22.1	0.69	Core 7
7888.9	same	21.5	0.78	Core 7
7889.8	same	21.4	0.94	Core 7

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
7890.8	ss	19.1	0.60	Core 7
7892.0	same	19.8	0.35	Core 7
7892.9	same	20.6	0.53	Core 7
7893.9	same	18.9	0.29	Core 7
7894.8	same	22.4	0.69	Core 7
7895.4	same	21.5	0.71	Core 7
7896.5	same	21.3	0.52	Core 7
7897.3	same	22.8	0.55	Core 7
7897.7	same	22.3	0.53	Core 7
7898.3	same	21.6	0.44	Core 7
7899.3	same	18.3	0.59	Core 7
7900.5	same	15.5	0.35	Core 7
7901.3	same	16.1	0.42	Core 7
7902	ss,vfg,v slty cly	27.2	4.6	Sidewall
7902.0	ss	16.4	0.37	Core 7
7903.2	same	16.4	1.21	Core 7
7904.0	same	16.3	132	Core 7, frac.
7904.9	same	15.1	0.67	Core 7
7906.0	same	17.0	0.38	Core 7
7906.8	same	16.2	0.18	Core 7
7907.9	same	17.6	0.31	Core 7
7908.7	same	20.3	0.49	Core 7
7910.0	same	17.6	0.12	Core 7
7910.8	same	17.6	0.64	Core 7
7911.3	same	24.0	0.67	Core 7
7911.9	same	24.4	0.66	Core 7
7913.0	same	22.9	0.91	Core 7
7913.7	same	21.9	0.65	Core 7
7914.8	same	18.2	0.50	Core 7
7915.8	same	17.7	0.45	Core 7
7916.7	ss	17.4	0.58	Core 7
7917.1	same	17.9	0.53	Core 7
7917.7	same	17.8	0.58	Core 7
7918.2	same	16.2	0.60	Core 7
7968	ss,vfg,v slty,cly	24.2	5.1	Sidewall
7982	same	27.0	9.7	Sidewall
8014	same	24.9	4.0	Sidewall
8052	same	24.3	8.0	Sidewall
8123	same	21.5	28	Sidewall
8178	same	24.4	2.0	Sidewall

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
8254	same	24.1	2.3	Sidewall
8297	same	26.0	4.9	Sidewall
8352	sltst,sdy,v cly	22.1	4.0	Sidewall
8401	same	20.1	3.7	Sidewall
8462	ss,vfg, v slty, cly	23.3	2.1	Sidewall
8500	same	23.4	3.1	Sidewall
8548	same	22.6	1.8	Sidewall
8596	ss,vfg,v slty, v cly	20.3	2.0	Sidewall
8650	ss,vfg,v slty, cly	22.5	8.5	Sidewall
8748	same	21.6	2.2	Sidewall
8802	sltst,sdy,v cly	19.0	0.7	Sidewall
8858				Sidewall
8902	same	20.6	5.7	Sidewall
8988	same	21.0	1.1	Sidewall
9048	sltst,sdy, v cly	19.0	170	Sidewall, frac.
9102	same	21.0	202	Sidewall, frac.
9148	same	20.2	36	Sidewall, frac.
9221	sltst,sdy,v cly	18.1	7.5	Sidewall
9225	sltst, v sdy, v cly	17.1	42	Sidewall
9258	sltst,sdy,v cly	17.8	20	Sidewall
9300	sltst, v cly	22.3	135	Sidewall
9300(A)	sltst,cly	16.9	3.6	Sidewall
9300(B)	same	19.1	5.0	Sidewall
9352	sltst, v cly	21.9	1338	Sidewall, frac.
9352	sltst,cly	19.8	7.1	Sidewall
9388	sltst., v cly	16.8	81	Sidewall, frac.
9450	same	20.4	304	Sidewall, frac.
9538	same	20.7	105	Sidewall, frac.
9600	sltst,sdy,v cly	23.5	8.9	Sidewall
9646.2	ss	14.8	0.15	Core 8
9647.2	ss	18.3	0.04	Core 8
9648.2	same	17.5	0.03	Core 8
9649.0	same	17.6	0.04	Core 8
9649.6	same	18.0	0.03	Core 8
9650	sltst,sdy,v cly	27.7	17	Sidewall
9650.8	ss	16.7	0.03	Core 8
9651.5	same	17.8	0.03	Core 8
9652.4	same	15.5	0.03	Core 8
9653.0	same	19.9	0.05	Core 8
9653.9	same	19.8	0.03	Core 8

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
9654.6	same	20.6	0.06	Core 8
9655.7	same	19.9	0.04	Core 8
9656.3	same	22.7	0.05	Core 8
9656.8	same	19.9	0.05	Core 8
9657.9	same	15.7	0.04	Core 8
9658.8	same	16.0	0.03	Core 8
9659.9	same	17.7	0.05	Core 8
9660.8	same	20.8	0.55	Core 8
9662.0	same	16.2	0.03	Core 8
9662.4	same	14.8	0.08	Core 8
9662.8	same	20.6	0.19	Core 8
9664.0	same	15.6	0.12	Core 8
9665.0	same	18.4	0.06	Core 8
9666.5	same	18.2	0.09	Core 8
9667.5	same	21.8	0.07	Core 8
9668.2	same	17.9	0.03	Core 8
9669.2	same	21.0	0.16	Core 8
9670.2	same	17.1	0.05	Core 8
9671.0	same	15.0	0.08	Core 8
9671.4	same	18.9	0.07	Core 8
9672.8	same	14.6	0.03	Core 8
9673.5	same	20.0	0.13	Core 8
9674.2	same	17.4	0.04	Core 8
9675.0	same	17.6	0.11	Core 8
9675.5	same	19.2	0.08	Core 8
9677.3	same	18.7	0.08	Core 8
9678.0	same	18.3	0.04	Core 8
9678.8	same	13.8	0.06	Core 8
9679.5	same	15.8	0.09	Core 8
9680.5	same	16.6	0.03	Core 8
9681.1	ss	12.1	0.03	Core 8
9682.5	same	14.9	0.02	Core 8
9683.5	same	11.8	0.03	Core 8
9684.2	same	12.4	0.02	Core 8
9685.2	same	17.0	0.04	Core 8
9686.2	same	15.9	0.04	Core 8
9687.1	same	15.3	0.02	Core 8
9687.6	same	14.9	0.03	Core 8
9688.3	same	19.0	0.06	Core 8
9689.8	same	18.1	0.06	Core 8

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
9708	sltst, v cly	24.4	42	Sidewall
9750	ss,vfg,v slty, cly	24.0	16	Sidewall
9803	same	27.9	42	Sidewall
9850	sltst, v sdy, cly	27.9	346	Sidewall
9900	ss, vfg, slty, cly	26.0	57	Sidewall
9950	sltst, v sdy, cly	22.5	2.8	Sidewall
9998	ss,vf-fg, slty	25.1	49	Sidewall
10,070	ss,vf-mg, slty,cly	21.8	40	Sidewall
10,100	sltst, sdy, cly	24.0	9.8	Sidewall
10,150	same	23.6	5.1	Sidewall
10,195	same	20.3	12	Sidewall
10,200	ss,vfg,slty,cly	23.6	5.5	Sidewall
10,205	same	26.6	8.7	Sidewall
10,210	same	26.7	28.7	Sidewall
10,243	ss,vf-fg,slty	22.4	4.3	Sidewall
10,324.2	ss	21.3	83	Core 9
10,326.6	same	25.0	2.1	Core 9
10,328.7	same	9.2	0.03	Core 9
10,330.0	same	10.6	0.02	Core 9
10,332.7	same	13.1	0.09	Core 9
10,357.1	same	14.6	15	Core 10
10,361.5	same	15.0	10.7	Core 10
10,369.7	same	13.3	1.0	Core 10
10,373.0	same	3.7	0.03	Core 10
10,373.7	same	6.7	0.71	Core 10
10,375.0	same	18.0	2.4	Core 10
10,905.3	basalt	2.4	5.8	Core 11, frac.
10,907.2	same	2.9	<.01	Core 11
10,910.7	same	8.3	1.5	Core 11, frac.
10,911.7	same	7.7	0.01	Core 11
10,913.7	same	8.2	0.09	Core 11
10,916.1	same	12.8	0.16	Core 11, frac.
10,918.5	same	11.0	0.45	Core 11, frac.
10,920.2	same	11.0	0.21	Core 11
10,921.2	same	4.5	0.01	Core 11
10,924.3	same	0.4	<.01	Core 11
10,925.3	same	0.5	3.8	Core 11, frac.
10,926.2	same	1.4	0.17	Core 11, frac.
10,927.8	same	0.4	0.15	Core 11, frac.
10,930.2	same	0.3	<.01	Core 11

Depth (Feet)	Lithology	Porosity (Percent)	Permeability (Millidarcies)	Remarks
10,933.6	basalt	0.3	0.04	Core 11, frac.
10,934.3	same	0.1	2.8	Core 11, frac.
10,936.8	same	1.0	0.02	Core 11
10,942.6	same	0.5	0.07	Core 11, frac.
13,082.1	same	9.5	0.01	Core 12
13,105.5	same	9.1	0.03	Core 12
13,106.6	same	14.2	0.01	Core 12
13,107.4	same	11.1	0.01	Core 12
13,108.4	same	11.1	<.01	Core 12
13,109.6	same	14.4	0.01	Core 12
13,110.5	same	16.0	0.04	Core 12
13,111.3	same	12.4	0.02	Core 12
13,112.4	same	13.1	0.01	Core 12
13,116.6	same	8.4	0.02	Core 12
13,121.9	same	9.8	0.03	Core 12

ORGANIC GEOCHEMISTRY

by

Arthur C. Banet, Jr.

INTRODUCTION

The geochemical analyses of the St. George Basin COST No. 1 well were designed to provide information on the organic richness, thermal maturity, and petroleum source potential of the sedimentary section at this location. Analyses were made on cuttings samples, sidewall cores, and conventional cores using standard geochemical methods. The sedimentary section between 1600 feet and approximately 10,380 feet consists of marine claystones, shales, siltstones, and sandstones. From 10,380 feet to TD the section consists of volcanic rocks and a few interbedded shales.

Four hundred forty-eight (448) samples of cuttings were sent to Geochem Laboratories, Inc., of Houston, Texas, for analysis (ref. Job No. 734). Samples were collected at intervals of 30 feet, washed, and sealed in press-on-lid cans with bactericide added to prevent biodegradation. One-half of the samples (224), representing every other interval, were analyzed. Geochem Labs reported that "several of the cans were damaged in transit" and that others "had not been collected according to instructions" (Bayliss, written communication, 1976), but no mention was made of the specific samples affected. Sixty sidewall cores and 13 conventional cores were also analyzed.

The samples were analyzed for total organic carbon (TOC), kerogen type and alteration, C_1-C_7 light gas and gasoline fractions, and C_{15}+ extractables. Cuts of the samples, aliquots of extracts, and ground rock residues were forwarded to Amoco Production Company Research Center, Tulsa, Oklahoma, for elemental analysis (carbon, hydrogen, oxygen, and nitrogen) and to Phillips Petroleum Company Research and Development, Bartlesville, Oklahoma, for stable carbon isotope analysis. Vitrinite reflectance data were provided by ARCO Exploration Company, Anchorage, Alaska.

Poorly consolidated sediments encountered during drilling necessitated the addition of walnut hulls and drilling-mud additives to prevent loss of circulation. Unfortunately, the hulls contaminated some of the analyses. Despite the addition of the hulls and additives, there was a great deal of downhole contamination which also adversely affected the analyses. Below 6700 feet, walnut hulls are a major component of the cuttings.

GEOTHERMAL GRADIENT

Geothermal gradients in most sedimentary basins range from approximately 0.90 to 3° F/100 feet. Lower gradients are common in arc trench basins, and higher gradients are reported from wells drilled in grabens (Doebl and others,

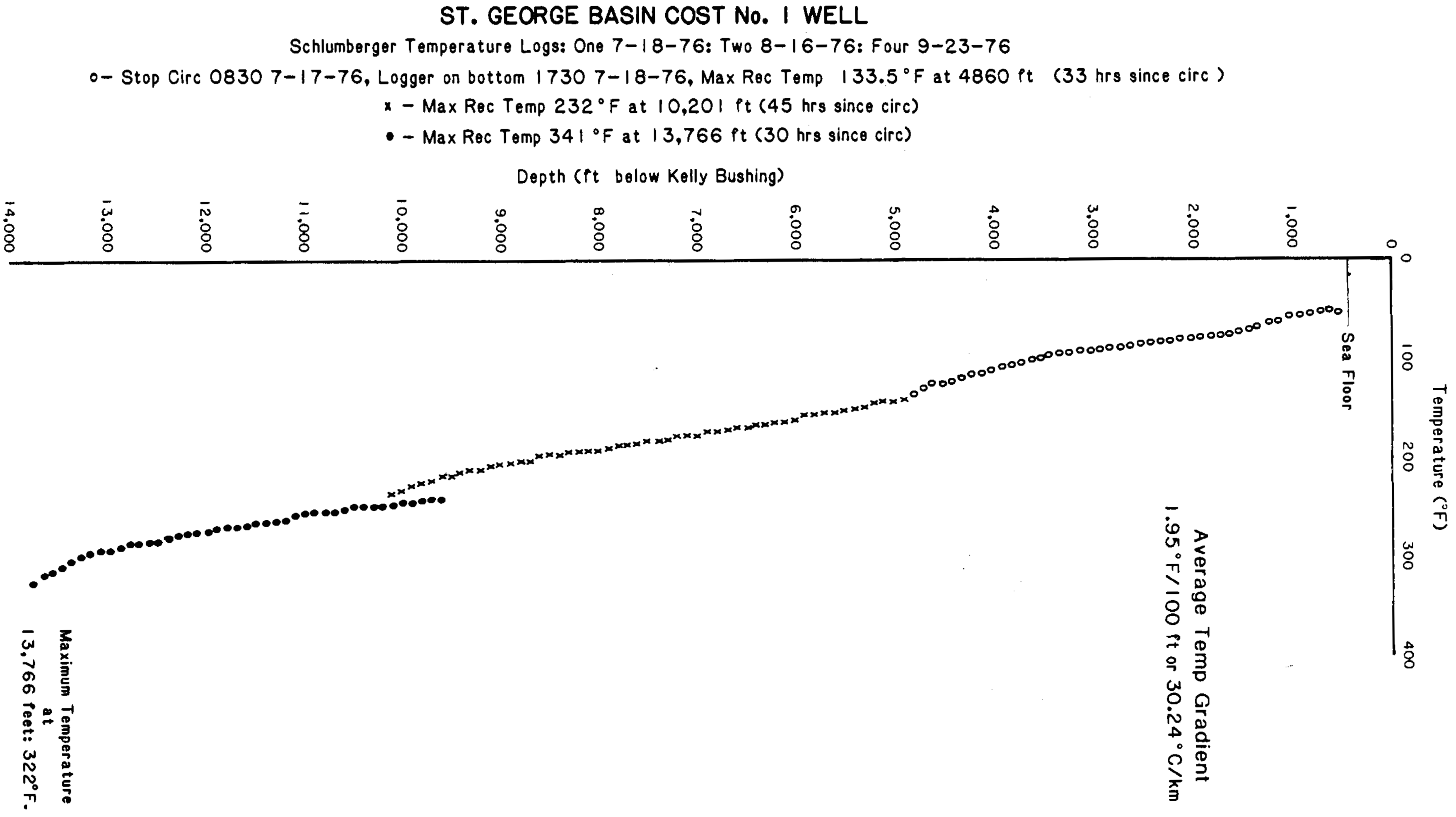


FIGURE 25. TEMPERATURE LOG DATA FROM ST. GEORGE BASIN COST NO. 1 WELL.
(Data from Schlumberger Limited)

1974). The apparent mean geothermal gradient for the No. 1 well was computed from temperature log data (fig. 25). The present geothermal gradient is 1.95°F/100 feet, which is well within the average for sedimentary basins.

GROSS LITHOLOGIC DESCRIPTION

The gross lithologic description (pl. 2) describes the cuttings samples received at Geochem Laboratories, with each identified rock type expressed as an approximate percentage. The sample descriptions are not matched to either the geophysical logs or the well site lithology. Briefly, the cuttings analyzed are as follows: 1600 to 3200 feet, claystone, light-gray and soft, with minor sandstone, unconsolidated, and siliceous shale; 3200 to 4800 feet, shale, light-gray, very silty, with minor amounts of unconsolidated sandstone; 4800 to 5500 feet, shale, light-olive-gray, with minor limestone (?) and chalk (?) (probably carbonate concretions); 5500 to 9100 feet, shale, medium- to light-gray, and sandstone, very fine to medium-grained, unconsolidated. The amount of sandstone increases with depth. By 6700 feet walnut hulls begin to appear as the predominant component of the cuttings. From 9100 to 10,200 feet, the cuttings are described as shale, medium- to light-gray, very silty, with minor amounts of walnut hulls and bentonite; from 10,200 to 10,380 feet, an admixture of shale, medium- to light-gray, very silty, and sandstone, very fine to coarse-grained, with minor amounts of walnut hulls and volcanic rock fragments.

Geochem Laboratories' gross lithologic report indicates that most of the sandstones are unconsolidated, composed of clear-to-frosted grains with good-to-excellent porosities. Most of the shales and claystones are described as slightly calcareous to calcareous. Igneous (volcanic?) rock fragments are reported in most of the description.

The volcanic section starts at 10,380 feet and extends to TD. Shale samples taken at 13,754 feet are very hard, dark-greenish-gray and non-calcareous. This is distinctly different from the shales in the overlying section. Data from the shales are probably valid but the exact depths of these samples are suspect because they do not show on the logs and there is a lot of sample mixing from upsection material.

WALNUT HULLS

Walnut hulls and other additives are often added to drilling muds whenever circulation problems develop. Careful washing and picking of chips from samples is necessary to minimize sample contamination. Some of the cuttings from the No. 1 well that were ground prior to analysis, for instance, some of the $C_{15}+$ extract samples, may have yielded spurious results because walnut hulls yield extracts much like those found in immature sediments (fig. 26). As a consequence, the Carbon Preference Index (CPI), the pristane/phytane ratio, and the total $C_{15}+$ extractables may be somewhat suspect.

TOC	33.78%
C_{15}+ total extract	7133 ppm
asphaltene	3344 ppm
paraffins and naphthenes	0.2 %

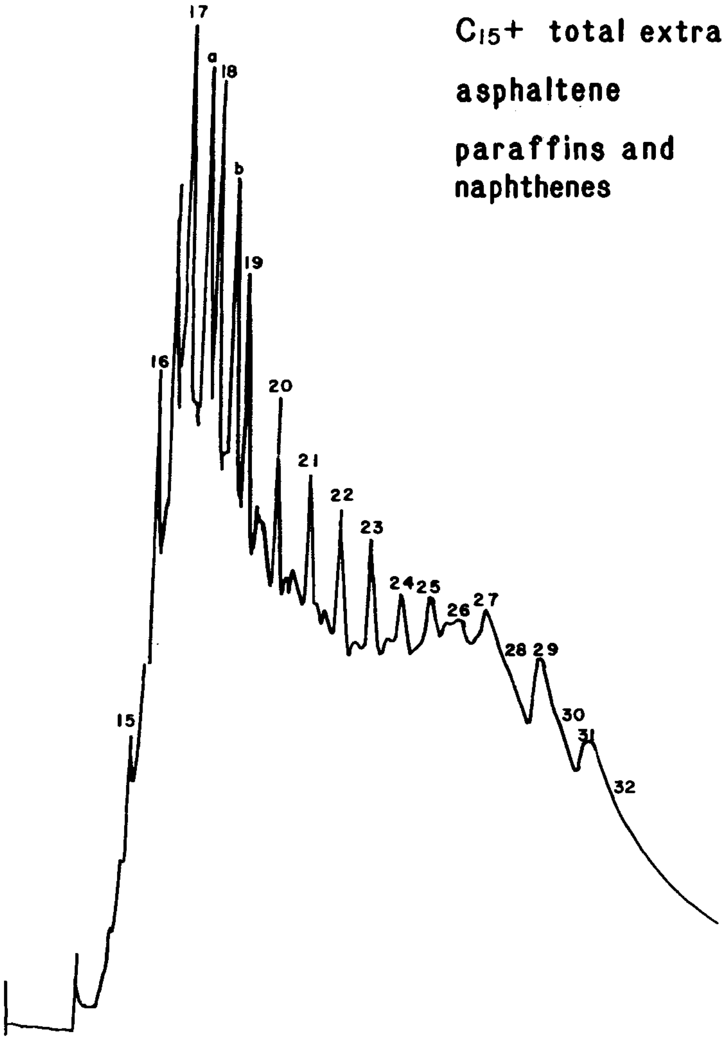


Figure 26. Analysis of walnut hull and gas chromatogram of walnut hull C_{15}+ extract showing alkane distribution, St. George Basin COST No. 1 Well. (From Geochem Laboratories, Inc.)

TOTAL ORGANIC CARBON

Total organic carbon (TOC) is perhaps the most important of the geochemical analyses; all other analyses require a sufficient amount of organic carbon to be present for meaningful results. Geochem Labs measures TOC from finely ground, acid-washed samples by combustion in a Leco carbon analyzer. Plates 1 and 2 show the TOC analyses for both cuttings and sidewall cores.

Both the carefully picked samples and the sidewall core samples are low in TOC. Almost all of the values are less than 0.5 percent except for a section between approximately 9000 and 9600 feet where TOC values reach 0.7 percent. This is still less than the average organic content (1 percent) of the average shale (Hunt, 1972). On the basis of total organic carbon present, the petroleum generating potential of the sedimentary section at this location is poor. Table 5 summarizes the TOC and source rock potential.

Table 5. Comparison of Organic Richness
(Source Rock Evaluation Reference Manual, Geochem Laboratories)

Percentage Organic Carbon (Clastics)	Percentage Organic Carbon (Carbonates)	Source Rock Potential
0-0.50	0-0.12	Poor
0.50-1.00	0.12-0.25	Fair
1.00-2.00	0.25-0.50	Good
2.00-4.00	0.50-1.00	Very Good
4.00-8.00+	1.00-2.00	Excellent

The TOC data apparently were not affected by caving because of the uniform distribution of organic carbon in the section. As expected, the volcanic section is virtually barren of organic carbon except for one point which may represent an interbedded shale. Some "finely ground" samples prepared for Soxhlet extraction were not picked clean of hulls prior to grinding. As a consequence, TOC data below 6000 feet reflect the addition of extraneous organic carbon.

KEROGEN

Kerogen is extracted from rock samples by systematically removing the soluble organic fraction with organic solvents and the mineral matrix with concentrated acids (HCl and HF), followed by flotation separation (aqueous ZnBr solution) and thorough washing. The organic residuum, kerogen, is mounted on glass slides for microscopic visual examination. Four of the main kerogen types were identified in cuttings from the No. 1 well: 1) amorphous material, presumably derived from algae, which is usually oil prone upon maturity; 2) herbaceous material consisting of spores, pollen grains, cuticles and leaf epidermis of terrigenous origin, which is mostly gas prone; 3) humic or woody material with recognizable microscopic cell structures, which is gas prone; and 4) coaly material or inertinite, which is black, unstructured, recycled organic material having no demonstrated hydrocarbon-generating potential

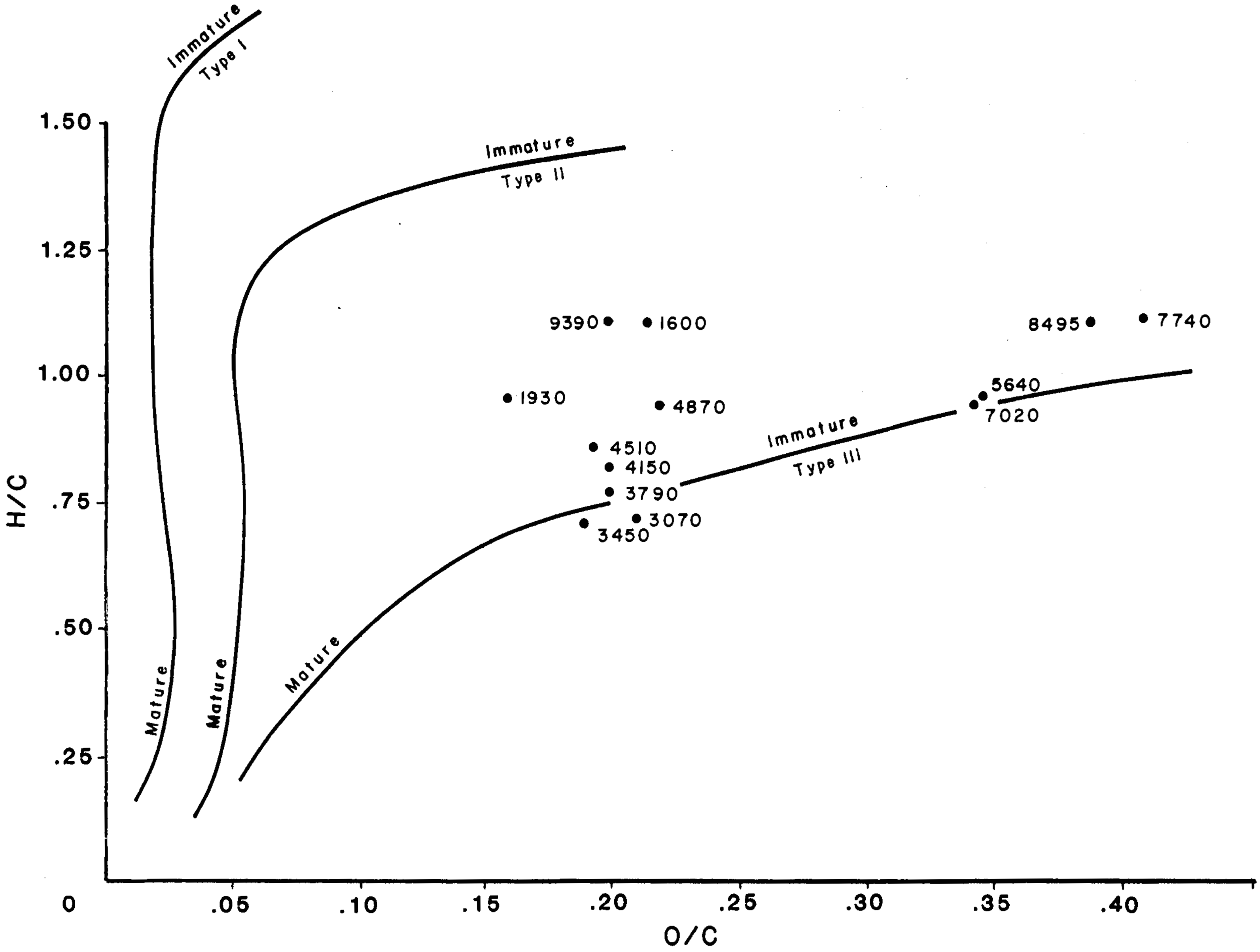


Figure 27. Van Krevelen diagram (atomic ratios) for kerogens. Depths given in feet. (Elemental analyses performed by Amoco Production Co.)

(Hunt, 1979; Tissot and Welte, 1978). The term inertinite is used in this report to minimize confusion with the palynological term "coaly," which refers to optically opaque, angular particles.

Plate 2 shows the kerogen distribution from cuttings normalized to 100 percent. Amorphous kerogen, the most important constituent for oil generation, is not found in all of the samples and, where present, is only a minor constituent. Only the shallowest sample (1600 to 1630 feet) contains greater than 25 percent amorphous kerogen. This represents a very low amount of indigenous sapropelic organic matter for marine rocks.

Herbaceous, humic, and inertinite kerogens indicate an influx of terrigenous organic matter. Herbaceous kerogen, the predominant type identified in the No. 1 well, is present in all samples in amounts ranging from approximately 25 to over 60 percent. Humic kerogen is a minor constituent in most of the samples. Inertinite is found in all of the samples. Upon reaching thermal maturity, these sediments would most probably generate gas and possibly minor condensate. However, Snowden and Powell (1982) and Smyth (1983) suggest that non-marine waxy oils may be generated from terrigenous kerogens.

Tissot, Durand, and others (1974) used hydrogen-to-carbon (H/C) and oxygen-to-carbon (O/C) ratios to characterize kerogen type and maturity. They defined Types I, II, and III as capable of generating liquid hydrocarbons, condensate and gas, and dry gas, respectively. Low H/C and high O/C ratios are diagnostic of polycyclic unsaturates and aromatics of structural and woody material. The kerogens identified from the No. 1 well are Type III and immature (fig. 27). The anomalous values seen in figure 27 and table 6 probably represent elemental analyses of walnut hull contaminants.

Table 6. Elemental analyses and atomic ratios of kerogen samples. (Elemental analyses performed by Amoco Production Co.)

DEPTHS FEET	PERCENT				RATIOS	
	C	H	O	N	H/C	O/C
1630-31	71.5	6.7	20.5	1.3	1.12	0.22
1930-31	73.1	5.9	19.4	1.7	0.96	0.16
3070-71	74.9	4.6	18.6	1.8	0.73	0.21
3430-31	74.6	4.5	19.3	1.7	0.72	0.19
3790-91	73.6	4.7	19.8	1.8	0.76	0.20
4150-51	73.7	5.0	19.4	1.9	0.81	0.20
4510-11	73.9	5.3	18.8	2.0	0.86	0.19
4870-71	71.6	5.6	20.8	2.1	0.93	0.22
5640-41	63.7	5.1	29.5	1.7	0.96	0.34
7020-21	69.9	5.1	29.3	0.7	0.94	0.33
7740-41	61.1	5.5	33.0	0.4	1.1	0.11
8495-96	61.2	5.4	33.1	0.3	1.1	0.39
9390-91	72.8	6.6	18.3	2.4	1.1	0.20

VITRINITE REFLECTANCE

Good single-mode reflectance measurements of primary vitrinite are probably the best indicator of organic maturity through the oil-generating zone. R_0 values between 0.6 and 1.2 percent (Dow, 1977), 0.6 and 1.5 percent (Tissot & Welte, 1978), and 0.6 and 1.35 percent (Hunt, 1979, p. 332) are generally accepted as the limits of generating and preserving liquid hydrocarbons. Gas may be generated to R_0 values of 3 percent or more (Hunt, 1979) owing to the thermal degradation of kerogen and previously generated hydrocarbons.

Mean values of first cycle primary vitrinite from cuttings and conventional cores are plotted on plates 1 and 2. The numbers in parentheses (pl. 2) are the size of the populations counted. Hunt (1979, p. 332) indicates that populations of 50 to 100 are necessary for valid interpretation of R_0 data, and Bayliss and Smith (1980) state that a minimum of 40 readings on vitrinite are necessary to determine thermal maturity. Based on these criteria, it is evident that the R_0 data populations from the No. 1 well are insufficient for precise interpretation. The small vitrinite data population is due to low TOC values and dilution by the unconsolidated sand. Nevertheless, several valid interpretations can be made from this data.

In the No. 1 well, sufficient thermal maturity for generating and preserving oil begins at a depth of approximately 4600 feet. Samples from the base of the sedimentary section at 10,380 feet exhibit an R_0 value of approximately 0.7 percent, which indicates that the sedimentary section is in the early stages of thermal maturity. The nearly uniform R_0 values imply either a lower than present geothermal gradient, a high sedimentation rate, or both.

The change in slope of R_0 data indicates a possible unconformity at the top of the Miocene section at 3600 feet. Above 3600 feet, the R_0 values increase from 0.37 to 0.57 percent. The rate (0.2 percent/2000 feet) is much greater than the 0.60 to 0.70 percent increase (0.1 percent/6780 feet) observed from 3600 to 10,380 feet. This trend suggests that the geothermal gradient has increased substantially since the Miocene or that sedimentation rates have been greatly reduced. There are also several reversals in the data trend where R_0 values decrease (4800 to 5200 feet; 6700 to 8200 feet; 8300 to 9300 feet). These reversals are probably due to caving and mixing of upsection material. Sloughing is so severe that R_0 data in these intervals are mostly single mode. Walnut hulls appear in the cuttings in these same intervals. Two data points below 10,380 feet may be representative of dark-gray shales that are still within the oil-generating window.

THERMAL ALTERATION INDEX

Staplin (1969) developed a technique for evaluating kerogen maturation based on changes in the color of spores, plant cuticles, pollen, algae, and amorphous organic matter. This technique records the color changes of the lightest colored in situ particulate organic matter of fine-grained rocks. On a numerical scale, the Thermal Alteration Index (TAI) ranges from 1 to 2.1 for immature rocks, 2.2 to 3.6 for mature rocks, and 3.7 to 5.0 for rocks that are past maturity (Staplin, 1969; Bayliss and Smith, 1980). This is a subjective measurement and is more widely applicable than vitrinite reflectance, but it is affected by interrelated variables such as color, light transmission, and reflectivity.

TAI measurements from cuttings and sidewall cores from the No. 1 well are in very close agreement. Both data sets indicate that thermal maturity begins at approximately 6500 feet and that the entire sedimentary section from 6500 to 10,380 feet is moderately mature. The depth of the onset of thermal maturity as indicated by TAI (6500 feet) differs from that indicated by vitrinite reflectance (4600 feet). This difference may be due to subjectivity in picking kerogen color changes, or to the small data populations used in determining R_o values. The TAI data are less sensitive and do not show a change in maturation above and below the possible unconformity at 3600 feet.

LIGHT HYDROCARBONS

The C_1-C_7 light hydrocarbons (obtained from blended "picked" cuttings and head space gas) are important direct indicators of hydrocarbon generation. Significant amounts of the C_2-C_7 fraction are found in oils and thermally mature sediments but not in plants, animals, and thermally immature sediments. Plate 2 shows minor amounts, approximately 1000-8000 ppm, of C_1-C_4, mostly methane, in the section from 1600 to 5000 feet. Since most of this section is thermally immature, the methane probably migrated from mature rocks. A less likely origin is methanogenic bacteria. The concentration of methane decreases downward through the section. The C_2-C_4 fraction shows minor increases with depth, but does not exceed 100 ppm concentration. There is an increase in wetness at approximately 4600 feet, coincident with the onset of R_o thermal maturity, and between 9000 and 10,000 feet, coincident with a decrease in methane and a minor increase in TOC. The C_5-C_7 fraction shows no systematic changes with depth. The lack of response of these maturity indicators is due to very low concentrations of organic carbon throughout the section, relatively minor increases in thermal maturity with depth, and the presence of non-indigenous methane in the upper 5000 feet of section. Replicate analyses are plotted where data are available (for samples above 6700 feet). The replicate concentrations are generally less than original analyses but show the same changes with depth.

C_{15}+ EXTRACTABLE BITUMENS

Bitumens, solvent-soluble organic material in sedimentary rocks, are composed of alkanes (n- and i-), naphthenes (cyclic alkanes), and asphaltenes (nitrogen, sulfur, and oxygen compounds). They are routinely analyzed in the C_{15}+ fraction. Extensive compilations of these data (Hunt, 1977, 1979; Tissot and Welte, 1978) suggest that C_{15}+ extractables are mostly the products of catagenesis and are dependent upon the concentration of TOC. The average C_{15}+ content of source rocks in petroliferous basins worldwide is in excess of 800 ppm (Tissot and Welte, 1978).

Total C_{15}+ extracts are plotted on plate 2 for both cuttings and sidewall cores. The extractable bitumens from the sidewall cores are anomalously high in the immature section, possibly because of contamination. The sidewall core extracts are only marginally higher than those from cuttings in the deeper samples. Almost all of the samples have less than 800 ppm C_{15}+ extractable bitumen and should not be considered as prospective source rocks.

Figure 28 shows gas chromatograms of the C_{15}+ fractions. Naphthenes, a major constituent in the samples, were not removed by molecular sieving and interfere somewhat with the alkane distribution. Alkanes are major constituents that are poorly resolved in chromatograms from the shallow samples. Chromatograms of samples from deeper in the section show the alkane fraction becoming better defined and resolved.

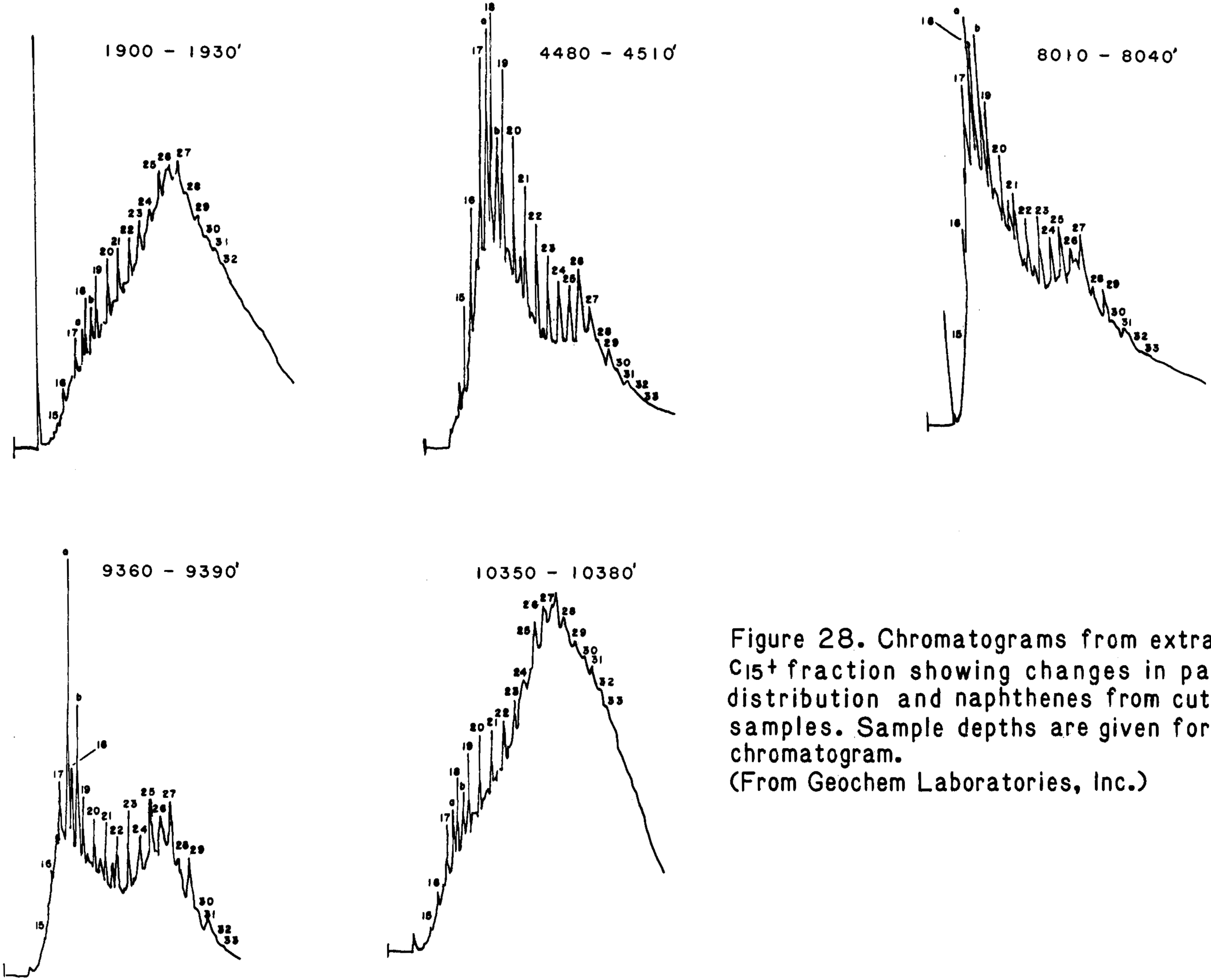
Figure 26 shows a chromatogram of walnut hull extracts that closely resembles chromatograms from cuttings samples extracts (fig. 28). The hulls yielded 33.78 percent TOC, 7133 ppm C_{15}+ extractable bitumen, and a combined paraffin and naphthene fraction of 0.2 percent. It is very likely that figure 28 shows more the effect of walnut hull contamination than changes in the alkane distribution due to increasing maturity.

CARBON PREFERENCE INDEXES

The Carbon Preference Index (CPI) is another method of determining the onset of thermal maturity. It is based on the odd/even ratio of n-alkanes. Bray and Evans (1961) pioneered this method, which is modified by Geochem Laboratories as follows:

$$CPI = \frac{\left[\dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{22}+C_{24}+C_{26}+C_{28}} + \dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{20}+C_{22}+C_{24}+C_{26}}\right]}{2}$$

CPI values are high (>1.0) and erratic in the section above 4500 feet. This type of distribution is typical of immature sediments. From 4500 to approximately 7000 feet, CPI values are generally less than 1.0, which Bray and Evans determined as the beginning of the oil-generating zone. From 7200 to approximately 10,200 feet, CPI values are again high and erratic, which may reflect downhole contamination. This is also reflected by an R_o reversal in the same interval.



1900 - 1930′

4480 - 4510′

8010 - 8040′

9360 - 9390′

10350 - 10380′

Figure 28. Chromatograms from extracted C_{15}+ fraction showing changes in paraffin distribution and naphthenes from cuttings samples. Sample depths are given for each chromatogram.
(From Geochem Laboratories, Inc.)

Initial pristane/phytane ratios are low, generally less than 1. This is normal for marine sediments (Hunt, 1979), but anomalous considering the amount of terrigenous material in these samples. The pristane/phytane ratio begins to increase at approximately 8500 feet, which coincides with the increase in wetness and C_{15}+ extractable hydrocarbons. The pristane/phytane ratio drops abruptly through the predominantly volcanic section.

Stable $\delta^{13}C$ isotope measurements for C_{15}+ extracts and kerogen are listed in table 7. The $\delta^{13}C$ values of the kerogen range from -25.3 per mil to -26.6 per mil, which is in the range where marine and terrestrially derived $\delta^{13}C$ values overlap (Tissot and Welte, 1978). This indicates that there are significant contributions of organic matter from both marine and terrigenous sources. The $\delta^{13}C$ values from the C_{15}+ extracts are 2 to 3 per mil lighter than the kerogen $\delta^{13}C$, which is considered normal (Tissot and Welte, 1978). The $\delta^{13}C$ values given for samples collected from the predominantly volcanic and pyroclastic rocks below 10,380 feet are probably the result of caving and contamination.

Table 7.
$\delta\,^{13}C$ Compositions

Depth (Feet)	Saturates (Per mil)	Asphaltenes (Per mil)	Kerogen (Per mil)
1600 - 1630	- 27.2	- 26.9	- 25.5
1900 - 1930	- 27.4	- 27.2	- 25.6
2320 - 2350	- 26.9	- 26.6	- 26.3
2680 - 2710	- 26.7	- 27.3	- 25.4
3040 - 3070	------	- 26.8	- 25.6
3400 - 3430	- 27.2	- 27.5	- 25.3
3760 - 3790	------	- 27.5	- 25.3
4120 - 4150	- 27.3	- 27.2	- 25.4
4480 - 4510	- 27.2	- 26.4	- 25.7
4840 - 4870	- 28.2	- 26.6	- 24.6
5250 - 5280	- 27.1	- 26.1	- 24.4
5610 - 5040	- 27.0	- 28.0	- 25.5
5940 - 5470	- 27.2	- 25.9	- 25.5
6300 - 6330	- 27.5	- 26.1	- 25.4
6660 - 6690	- 27.3	- 26.6	- 25.2
6990 - 7020	- 28.1	- 27.3	- 25.8
7350 - 7380	- 27.8	- 27.0	- 25.4
7710 - 7740	- 28.1	- 27.2	- 25.8
8010 - 8040	- 29.3	- 27.1	- 26.4
8430 - 8460	------	- 27.1	- 26.5
8640 - 8670	- 29.1	- 27.4	- 25.7
9000 - 9030	- 27.5	- 26.8	- 26.4
9360 - 9390	- 27.2	- 24.4	- 26.6
9690 - 9720	- 28.0	- 27.4	- 25.3
10,050 - 10,055	- 28.1	- 27.3	- 26.6
10,350 - 10,380	- 28.8	- 27.0	- 25.4
(predominantly volcanic and pyroclastic rocks)			
10,680 - 10,710	- 27.8	- 27.5	- 26.5
11,010 - 11,040	- 26.7	- 26.1	- 26.9
11,340 - 11,370	- 27.1	- 27.3	- 26.6
11,700 - 11,730	- 28.0	- 26.5	- 26.9
12,060 - 12,090	- 27.1	- 26.7	- 25.8
12,426 - 12,450	------	- 27.1	- 25.9
12,750 - 12,780	- 27.3	- 27.7	- 25.4
13,060 - 13,090	- 27.6	- 27.3	- 25.5
13,440 - 13,470	- 27.6	- 27.6	- 25.7
13,740 - 13,755	- 27.5	- 27.1	- 25.6

$$\left[\delta\,^{13}C = \frac{^{13}C/^{12}C \text{ sample}}{^{13}C/^{12}C \text{ standard}} - 1 \right] \times 1000$$

Standard-PDB (Pee Dee Belemnite)

SUMMARY AND CONCLUSIONS

Organic geochemical analyses of cuttings samples, sidewall cores, and conventional cores show that the sedimentary section penetrated by the St. George Basin COST No. 1 well consists of predominantly light- to medium-gray claystone, shale, siltstone, and sandstone. The entire sedimentary section analyzed is marine and low in total organic carbon. The average TOC value is approximately 0.5 percent. The maximum TOC is 0.74 percent, which is too low to be considered a good petroleum-generating source rock (Hunt, 1977). Kerogens isolated from samples throughout the section are predominantly herbaceous and inertinite types with minor amounts of the humic and amorphous varieties. The light- to medium-gray color of the cuttings indicates that these sediments were deposited under oxic conditions. The low TOC values reflect the lack of preservation of organic matter in this nonreducing environment. The predominance of herbaceous kerogen with low H/C and high O/C ratios implies a substantial influx of terrigenous organic material. Organic facies modeling (Demaison, 1981; Summerhayes, 1981) suggests that light-gray to olive-colored marine rocks characterized by extensive bioturbation, low TOC, and kerogens that are predominantly herbaceous, humic, and inertinite (terrigenous) are likely to generate gas, although oil may be possible (Snowden and Powell, 1982; Smyth, 1983).

Thermal maturity indicators, such as R_0, gas wetness, and CPI, indicate that thermal maturity sufficient for generating and preserving petroleum hydrocarbons begins at approximately 4600 feet in the No. 1 well. However, TAI measurement places the threshold of petroleum generation at approximately 6500 feet. All of the thermal maturation indicators increase only minimally with depth. R_0 values vary from approximately 0.6 to 0.7 percent from 4600 to 10,380 feet and TAI varies from 2.2 at 6500 feet to 2.3 at 10,380 feet, which suggests either a low geothermal gradient, a high sedimentation rate, or both. Because of the low TOC and minimal thermal maturation there is only slight generation of C_1 - C_7 and C_{15}+ hydrocarbons at depth.

ENVIRONMENTAL CONSIDERATIONS

by

Allen J. Adams

Atlantic Richfield Company, as operator for itself and other participants, submitted a letter to the Minerals Management Service (formerly Conservation Division, USGS) dated February 20, 1976, 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, and an Oil-Spill Contingency Plan. A site-specific biological survey and a geohazards survey at the primary and alternate sites were required to investigate and document 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 for this well.

A Deep Stratigraphic Test well is drilled 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 is not intended to locate hydrocarbon accumulations. The St. George Basin COST No. 1 well was drilled off-structure. The information gathered from this test well was used to 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 process, an Environmental Assessment (EA) under the National Environmental Policy Act (NEPA) directive was prepared. An 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 NEPA, Section 102(2)(C). An EA addresses and includes the following: a description of the proposed action, a description of the affected environment, the environmental consequences, alternatives to the proposed action, unavoidable adverse environmental effects, and controversial issues.

On the basis of existing data and regulations in effect at the time the proposal was reviewed, factors taken under advisement by MMS before giving approval of the drilling plan and monitored during drilling operations included 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 a 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 clockwise circulation in the vicinity of Rat Island, and a counter-clockwise circulation system within the Western Aleutian Basin. 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. The well location is ice free from May through December, and is essentially open, with less than one-tenth surface coverage, from January through April. Problems of superstructure icing were not encountered.

OCS Order No. 2 required the operator to collect meteorological and oceanographic information to aid in future operations in the area. 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 water salinity, density, dissolved oxygen, and pH 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 commerical 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, grain size analysis, plankton tows, infaunal sampling, and trawling, ARCO (Tetra Tech, 1976) determined the relative abundance and types of organisms present in various habitats. These surveys were conducted from May 29 to May 31, 1976. The results are summarized as follows:

1. The major phytoplankton populations consisted of diatoms and dinoflagellates. The dominant zooplankton component was copepods. Rank abundances of zooplankton were presented.

2. Grab samples contained a predominance of polychaete worms and amphipod crustaceans. The species diversity was low. The total number of species for the nine grab samples was 52.

3. Otter trawl samples indicated that the most dominant epibenthic species (by numerical abundance and biomass) was the sea anemone Liponema brevicornis, an unexpected occurrence. The second most dominant species was the small cushion star Ctenodiscus crispatus. The most abundant nectobenthic organism

was the commercial shrimp Pandalus borealis, which represented 99 percent of the total shrimp haul. There were relatively few Tanner crabs present at the No. 1 well site.

On the basis of the biological survey conducted by Tetra Tech, the area supported no unique habitats or species that would require rejection or modification of the drilling program. It was determined that normal operations at either of the two sites would not adversely affect the environment. No additional biological resources were discovered during the drilling operations. No adverse impacts on existing biological resources were apparent from drilling activities.

Marine Mammals, Endangered Species, and Birds

The marine resources of the St. George Basin include the Pribilof fur seal herd, concentrations of harbor seals, sea lions, whales, and millions of sea birds and waterfowl.

The primary and secondary drill sites were located on or near the migration routes of several species of endangered marine mammals, including the bowhead, Pacific right, fin, sei, blue, humpback, gray, and sperm whales. The proposed program was submitted to the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) for review and comment regarding potential impacts of the operation on living resources in the area. A letter was received from NMFS recommending stipulations to be carried out in concert with the Alaska OCS Orders, March 1976, and was included as an attachment to the EA.

The most abundant homotherm observed was the black-legged kittiwake. Fulmars, common murres, glaucous-winged gulls, a petrel, stray western kingbirds, and northern sea lions were observed in the study area during the period of the biological survey.

Fisheries

St. George Basin contributes significantly to Bering Sea fisheries production. In the past, Bering Sea fishery resources have been largely exploited by Japanese, Korean, and Soviet fishing fleets, but with the advent of extended jurisdiction, NMFS predicted that these resources would be intensively harvested by U.S. fishermen. Approximately 315 species of fish are present in the Bering Sea, of which 25 are commercially valuable. Herring, salmon, cod, halibut, ocean perch, and various flatfish are the most important of the commercial species. Noteworthy also are the productive groundfish stocks, valuable populations of King and Tanner crab, and western Alaska salmon.

CULTURAL RESOURCES

It was determined that cultural and archeological surveys would not be required for the St. George Basin well sites, as they were located in a low-probability area for cultural resources. If the TV transects, side-scan sonar, or magnetometer surveys had indicated unexplained anomalies, a review by a qualified marine archeologist would have been required and 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 were 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 other additives were either nontoxic or would chemically neutralize in the mud or upon contact with seawater. No oil-based drilling 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 treated sewage, gray water, and some drilling by-products, were discharged in accordance with regulations set forth by the U.S. Environmental Protection Agency (EPA).

CONTINGENCY PLAN 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 programs for contingency operations and identified 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 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 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 all equipment that was available from other response organization sources, agreements to commit these resources, and requirements for obtaining the equipment.

The probability of encountering hydrocarbons that could cause a blowout at any depth was minimized 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.

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

As part of the EA process, the proposed program was submitted to the appropriate Federal and State agencies, as well as interested parties, for comments. Responses were included as part of the EA. On the basis of the EA, on May 11, 1976, the Oil and Gas Supervisor, Alaska Area, with the concurrence of the Conservation Manager, signed a Finding of No Significant Impact (FONSI) on ARCO's proposed action and determined that an Environmental Impact Statement was not required. A notice was issued to that effect. The Office of the Oil and Gas Supervisor consequently issued a letter to ARCO approving their proposed action. The EA and 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. 1 Well was drilled to a measured depth of 13,771 feet. The Kelly Bushing was 98 feet above sea level and 540 feet above mudline. The water depth was 442 feet. The well site was approximately 105 miles southeast of St. George Island, Alaska. Drilling commenced on July 2, 1976, and was completed on September 22, 1976. The well was drilled from the Ocean Ranger, a self-propelled semisubmersible column-stabilized mobile drilling unit. Three strings of casing were set during drilling: 30-inch casing at 642 feet, 20-inch casing at 1556 feet, and 13 3/8 inch-casing at 4833 feet. The drilling fluid program was as follows: seawater and spotted viscous gel pills to 1580 feet; 8.6 pounds/gallon fresh-water mud to 4200; 9.0 to 9.6 pounds/gallon mud from 4200 to 13,771 feet (TD).

Thirteen conventional cores, 550 percussion sidewall cores, and well cuttings collected at 30-foot intervals (from 1600 to 13,755 feet) were analyzed for porosity, permeability, lithology, hydrocarbon content, and paleontology.

Logging runs were made at depths of 4921 feet, 10,217 feet, 13,006 feet, and 13,771 feet. The types of well logs run are listed in the Operational Summary chapter. No drill stem tests were made.

As required by 30 CFR 251, the operator (ARCO) filed a Drilling Plan, Environmental Report, Oil-Spill Contingency Plan, and Coastal Zone Management Certification. In addition, the Minerals Management Service (formerly U. S. Geological Survey, 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. 1 well were defined on the basis of microfossil content, lithological and log characteristics, correlation with the No. 2 well, seismic character, and absolute dating techniques. The strata encountered in the No. 1 well were Pliocene from 1600 to 3600 feet, Miocene from 3600 to 5370 feet, Oligocene from 5370 to 8410 feet, and Eocene from 8410 to 10,380 feet. The age of the predominantly igneous section from 10,380 to 13,771 feet could not be determined. It is provisionally assigned an age of middle Eocene or older, but may be as old as Mesozoic.

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

Three seismic horizons in the No. 1 well were mapped and correlated across the St. George graben: the basement unconformity between Cenozoic sediments and the acoustic basement, 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 indicate that the most common organic material present is Type III humic kerogen. Average total organic carbon values in the well are low (0.5 percent) and the maximum value was only 0.74 percent. Sufficient maturity for gas generation was not attained in the sedimentary section penetrated. Adequate thermal maturity for peak oil generation may occur as high as 4,600 feet. There is no evidence of crude oil or oil-associated gases. The calculated geothermal gradient is 1.95°F per 100 feet.

It is probable that strata with better reservoir and source rock characteristics than those encountered in the No. 1 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. 1 Well

Schlumberger Offshore Services
Anchorage, Alaska

Arrow Plot
Runs 1, 2, 3

2 in. Borehole Compensated Sonic Log
Runs 1, 2, 3, 4 4902-13,760 ft

5 in. Borehole Compensated Sonic Log
Runs 1, 2, 3, 4 4902-13,760 ft

5 in. Cement Bond Log - VDL
Run 1 1500-4833 ft

Cement Bond Log-Gamma Ray
Run 1 1400-4829 ft

5 in. Compensated Neutron Formation Density
Runs 1, 2, 3 60-13,003 ft

5 in. Compensated Formation Density Log Gamma-Gamma
Runs 1, 2, 3 60-13,003 ft

Continuous Dipmeter
Runs 1, 2, 3 1557-13,001 ft

Dipmeter Cluster Listings
Runs 1, 2

Delta Chlorides Log

5 in. Dual Induction-Laterolog
Runs 1, 2, 3, 4 1553-13,760 ft

2 in. Dual Induction-Laterolog With Linear Correlation Log
Runs 1, 2, 3, 4 1553-13,760 ft

Dual Induction-Laterolog for SP Correlation
Run 3

Gamma Ray
Run 1 1535-2886 ft

Schlumberger - cont.

Instantaneous Drilling Evaluation Log
1600-13,771 ft

2 in. Microlaterlog-Microlog With Caliper
Runs 1, 2 1554-10,208 ft

5 in. Microlaterlog-Microlog With Caliper
Runs 1, 2 1554-10,208 ft

Physical Formation Log
1600-13,771 ft

2 in. Sonic Log Long Spacing V.T.
Run 1 4829-10,214 ft

5 in. Sonic Log Long Spacing V.T.
Run 1 4829-10,214 ft

2 in. Sonic Log Gamma Ray Long Spaced 8-10/10-12 in.
Run 2 10,000-13,001 ft

5 in. Sonic Log Gamma Ray Long Spaced 8-10/10-12 in.
Run 2 10,000-13,001 ft

Saraband Synergetic Log
1570-10,400 ft

2 in. Temperature Log
Run 1 460-4860 ft
Run 1 2000-4500 ft
Run 3 9000-13,001 ft
Run 4 9500-13,765 ft

5 in. Temperature Log
Run 2 4800-10,200 ft
Run 4 9500-13,766 ft

Geogram Surveys

Pressure Evaluation Profile
1600-13,771 ft

Atlantic Richfield Co.
Anchorage, Alaska

Lithology Log
1600-13,771 ft

Seismic Reference Service
Anchorage, Alaska

Velocity Surveys
Runs 1, 2, 3, 4 1600-13,700 ft

Velocity Curves/Time Comparisons

Velocity Records-Trace Arrangements

Shot Point Records

Mobil Research and Development Corp.
Dallas, Texas

Isotropic Age Dating

Union Oil and Gas Division
Anchorage, Alaska

Lithology, Age, and Petrography From Cores 9, 10, 11

Elliot Geophysical Company
Tucson, Arizona

Volume Magnetic Susceptibility

Amoco Production Co.
Tulsa, Oklahoma

Water Analysis
Density and Porosity of Shale cuttings
Elemental Analysis

Biostratigraphics
San Diego, California

Final Paleographic Report

Anderson and Warren
San Diego, California

Sidewall Core Descriptions

Core Laboratories
Dallas, Texas

Core Analysis and Petrographic Studies of Cores and Sidewall Cores
Sidewall Core Descriptions
Cores Studies for Cores 1-13 and Sidewall Cores
Core Photographs-Black and White Prints and Color Slides

PBI Inc.
Golden, Colorado

Acoustic Core Measurements Final Report

Shell Oil Company
Houston, Texas

Scanning Electron Microscope Photographs 2 v.
Core Analysis

Geochem Laboratories, Inc.
Houston, Texas

Hydrocarbon Source Facies Analysis
Gas Composition Analysis

Cities Service
Tulsa, Oklahoma

Analysis of Basalt Samples

Teledyne Isotopes
Westwood, N.J.

K-Ar Age Determination

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

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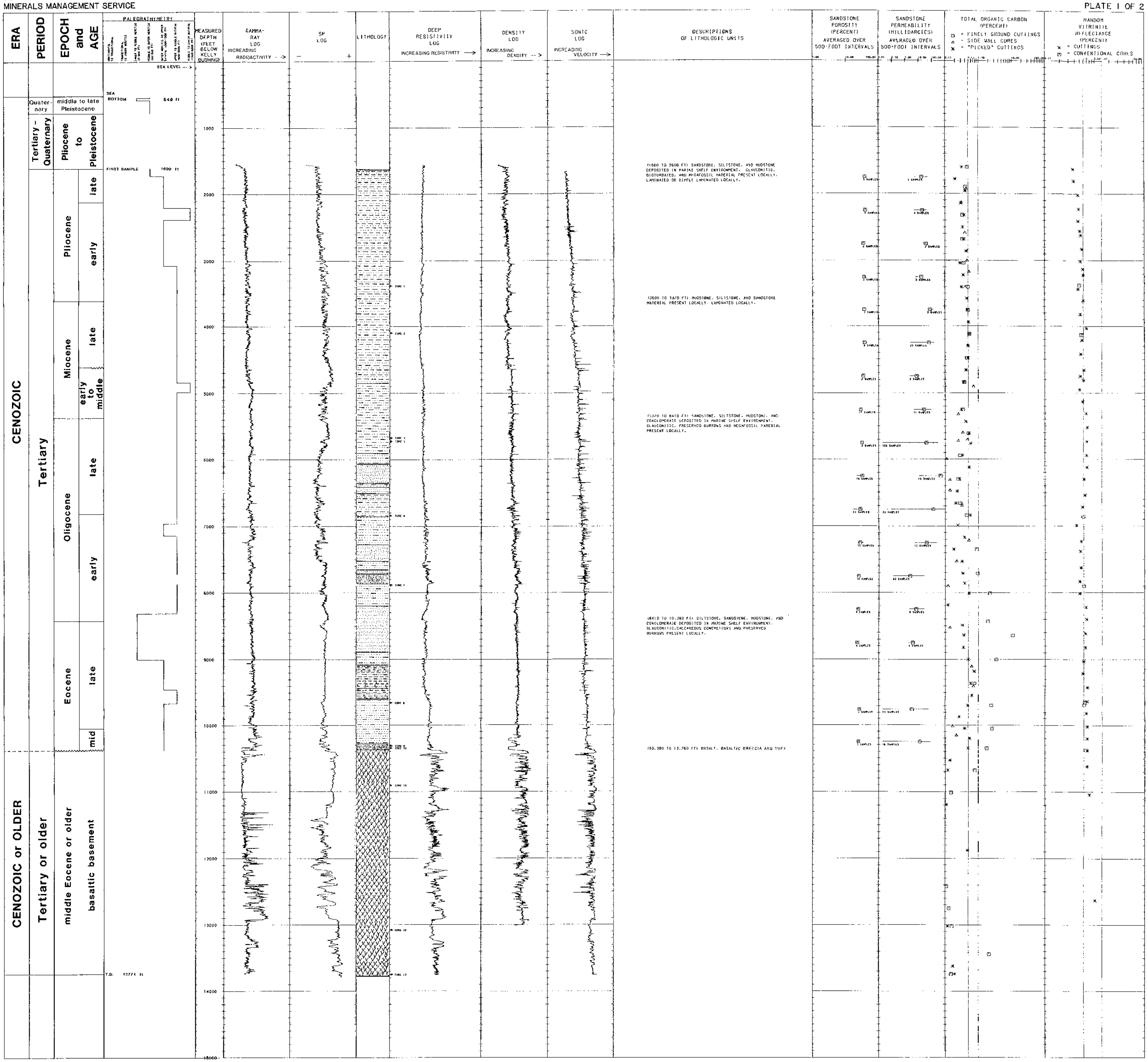
PLATE 1 OF 2



(1600 TO 3600 FT) SANDSTONE, SILTSTONE, AND MUDSTONE DEPOSITED IN MARINE SHELF ENVIRONMENT. GLAUCONITIC, BIOTURBATED, AND MEGAFOSSIL MATERIAL PRESENT LOCALLY. LAMINATED OR RIPPLE LAMINATED LOCALLY.

(3600 TO 5370 FT) MUDSTONE, SILTSTONE, AND SANDSTONE MATERIAL PRESENT LOCALLY. LAMINATED LOCALLY.

(5370 TO 8410 FT) SANDSTONE, SILTSTONE, MUDSTONE, AND CONGLOMERATE DEPOSITED IN MARINE SHELF ENVIRONMENT. GLAUCONITIC. PRESERVED BURROWS AND MEGAFOSSIL MATERIAL PRESENT LOCALLY.

(8410 TO 10,380 FT) SILTSTONE, SANDSTONE, MUDSTONE, AND CONGLOMERATE DEPOSITED IN MARINE SHELF ENVIRONMENT. GLAUCONITIC, CALCAREOUS CONCRETIONS AND PRESERVED BURROWS PRESENT LOCALLY.

(10,380 TO 13,760 FT) BASALT, BASALTIC BRECCIA AND TUFF

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PLATE 2 OF 2