UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGICAL AND OPERATIONAL SUMMARY, ATLANTIC RICHFIELD LOWER COOK INLET, ALASKA, COST WELL NO. 1

By John C. Wills, J. G. Bolm, G. H. Stewart, Ronald F. Turner, Maurice B. Lynch, George W. Petering, John Parker, and Brian Schoof.

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

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INTRODUCTION

This open-file report is presented in accordance with Title 30, Code of Federal Regulations, Chapter II, paragraph 251.15, which requires that geological data and processed geological information acquired from the Continental Offshore Stratigraphic Test (COST) wells on the Outer Continental Shelf (OCS) be made available for public inspection following the issuance of the first Federal lease within 50 geographic (nautical) miles (92.6 km) of the drill site. Tracts within this distance of the site of the Atlantic Richfield Lower Cook Inlet, Alaska, COST Well No. 1 were offered for lease in OCS Sale No. CI on October 27, 1977, and the first leases became effective December 1, 1977.

The Atlantic Richfield Lower Cook Inlet, Alaska, COST Well No. 1, which will be referred to as "the COST well" hereafter, was drilled on OCS Lease Tract 46, Block 489, OCS Map 5-2 (Seldovia), in 216 feet

(66 m) of water approximately 42 (statute) miles (68 km) southwest of Homer, Alaska, and 20 miles (32 km) from shore (fig. 1). There were no bids on the OCS Lease Tract 46 at the lease sale October 27, 1977.

The COST well was drilled as a deep stratigraphic test to acquire information on the structure, stratigraphy, and geochemistry of the unexplored area. Nineteen companies shared the costs of drilling; Atlantic Richfield Company served as operator for the group. The U.S. Geological Survey received geological information from this well, as required by regulations.

On June 3, 1977, Atlantic Richfield Company was issued the final permit to drill a 16,500 foot (5029 m) deep stratigraphic test well to test the hydrocarbon potential of the Naknek and Chinitna Formations. Because the COST well was drilled primarily for geologic information, it was intentionally located off-structure to reduce the possibility of penetrating significant quantities of hydrocarbons. The well was spudded on June 10, 1977, and plugged and abandoned at a total depth of 12,387 feet (3778 m) relative to the rotary Kelly bushing (RKB) on September 24, 1977. Drilling was terminated on September 19, 1977, before the proposed depth of 16,500 feet was reached in order to comply with regulations required by the OCS Lower Cook Inlet Lease Sale October 27, 1977.

This report expresses all depths in the well in feet below the rotary Kelly bushing because that is the unit in which the original measurements were made. These depths may be converted to depths in feet below mean sea level by subtracting 100 feet (31 m).

This introduction and the section on well data were written by G. H. Stewart. John C. Wills and Maurice B. Lynch wrote the sections

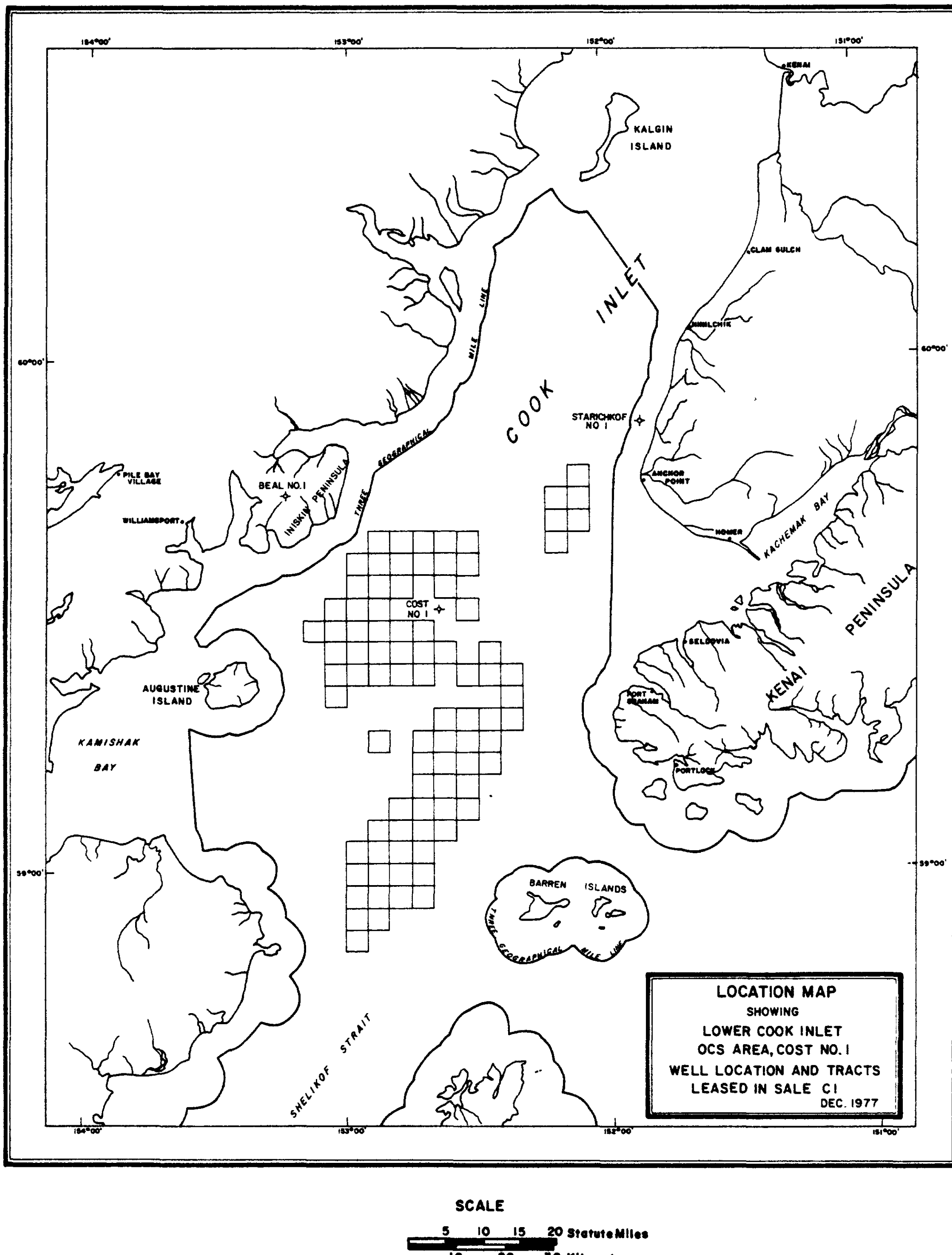

FIGURE 1 – LOCATION MAP

on stratigraphy and geophysical log interpretation. J. G. Bolm and George W. Petering wrote the petrography section. The sections on paleontology, geophysics, and environmental considerations were written by Ronald F. Turner, John Parker, and Brian Schoof, respectively. John Wills coordinated the overall writing of the report.

WELL DATA

Summary of Well Data

Lease designation: Unleased

Well name and number: Atlantic Richfield Lower Cook Inlet COST Well No. 1, OCS 77-5 No. 1

Location:

x = 520,173.68

y = 6,597,628.17

Block 1375N,105E (Block No. 489, Tract No. 46) OCS Map 5-2 Seldovia.

Latitude: $59^{o}31'06.3445''$ N

Longitude: $152^{o}38'36.6037''$ W

Classification: Offshore deep stratigraphic test

Elevation: Rotary Kelly bushing 100 feet (31 m)

Water depth: 216 feet (66 m)

Spud date: June 10, 1977

Date total depth reached: September 19, 1977

Completion date: September 24, 1977

Status: Plugged and abandoned

Total depth: 12,387 feet RKB (3778 m)

Plug-back depth: 425 feet RKB (130 m), 109 feet (33 m) below sea floor

Operator: Atlantic Richfield Company

Participants

Aminoil USA, Inc.

Amoco Production Company

Atlantic Richfield Company

BP Alaska Exploration

Champlin Petroleum Company

Chevron USA

Cities Service Oil Company

Depco, Inc.

Exxon Company, USA

Freeport Oil Company

Getty Oil Company

Gulf Energy & Minerals

Hunt Oil Company

Mobil Oil Corporation

Murphy Oil Corporation

Phillips Petroleum Company

Shell Oil Company

Texaco Incorporated

Union Oil Company of California

Principal contractor: ODECO International, Inc.

OCEAN RANGER - Semi-submersible drilling vessel

Support contractors and services:

Adolf Curry--support boats

Alaska Aeronautical, Inc.--air transportation

Big T Oilfield Services--expediting services

Christensen Diamond--bits

Eastman Whipstock--directional survey

Evergreen Helicopters of Alaska, Inc.--helicopters

GBR Equipment Rental--tool rental

Halliburton Services--cement

Hughes Tool Company--bits

International Technology Ltd.--position survey

IMCO Services, Inc.--mud

Land and Marine Rental Company--casing services and rentals

Manley Terminals--warehouse, office space, and logging

Oceaneering International, Inc.--diving

ODECO International Corporation--rig

Offshore Logistics, Inc.--boats

Regan Offshore International, Inc.--wellheads

Smith Tool Company--bits

Tri-State Oil Tools--tool rentals

Geoscience contractors and services:

The Analysts, Inc.--mud logging

BBN Geomarine Services Company--hazard survey

Geoscience contractors and services (continued):

Core Laboratories--core & cutting and analysis

Dames and Moore--meteorological services and bio-assay

Geochem Laboratories, Inc.--geochemical analyses

Schlumberger Ltd.--logging

Seismic References Service--velocity survey

Warren Anderson and Associates--micropaleontology

Operational Data

Mud Program: The drilling fluid used for the initial 1346 feet (410 m) of drilled hole below the ocean floor was salt water. From this point to total measured depth of 12,387 feet, a lignosulfonate mud was used. A mud log was made from measured depths of 1350 to 12,387 feet.

Hole Dimensions: A 36-inch hole was drilled to a depth of 130 feet (40 m) below the ocean floor (446 feet RKB), thence a 26-inch hole to 1030 feet (314 m) below the ocean floor (1346 feet RKB), a 17 1/2-inch hole from 1030 feet (314 m) to a total depth of 4580 feet (1396 m) below the ocean floor (4896 feet RKB), and a 12 1/4-inch hole from 4580 feet (1396 m) to a total depth of 12,071 feet (3680 m) below the ocean floor (12,387 feet RKB). A diagram of casing depths is show in Figure 2.

Hole Deviation: The well was drilled as a vertical hole. At total depth the hole was classified as straight.

Pipe Record:

Size	Depth Set	Hole Size	Cementing Record	Casing Recovered
30 inch	417 feet	36 inch	1000 sx "G" w/2 1/4% GEL w/3% $CaCl_2$ + 1537 sx "G" w/3% $CaCl_2$	35 feet
20 inch	1325 feet	26 inch	1804 sx "G" w/2 1/4% GEL w/3% $CaCl_2$ + 400 sx "G" w/3% $CaCl_2$	35 feet
13 3/8 inch	4840 feet	17 1/2 inch	1700 sx "G" w/2 1/2% GEL w/2% HR-7, w/.03% NF-1 + 400 sx "G."	232 feet

Note: Drill floor 100 feet (31 m) above mean water level, water depth 216 feet (66 m).

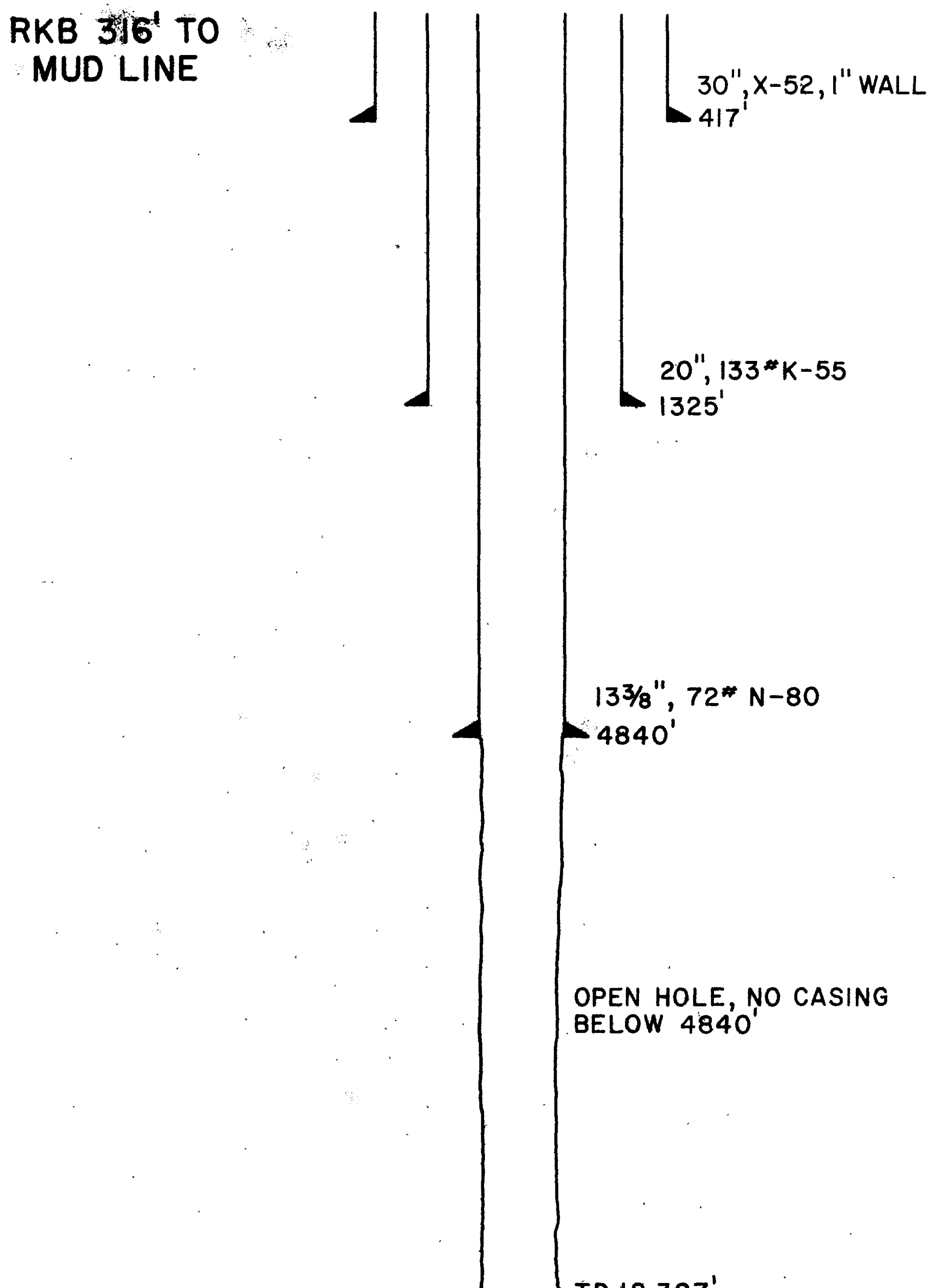

FIGURE 2

Casing depths in the Lower Cook Inlet COST Well, OCS Permit No. 77-5

Geoscience Data

The following geoscience data were received and are available for public inspection at the Office of the Oil and Gas Supervisor, Conservation Division, U.S. Geological Survey, 800 "A" Street, Suite 109, Anchorage, Alaska 99501:

1) Daily operations and geologic report for 109 rig days.
2) One-quart, canned, unwashed drill cuttings at 30 foot intervals, 1356-12,375'.
3) One set washed and dried drill cuttings at 30 foot intervals, 1356-12,375'.
4) Sepia prints of the final composite of the following logs:
   a) Dual induction laterolog, 300-12,387'.
   b) Borehole compensated sonic log, 1325-12,391'.
   c) Long spaced sonic log (8' - 10' and 10' - 12' spacings), 1325-12,387'.
   d) Compensated formation density log, 425-12,392'.
   e) Compensated formation density log, 421-1319'.
   f) Compensated neutron-formation density log, 1325-12,392'.
   g) Proximity log - microlog, 4840-10,238' and 9800-12,387'.
   h) Four-arm continuous dipmeter, 1325-4889', 4840-10,236', and 10,000-12,387'.
   i) Dipmeter arrow plot, 1348-4884', 4855-10,229', and 10,002-12,357'.
   j) Temperature log, 0-12,387'.

k) Repeat formation tester, three tests on 8/22/77, seven tests on 9/18/77.

l) Well-site geologist's lithology log, 1351-12,387'.

m) Mud log, 1356-12,387'.

n) The Analysts - instantaneous drilling evaluation log, 1350-12,387'.

o) The Analysts - delta chloride log, 1400-12,387'.

p) The Analysts - shale density log, 6650-12,350'.

5) Dipmeter cluster circulation listings for three dipmeter runs - three computer print-outs.

6) Log quality control records for log runs #1-4, 16 data sheets.

7) The Analysts - daily drilling log, 6/17/77 through 6/26/77, 7/8/77 through 8/20/77, 8/24/77 through 9/17/77, 79 pages.

8) Conventional core descriptions, cores #1-4, 8 pages.

9) Sidewall core descriptions, samples from 1660-12,352', 45 pages.

10) Final report, P&P, etc. analyses on conventional and sidewall core samples (8 data sheets), and core-gamma correlation log.

11) Final report on shale density measurements on drill cuttings, 2170-12,375'.

12) Color Photos 8" x 10" of slabbed cores #1-4.

13) Preliminary biostratigraphic reports - 16 reports.

14) Final micropaleontology reports, Parts I, II, and III. Each part contains final reports on Foraminifera, calcareous nannofossils, and palynology.

15) Ten interim data reports "Hydrocarbon Source Facies Analysis."

16) Final data and interpretive report "Hydrocarbon Source Facies Analysis."

17) Technical report #62, "Alteration of Sandstone from the Lower Cook Inlet COST #1."

18) X-ray diffraction data, 82 analyses.

19) Petrographic report on 23 sidewall samples, 5120'-10,145'.

20) Petrographic report on 33 samples. Sidewall cores samples 1810'-4560' and full diameter cores #1 and #2.

21) SEM photographs and X-ray analyses on cuttings samples 2530-8500', and sidewall cores 6205-9885'.

22) "Petrographic, Scanning Electron Microscope, and X-ray Diffractometer Analyses of Cretaceous and Jurassic Samples from the Lower Cook Inlet COST #1 Well, Alaska."

23) "Carbon Isotopic Composition of Organic Extract Fractions of Cuttings Samples." Two reports dated 10/18/77 and 10/21/77.

24) Interim vitrinite reflectance report, (9/7/77) on cuttings and one core sample, 1390-9344'.

25) Final vitrinite reflectance report (9/30/77) on cuttings and core samples, 1390-12,384'. Also an emendation to the final vitrinite report issued 10/14/77.

26) Vitrinite reflectance analyses from cores #1-4, telex report 10/13/77.

27) Water analysis reports on four repeat formation tester samples (4 data sheets).

28) Petrographic description of thin sections from Lower Cook Inlet COST #1 well, 10/17/77.

29) Addendum report covering carbon isotopic determinations for the saturates fraction, 11/10/77.

Operational Problems

No extraordinary problems were encountered in drilling this hole. The stability of the world's largest semi-submersible drilling vessel, OCEAN RANGER, contributed greatly to the successful drilling program.

GEOLOGY

Geologic data from the COST well provided information on the lithology, ages, and depths of the strata penetrated, on the hydrocarbon source-rock potential of the rocks, and on the quantity and quality of reservoir rocks. No samples were taken above 1351 feet, and the lithology of this interval is determined wholly from the interpretation of geophysical logs.

Stratigraphy

Plate I (correlation section) illustrates the probable stratigraphic relationships of the strata penetrated by the COST well to known formations in other wells.

Quaternary strata

Approximately 225 feet of glacial strata were penetrated by the well. The base of the Quaternary is at 546 feet depth according to induction log interpretation.

Tertiary strata

The well penetrated 2004 feet of nonmarine Tertiary strata between 546 feet and 2550 feet depth. The Tertiary sequence is composed of claystone, siltstone, sandstone, and conglomerate with minor coal and tuffaceous zones. Sandstone and conglomerate are dominant rock types. Typical conglomerates include a large percentage of volcanic, plutonic, and metamorphic clasts, and typical sandstones are chiefly composed of varicolored grains, suggesting a similar origin. Coal is present as thin beds up to 5 feet in thickness.

On the basis of palynological data, the Tertiary stratigraphic section can be subdivided into Eocene rocks (1351 feet to 1770 feet) and Paleocene rocks (1770 feet to 2550 feet). No age data are available above 1351 feet. The Eocene part of the section contains a higher percentage of siltstone, claystone, and coal than does the Paleocene part, which is almost entirely sandstone and conglomerate.

Cretaceous strata

Cretaceous rocks penetrated by the well can be divided into two age groups: Late Cretaceous (Maestrichtian) and Early Cretaceous (Neocomian). The two are separated by an unconformity that represents a hiatus of approximately 40 to 50 million years.

The well penetrated 2508 feet of Upper Cretaceous strata from 2550 feet to 5058 feet in depth. From 2550 feet to 4730 feet, the section is a claystone, siltstone, and sandstone sequence with occasional minor coal. It includes sandstone bodies, up to 130 feet in thickness, that are the most promising potential reservoirs in the well. The depositional environment is interpreted as fluctuating from marginal marine to nonmarine.

The bottom 328 feet of the Upper Cretaceous is a marine claystone and siltstone unit. This unit is markedly different in geophysical log character than the Upper Cretaceous strata above it, and the stratigraphic relationship of the two is unclear at this time.

The well penetrated 2967 feet of Lower Cretaceous (Neocomian) strata from 5058 feet to 8025 feet in depth. These strata are composed of sandstone, siltstone, and claystone. On the basis of lithological differences, general subdivisions of the Lower Cretaceous strata may be made as follows:

5058 feet to 6450 feet.--A sandstone, siltstone, and claystone sequence with sandy siltstone as the dominant lithology. Sandstone beds up to 56 feet in thickness are present, but their reservoir potential appears to be poor (see pages 24 and 27).

6450 feet to 6850 feet.--The dominant lithology is claystone with occasional thin sandstone beds. Inoceramus shell fragments and prisms were abundant, and in one 10-foot interval they compose as much as 25 percent of the total sample.

6850 feet to 8025 feet.--There is a sudden, simultaneous increase in resistivity, sonic velocity, and formation density at 6850 feet that indicates decreased porosity of the rocks (Plate II). This condition persists in all rocks below this depth in the well. Petrographic studies (see page 25) show this is mainly due to authigenic emplacement of zeolite in the available pore spaces in the rocks. The stratigraphic nature of this "zeolite boundary," i.e., whether it is strictly a pressure-temperature boundary, or a stratigraphic or erosional boundary, cannot be determined from the data available.

The Lower Cretaceous rocks within this interval are mostly massive sandstones with interbedded thin siltstones down to 7370 feet, and sandy siltstones from 7370 feet to the top of Jurassic rocks at 8025 feet. The sandstones are not generally recognized on the geophysical logs due to the zeolite-filled pores and the resultant lack of permeability.

Carbonaceous plant remains, Inoceramus fragments, and pyrite are frequently noted in the sample descriptions.

Jurassic strata

Upper Jurassic rocks first occurred at 8025 feet in the well and were still being drilled at the total well depth of 12,387 feet. The geophysical logs show that the rocks are high in density and have little or no porosity and permeability.

On the basis of the lithology logs, subdivision of the Jurassic rocks penetrated by the well may be made as follows:

8025 feet to 8270 feet.--Interbedded claystone, siltstone, and sandstone, including scattered granules, rock fragments, and thin beds of tuff.

8270 feet to 11,700 feet depth.--The dominant lithology is massive sandstones, up to several hundred feet in thickness, that are separated by thin interbeds of siltstone and claystone. The massive sandstones are generally described as approximately 50/50 quartz and feldspar, fine- to medium-grained, hard, and tight. They are probably the lateral equivalent of the massive sandstones of the Naknek Formation that are exposed on the Iniskin Peninsula to the northwest of the COST well location.

11,700 feet depth to 12,387 feet total depth.--Interbedded siltstone, sandstone, and claystone with occasional thin beds of tan to brown limestone and gray tuff.

Structural Position

The well is located on the northeast flank of a large regional feature known as the Augustine-Seldovia arch. Structural dip in the well is not more than 5^{o} to the northeast. No known faults occur in the immediate vicinity of the well.

The structural position of the well resulted in a poor location for the evaluation of the extremely shallow Tertiary rocks. However, the location was good for the evaluation of the Mesozoic rocks, which could be prospective in nearby structures.

Relationships to Other Wells and Onshore Exposures

Iniskin Peninsula

Twenty miles northwest of the COST well site, Jurassic rocks are exposed on the Iniskin Peninsula, where several early exploratory wells were drilled near the core of a large breached and faulted anticline (Plate I). These wells were drilled in rocks older than those penetrated in the COST well; thus, no direct correlation can be established between the COST well and these early wells. The massive Jurassic sandstones in the COST well (from approximately 8270 feet to 11,700 feet in depth) are most likely the lateral equivalent to the massive sandstones of the Naknek Formation that dip eastward into Cook Inlet along the east shore of the Iniskin Peninsula.

Kenai Peninsula

Several exploratory wells have been drilled on and just offshore from the southern part of the Kenai Peninsula, 30 to 40 miles northeast of the COST well. The most basinward of these wells and the most likely one to use for correlation with the COST well is the Pennzoil-operated Starichkof State No. 1, located 2 miles offshore and just north of Anchor Point (Plate I). This well penetrated a typical Tertiary, Kenai Group, sedimentary sequence and entered Upper Cretaceous marine siltstones at 8785 feet. The well penetrated 3327 feet of the Upper Cretaceous strata before reaching a total depth of 12,112 feet.

The lowermost Tertiary strata in the Starichkof well may be equivalent to the Eocene rocks in the COST well (down to 1770 feet). The relationship of the Paleocene strata in the COST well (1770 feet to 2550 feet) to the lower Tertiary strata in the Starichkof well is unclear. Certainly, the lithologic types are not similar, and the Paleocene strata found in the COST well may be a separate and older unit than the lowermost Tertiary rocks found in the Starichkof well.

The Upper Cretaceous strata in the two wells are of Maestrichtian age. However, the Upper Cretaceous strata in the Starichkof well are almost entirely marine siltstone and claystone and represent a bathyal depositional environment, while the upper 2180 feet of age-equivalent strata in the COST well contain potential sandstone reservoirs and represent marginal marine to nonmarine depositional environments. Only the lowermost 328 feet of Upper Cretaceous strata in the COST well are similar to that in the Starichkof well.

Strata below 5058 feet depth in the COST well are older than any penetrated by the Starichkof well, and thus no further correlation between the two wells can be established.

Geophysical Log Interpretation

With the exception of the upper 1346 feet, the COST well was drilled with a fresh mud system, and electric log response was normal. Permeable intervals were well defined by the spontaneous potential (S.P.) (Plate II). Figure 3 shows an interpretation of the interval velocity versus depth derived from the integrated sonic log.

Identification of lithology is not a problem in this well, and cross-plotting techniques were not used. No probable zones of oil or gas saturation were penetrated by the well, and formation evaluation for oil and gas was not attempted. The log interpreter investigating this well is mainly interested in:

- identification and correlation of stratigraphic units penetrated by the well;
- evaluation of potential reservoir rock quantity and quality.

Tertiary rocks (546 feet to 2550 feet depth)

The hole was drilled with a salt-water drilling fluid down to 1346 feet, and thus the S.P. response is unreliable as an indicator of porous sand above that depth. Comparison of the gamma ray log with the S.P. in lower Tertiary intervals indicates that the gamma ray is not a reliable indicator of porous sand either, and the absence of samples also makes

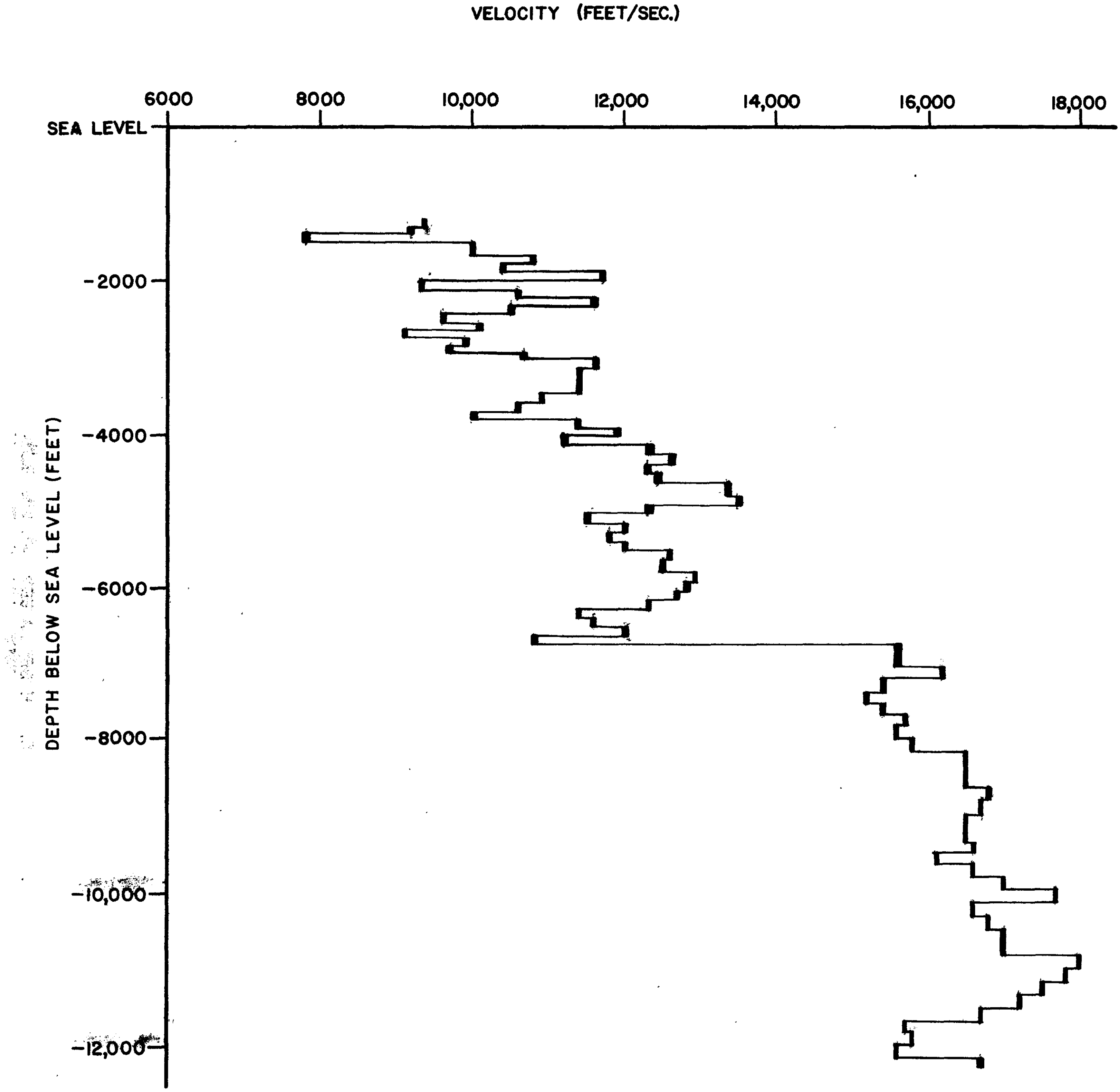

FIGURE 3. VELOCITY DERIVED AT 10 MILLISECOND INTERVALS FROM THE INTEGRATED, BOREHOLE COMPENSATED SONIC LOG FOR THE LOWER COOK INLET COST WELL NO. 1.

interpretation of the interval uncertain. Investigation of the resistivity, sonic, and density logs (Plate II), however, indicates that the rocks above 1351 feet are probably a claystone, siltstone, and sandstone sequence similar to the Eocene rocks below 1351 feet, but no quantitative evaluation of reservoir potential rocks can be made.

The S.P. response shows that the Tertiary strata from 1351 feet to 2550 feet include 160 feet of porous sandstone and conglomerate. The sandstones are thin, not more than 35 feet thick, and scattered throughout the unit. Most are conglomeratic and contain considerable volcanic, plutonic, and metamorphic rock fragments. Density and sonic derived porosities average 18.5 percent and range from 5 percent to 24 percent. No conventional cores were taken from the Tertiary rocks, but average porosity of the sidewall cores is 21 percent. The range in permeability is from 2 to 565 millidarcies; the average permeability is 113 millidarcies.

<u>Upper Cretaceous rocks</u> (2550 feet to 5058 feet)

This stratigraphic unit contains the most promising reservoir sandstones penetrated by the well. The S.P. response indicates a total of 362 feet of porous sandstone (Plate II). The sandstone bodies are up to 130 feet thick and probably represent nonmarine to marginal marine distributory channel systems. Density and sonic derived porosity averages 19 to 20 percent. No conventional cores were taken from the Upper Cretaceous rocks, but average porosity of sidewall cores from Upper Cretaceous sandstones is 24 percent. The range in permeability is from 2 to 137 millidarcies; average permeability is 48 millidarcies.

Lower Cretaceous rocks (5058 feet to 8025 feet)

The more subdued S.P. response and higher resistivities in the Lower Cretaceous sandstones show that these rocks are more indurated than the Upper Cretaceous rocks. A total of 293 feet of porous sandstone may be identified on the S.P. log between 5058 feet and 6850 feet (Plate II). S.P. deflections are not more than 15 millivolts. Density and sonic derived porosities range from 10 percent to 18 percent and average 15 percent. A conventional core was taken from the sandstone at 5390 feet. Average laboratory-derived porosity from this core is 14 percent; average permeability is near zero. The average porosity of sidewall samples of sandstone from the 5058 foot to 6850 foot interval is 22 percent; average permeability is 141 millidarcies. Sidewall core porosity and permeability values may be anomalously high when compared to the conventional core values because of shock-induced fracturing in the sidewall cores.

Secondary growth of clays and zeolites in pore spaces destroyed most porosity and permeability originally in the rocks below 6850 feet in depth. The S.P. response is low, and resitivities are generally greater than 40 ohms. Rock density and velocity are high (see reduced E-log section). A conventional core of the sandstone at 7104 feet yielded an average porosity of 3 percent and average permeability near zero. Three sidewall cores were taken from sandstones in the interval of 6850 feet to 8025 feet. Average porosity of the three is 24 percent;

average permeability is 135 millidarcies. Again, the high values obtained from the sidewall samples may be anomalous.

Jurassic rocks (8025 feet depth to 12,387 feet total depth)

High density rock and resultant low porosity and permeability continue throughout the Jurassic section. The S.P. does not respond well to changes in lithology, and formation resistivity is, generally, approximately 100 ohms. Density and sonic derived porosities range from 2 percent to 6 percent. A conventional core from 9332 feet yielded an average sandstone porosity of 2 percent and an average permeability near zero. The four sidewall cores of Jurassic sandstone yielded an average porosity of 15.5 percent and average permeability of 10 millidarcies.

In summary, moderate amounts of reservoir sandstone and conglomerate were penetrated by the COST well. Porosity and permeability of the rocks vary and, in general, decrease with depth in the well. Diagenetic alteration of the reservoir rocks affected the permeability to varying degrees and almost completely obliterated it below 6850 feet in depth.

Petrography

Survey personnel examined the set of thin sections that were made for COST well participants. Thin sections were made from conventional and sidewall cores and from cuttings. They were stained to aid in the identification of K-feldspar, and the thin sections from sidewall cores were impregnated with blue epoxy to aid in the identification of pore spaces.

All samples are arkosic rock composed principally of quartz, feldspar, and volcanic rock fragments; murky dark brown clay is a major component in many of the samples. In grain size, the samples range from silty mudstone to coarse sandstone. Coarse clasts are generally angular to subrounded.

Quartz is common in the coarse silt and coarser size grades. Most quartz clasts are monocrystalline. Chert is common as a minor constituent in samples from above 3000 feet measured depth but occurs only sporadically in samples from greater depths.

K-feldspar is the dominant feldspar in samples down to 2500 feet, while plagioclase is the more abundant feldspar at depths greater than 4000 feet. At depths between 2500 and 4000 feet, K-feldspar and plagioclase are generally of subequal abundance. Some K-feldspar shows grid twinning, and plagioclase, ranging from oligoclase to andesine in composition, is commonly twinned according to the albite law. Zoning is common in plagioclase clasts. Feldspar is fresh in most samples, but the plagioclase in some samples is moderately altered to kaolinite and sericite. The alteration is not related to clast surfaces and may be attributed to weathering or hydrothermal activity in the source area.

The volcanic rock fragments are holohyaline, hypocrystalline, and holocrystalline. Abundance of these rock fragments decreases downward in the well; thus, volcanic fragments are more common than feldspar in many shallow samples and are present only in much smaller quantities in deeper samples. This decreasing abundance of volcanic rock fragments is accompanied by a decrease in the amount of glassy material in the rock fragments.

Most samples contain minor amounts of brown biotite, chlorite, epidote, and pyrite; many contain green hornblende; and some contain small quantities of sedimentary rock fragments, generally mudstone. Muscovite, zircon, and sphene are accessories in many samples, and garnet occurs in a few samples.

All rocks penetrated by the COST well show considerable compaction. Mica and some rock fragments are commonly deformed to conform to space available around harder framework clasts; in many samples, clasts are so altered as to form a pseudomatrix. Cushioning by softer clasts, pseudomatrix, and detrital clay prevented extensive compaction-related, in situ breaking of clasts in many samples. The presence of fine angular fragments similar in composition to nearby larger hard framework clasts shows that some grinding has occurred along the boundaries of hard framework clasts that are in direct contact.

Both intergranular and fracture porosity were observed in the samples; fracture porosity, except where the fractures are filled with secondary minerals, could be an artifact of sampling. Intergranular porosity is as high as 10 percent in some samples and is of both primary and secondary, solution-produced origin. Secondary intergranular porosity becomes more evident with increased depth, especially in deeper samples where zeolite has filled large intergranular pores and prevented their destruction by compaction.

The first evidence of diagenesis consists of authigenic clay rims on framework clasts that is seen in samples from 1900 feet and greater depths. This authigenic clay is clear, light yellow or light green, and of low birefringence. Commonly it grades into the murky dark brown detrital matrix and apparently is a recrystallization product of clay material already in the rock. If so, no significant change in porosity would have occurred as a result of authigenesis, but redistribution of material during authigenesis, especially into the narrowest intergranular spaces, might have reduced permeability.

Boundary accommodation between touching hard framework clasts was first observed in the sample from 2060 feet and becomes more common with increased depth. Accommodation is shown by well-fit, straight or curved boundaries between clasts. This causes a closer packing of clasts and a concomitant reduction in porosity.

Extensive alteration of pyrite to hematite was observed in samples from depths shallower than 3500 feet; such alteration is rare in samples from greater depths.

Zeolite has filled all available pore spaces in the samples from 7040 feet or greater depths and is present in minor amounts in some shallower samples. There are no petrographic samples from the interval between 6732 and 7040 feet in the well; thus, the top of the zeolite zone could be anywhere between these two depths. A strong deflection in the resistivity, sonic velocity, and density curves on geophysical logs from the well is marked at 6850 feet and may represent the top of the zone of complete zeolitization. Zeolite occurs to a limited extent as an alteration product of plagioclase and volcanic rock fragments but primarily as a pore-filling cement which makes up as much as 15 percent of some samples.

Hydrocarbon-filled pore spaces were first observed in the sample from 3543 feet and then sporadically in various samples from greater depths in the well. The principal mode of occurrence of free hydrocarbon in the zeolitized portion of the well is in small fractures in dark, organic-rich mudrock. Some hydrocarbon-bearing fractures are lined with zeolite in a cockscomb texture.

Geothermal Gradient

The temperature gradient in the COST well is 1.3^{o} Fahrenheit of temperature rise per hundred feet of depth (2.38^{o}C per 100 meters).

This figure is calculated from the temperature of 202.5^{o}F (94.72^{o}C) at 12,387 feet (3778.0 meters) depth (taken from the temperature log) and a water surface temperature of 41.72^{o}F (5.4^{o}C) (taken from the Lower Cook Inlet Final Environment Impact Statement water surface temperature chart on page 53 of section II A-4). The Kelly bushing height of 100 feet, from which all of the well depths are measured, must be subtracted to obtain the actual distance from the surface of the water in Cook Inlet to the bottom of the well. This produces a measurement of 12,287 feet (3747.5 meters).

$$\text{gradient (per hundred units)} = \frac{\text{bottom temperature - surface temperature}}{\frac{\text{hole depth}}{100}}$$

$$g_{o_F} = \frac{202.5 - 41.72}{\frac{12,287}{100}} = \frac{160.98}{122.87} = 1.3^{o}\text{F per 100 ft.}$$

$$g_{o_C} = \frac{94.72 - 5.4}{\frac{3747.5}{100}} = \frac{89.32}{37.48} = 2.38^{o}\text{C per 100 meters.}$$

GEOCHEMISTRY

Canned well samples (cuttings) and samples from the sidewall and conventional cores were analyzed for the amount and type of organic material (kerogen) present in the rocks and for thermal maturity of the rocks. The maturity was largely determined on the basis of the color of the organic material. Direct evidence of hydrocarbon generation and accumulation, such as minute amounts of oil or gas trapped in the pore spaces, was also evaluated.

The results of the geochemical analyses on the sedimentary section penetrated by the COST well are as follows:

From 1356 feet to 4900± feet (Tertiary and Late Cretaceous), the sediments have acted as a good source of C_1 methane gas, but have immature to moderately immature, poor oil source characteristics.

From 4900± feet to 12,375 feet (Early Cretaceous and Late Jurassic), the sediments have an overall poor oil source character and poor to fair C_1 methane gas source character. The maturity of this section increases progressively with well depth from moderately immature at the top to mature at total depth.

Minor oil shows were detected within the gross well interval 4420 feet to 4300 feet; 7210 feet to 7360 feet; and 7690 feet to 7750 feet. The shows were rated as insignificant from the standpoint of commercial production.

PALEONTOLOGY AND BIOSTRATIGRAPHY

Age and environmental interpretations in the Lower Cook Inlet COST well are based on detailed analyses of microfossil assemblages utilizing Foraminifera, marine and terrestrial palynomorphs, calcareous nannoplankton, and Radiolaria. Well cuttings collected at 30-foot intervals were disaggregated by treating with mineral spirits or by boiling in Quaternary-O industrial detergent and washed over a 200 mesh (75 micron) screen. Conventional cores and material taken from sidewall cores were examined. Palynological slides, calcareous nannoplankton slides, and reports prepared for the participants by contract paleontological consultants were also utilized.

Paleogene

Eocene.--The interval from 1356 feet (first sample) to 1810 feet represents a predominantly nonmarine depositional environment of Eocene age. A warm temperature paleoclimate is indicated by a microfloral assemblage characterized by *Alnus* sp., *Carya* spp., *Ulmus* sp., *Tilia* sp., *Nyssa* sp., *Fagus* sp., and *Ilex* sp. Calcareous nannoplankton are quite rare and poorly preserved in this interval, although specimens with affinities to *Markalius* sp. and *Cyclococcolithina* sp. support a Paleogene age. No Foraminifera are present. Rare reworked *Inoceramus* prisms occur in the first sample. Coal is present in most samples.

Paleocene.--The nonmarine interval from 1810 to 2620 feet is Paleocene based on the presence of a palynomorph assemblage containing

Paraalnipollenites confusus associated with *Alnus* sp., *Carya* spp., and *Tilia* sp. Reworked specimens of Cretaceous and Jurassic palynomorphs occur sporadically through this interval. No Foraminifera, calcareous nannoplankton, or siliceous microfossils were observed.

Mesozoic

Late Cretaceous.--The interval between 2620 feet and 5050 feet is Late Cretaceous (Maestrichtian). A well developed Maestrichtian microflora containing specimens of *Aquilapollenites striatus*, *Aquilapollenites bertillonites*, *Cranwellia striata*, *Kurtzipites tripissatus*, *Sympolcacites sibiricus*, and *Wodehouseia spinata* occurs in a nonmarine coal-bearing sandstone section from 2620 feet to 3160 feet.

An Upper Cretaceous marine microfossil assemblage of Foraminifera, ostracodes, dinoflagellates, coccoliths, and molluscan fragments occurs from 3160 feet to 3400 feet. Rare specimens of the dinoflagellate *Palaeocystodinium golzowense* and the calcareous nannoplankters *Arkhangelskiella cymbiformis* and *Chiastozygus initialis* at 3160 feet presage the appearance of the relatively diverse Maestrichtian assemblage. The foraminiferal fauna is characterized by *Gavelinella whitei*, *G.* cf. *G. stephensoni*, *Cribrostromoides cretaceus*, *C. trifolium*, *Haplophragmoides kirki*, *H. excavatus*, *H.* sp., *Trochammina* sp., *T.* cf. *T. texana*, *Bathysiphon vitta*, *Gyroidinoides* cf. *G. nitidus*, *Praebulimina* sp. and *P. kickapooensis*. Rare trachylebrid ostracodes are present. A paleoecological analysis of this assemblage indicates that deposition occurred in an outer shelf to upper slope environment (100-600 meters).

A dinoflagellate assemblage consisting of relatively rare specimens of Australliella cooksoni, Palaeocystodinium golzowense, Spiniferites spp., and Deflandera cf. D. cretacea is also present. This marine component of the palynomorph assemblage persists to a depth of 3926 feet (sidewall core data) and reappears with new elements at 4240 feet.

The predominantly sandstone section between 3400 feet and 4600 feet represents marginal marine (inner neritic to estuarine) to nonmarine deposition. The interval from 3400 feet to 3926 feet is marginal marine based on the presence of the sparse, low-diversity dinocyst assemblage noted above. The interval from 3926 feet to 4150 feet is nonmarine based on the presence of a terrestrial microflora. Rare specimens of the calcareous nannoplankton Micula cf. M. decussata, Watznaueria sp. and W. barnesae, and a marine palynomorph assemblage characterized by Pareodina certaphora, Wanea fimbriata, Hystrichosphaeridium cf. H. stellatum, Ceratiopsis diebeli, Deflanderea cf. D. cretacea, D. cf. D. belfastensis, Baltisphaeridium sp., Spiniferites spp. and Palaeocystodinium golzowense indicate a marginal marine interval from 4150 feet to 4600 feet. The dinocyst assemblage continues down to the major unconformity at 5050 feet.

An abundant and diverse Upper Cretaceous (Maestrichtian) foraminiferal fauna indicative of an upper slope paleoenvironment occurs between 4600 feet and 5050 feet. Forty-one genera containing 90 species were identified. The most significant of these are: Gavelinella whitei, G. stephensoni, G. eriksdalensis, G. nacatochensis, G. cf. G. henbesti, Cribrostomoides cretaceus, Haplophragmoides kirki, H. fraseri, H.

excavatus, H. famosus, Reophax globosus, Trochammina boehmi, T. texana, T. pilea, Silicosigmolina california, Rzehakina epigona, Dorothia bulleta, Bathysiphon brosgei, B. vitta, B. varans, B. californicus, Glomospira charoides corona, Psammosphaera spp., Hippocrepina sp., Saccammina sp., Gyroidinoides trujilloi, G. nitidus, G. globosa, G. quadratus, G. cf. G. bandyi, Pullenia spp., Bolivina incrassata, B. cf. B. decurrens, Lenticulina ovalis, L. cf. L. williamsoni, L. cf. L. warregoensis, Praebulimina kickapooensis, P. venusae, P. spinata, P. cushmani, P. aspera, P. lajollaensis, Pyramidina prolixa, Gaudryina tailleuri, G. cf. G. austinana, G. pyramidata, Hoeglundina supracretacea, Osangularia cordieriana, Svratkina lajollaensis, Dentalina spp., Nodosaria spp., Lagena spp., Fissurina spp., Pseudonodosaria spp., Quinqueloculina sandiegoensis, Stilostomella pseudoscripta, Marginulina curvatura, M. bullata, Sarcenaria triangularis, Marginulinopsis texasensis, Guttulina adhaerens, Pyrulina sp., and Globulina lacrima.

Planktonic Foraminifera are extremely rare in the Upper Cretaceous section. Only one poorly preserved specimen of Hedbergella ? sp. was observed. Fragments and crushed specimens of ostracodes with affinities to Cytheresis? sp., Cletocythereis? sp., and Paracypris sp. are present.

Early Cretaceous.--A major unconformity exists between the Late Cretaceous (Maestrichtian) and the Early Cretaceous (Neocomian). The Neocomian (Hauterivian to Valanginian) section from 5050 feet to 7930 feet contains a relatively diagnostic assemblage of Foraminifera, calcareous nannoplankton, and marine and terrestrial palynomorphs. However, the presence of reworked material, downhole contamination, poor preservation, and sparsely fossiliferous intervals progressively complicate age and environmental interpretations in this section and in the underlying Jurassic.

A marine palynomorph assemblage indicative of a Hauterivian to Barremian age occurs from 5050 feet to 6840 feet. This microplankton assemblage is characterized by Cyclonephelium distinctum, Clathroctenocystis elegans, Dimidiadinium uncinatum, Herendeenia pisciformis, Oligosphaeridium complex, Prionodinium spp., and Muderongia simplex. The presence of Nelchinopsis kostromiensis at 6840 feet suggests a possible Valanginian age. A calcareous nannoplankton assemblage of Hauterivian to Valanginian age containing Cruciellipsis cf. C. cuvillieri, Calcicalathina cf. C. oblonga, Cyclagelospheara sp., Diazomatolithus lehmanni and Nannoconus colomi occurs between 6040 feet and 7000 feet.

A foraminiferal fauna containing Lenticulina muensteri, L. bronnii, L. saxonica, L. gaultina, L. discrepans, L. eichenbergi, L. heiermanni, L. schloenbachi, L. spp., L. cf. L. guttata, L. turgida, L. ouachensis, Gavelinella andersoni, G. cf. G. barremiana, Astacolus onoanus, A. calliopsis, A. pachynota, Sarcenaria aff. S. triangularis, Marginulinopsis cf. M. collinsi, M. cf. M. gracilissima, M. cf. M. cephalotes, Globulina prisca, Ramulina sp., Vaginulina sp., Citharina sp., Rhizammina sp., Glomospira charoides corona, Dentalina spp., D. distincta, D. aff. D. porcatulata, D. gracilis, Bathysiphon sp., Dorothia gradata, Textularia cf. T. klamathensis, Haplophragmoides topagorukensis, H. cf. H. inconstans, Trochammina spp., Lingulina buddencanyonensis, Planonalina buxtorfi, Praebulimma sp., P. cf. P. churchi, Rheinholdella aff. R. dreheri, Hoeglundina anterior, H. caracolla caracolla, Marssonella kummi, M. cf. M. trochus and Gubkinella californica is present over the interval from 5200 feet to 6910 feet. The Foraminifera indicate a Hauterivian to Barremian age.

Lower Cretaceous paleobathymetry fluctuated from nonmarine to upper slope depths. The interval from 5050 feet to 5200 feet represents an inner to middle shelf (0-100 meters) depositional environment. Upper slope faunas occur from 5200 feet to 5500 feet and from 6340 feet to 6910 feet. The interval between these transgressive events represents an inner to middle shelf paleoenvironment.

A marked decline in dinoflagellate and calcareous nannoplankton occurs below 7030 feet, marking the onset of marginal marine conditions. A nonmarine Neocomian to Upper Jurassic microflora containing, among others, Deltoidospora spp., Lycopodiumsporites spp., Osmundacites sp., and Taurocusporites segmentatus occurs from 7087 feet to 7930 feet.

Late to ?Middle Jurassic.--The exact position and nature of the Cretaceous-Jurassic contact in the well are problematical. A hiatus representing Berriasian time may be present. However, this stage may be represented by the undifferentiated Neocomian to Upper Jurassic nonmarine to marginal marine interval between 7087 feet and 7930 feet. An Upper to Middle Jurassic (Tithonian to ?Callovian) dinoflagellate assemblage characterized by Gonyaulacysta cladophora, G. jurassica, Pareodina certaphora, P. osmingtonense, Sirmidodinium crystallinum and *S. grossi* is present over the interval from 7930 feet to 12,387 feet (total depth). The assignment of an age range as old as Callovian is based on the possibility that the Upper Jurassic species *Pareodina osmingtonense* may be conspecific with a form that ranges into the Callovian in Arctic Canada. The terrestrial microflora is essentially the same from 7087 feet to 12,384 feet. The calcareous nannoplankton assemblage contains species that occur in both the Cretaceous and Jurassic, although below 8020 feet forms with Jurassic affinities increase. No age-diagnostic Foraminifera were observed. The Jurassic paleoenvironment was predominantly marginal marine. Reworked silicified and pyritized Upper to Middle Jurassic Radiolaria are present throughout the Mesozoic section. They are particularly abundant in the Lower Cretaceous interval from 5200 feet to 5380 feet. The radiolarian fauna contains *Parvicingula* cf. *P. hsui*, *Hsuum* cf. *H. stanleyensis*, *Cenosphaera* spp., *Spongodiscus* spp. and *Archaeodictyomitra* cf. *A. rigida*. It is difficult to ascertain whether the Radiolaria that sporadically occur in the Jurassic section are *in situ*.

BIOSTRATIGRAPHIC SUMMARY

	Depth (feet)
Paleogene	
Eocene	1356 - 1810'
Paleocene	1810 - 2620'
Mesozoic	
Late Cretaceous	
Maestrichtian	2620 - 5050'
Early Cretaceous	
Hauterivian-Barremian	5050 - 6840'
Valanginian	6840 - 7087'
Neocomian-Late Jurassic undifferentiated	7087 - 7930'
Jurassic	
Tithonian-Callovian	7930 - 12,387' (T.D.)

ENVIRONMENTAL CONSIDERATIONS

An environmental analysis, part of the permit-application procedure for the COST well, determined that the granting of a permit to perform the test was not a major Federal action and would not require an Environmental Impact Statement.

Cultural and archeological site-specific surveys were not run because of the fast current of the tides in Cook Inlet and the extreme changes in the bottom of the inlet due to tidal action. Cook Inlet is a tidal estuary where the major water movement, a to-and-fro pulsation in the lengthwise direction of the inlet, is caused by ebb and flood tides. Coriolis force, basin morphology, and winds modify the pulsations to produce a net circulation pattern within the inlet. The tidal front moves 150 miles up the inlet in four and one-half hours. Tides are semi-diurnal with a significant inequality between successive low waters; the mean diurnal range in Lower Cook Inlet varies from 19.1 feet (5.8 m) on the east shore to 16.6 feet (5.1 m) on the west shore. Current velocities are moderate to severe, reaching a mean velocity of 3.8 knots and maximum velocities exceeding 6.5 knots.

A bio-assay was run during the drilling phase of the well, and preliminary reports indicate there is no long-term adverse environmental impact. The bio-assay tested various adult stages of sea life; no larval stages were tested because of the time of the year.

SUMMARY AND CONCLUSIONS

The Lower Cook Inlet COST well was drilled to 12,397 feet total depth (12,297 feet below sea level) in 197 days. No significant operational problems were encountered. The well was intentionally located in a structurally low position to minimize the possibility of encountering significant quantities of hydrocarbons.

Analysis of geoscience data from the well has led to the following conclusions about the strata penetrated by the well:

1. The well penetrated strata of early Tertiary, Late Cretaceous, Early Cretaceous, and Late Jurassic ages.
2. Moderate amounts of sandstone reservoir rocks were encountered in the Tertiary and Cretaceous strata.
3. The reservoir sandstones encountered have been diagenetically altered to varying degrees by the authigenic growth of clays and zeolites. The alteration of the sandstones has resulted in reduction of their permeability and has almost entirely obliterated any original porosity and permeability in the rocks below 6850 feet of depth in the well.
4. The Tertiary and Upper Cretaceous rocks penetrated by the well exhibit good methane gas source characteristics and poor oil source characteristics. The Lower Cretaceous and Upper Jurassic rocks exhibit poor to fair methane gas source

characteristics and poor oil source characteristics. The thermal maturity of the rocks increases from moderately immature at shallow depths to mature at total depth.

REFERENCES

Bandy, O. L., 1951, Upper Cretaceous Foraminifera from the Carlsbad area, San Diego County, California: Jour. Paleontology, v. 25, no. 4, p. 488-513, pls. 72-75.

Bartenstein, H., and Bettenstaedt, F., 1962, Marine Unterkreide (Boreal and Tethys), in Leitfossilien der Mikropalaeontologie p. 225-297, pls. 35-51: Borntraeger, Berlin (1962).

Bergquist, H. R., 1961, Foraminiferal zonation in the Matanuska Formation, Squaw Creek-Nelchina River area, south-central Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 12, p. 1994-2011.

Church, C. C., 1968, Lower Cretaceous Foraminifera of the Orchard Peak-Devils Den area, California: California Proc. Acad. Sci., v. 32, no. 18, p. 523-580, pls. 1-8.

Dailey, D. H., 1973, Early Cretaceous Foraminifera from the Budden Canyon Formation, northwestern Sacramento Valley, California: Univ. Calif. Pub. Geol. Sci., v. 106, p. 1-113, pls. 1-19.

Detterman, R. L., and Hartsock, J. K., 1966, Geology of the Iniskin-Tuxedni region, Alaska: U.S. Geol. Survey Prof. Paper 512, 78 p.

Holden, J. C., 1964, Upper Cretaceous ostracodes from California: Paleontology, v. 7, pt. 3, p. 393-429.

Imlay, R. W., and Detterman, R. L., 1973, Jurassic paleobiogeography of Alaska: U.S. Geol. Survey Prof. Paper 801, 34 p.

Johnson, C. D., and Hills, L. V., 1973, Microplankton zones of the Savik Formation (Jurassic), Axel Heiberg and Ellesmere Islands, District of Franklin: Canada Petroleum Geology Bull., v. 21, no. 2, p. 178-218.

Lyle, W. M., and Morehouse, J. A., 1977, Physical parameters of potential petroleum reservoir and source rocks in the Kamishak-Iniskin-Tuxedni region, Lower Cook Inlet, Alaska: Alaska Div. of Geophysical and Geological Surveys Open-File Rept. 104, 20 p., 13 pls.

Magoon, L. B., and others, 1976, Hydrocarbon potential, geologic hazards, and infrastructure for exploration and development of the Lower Cook Inlet, Alaska: U.S. Geol. Survey Open-File Rept. 76-449, 124 p.

Martin, Lewis, 1964, Upper Cretaceous and lower Tertiary Foraminifera from Fresno County, California: Jahrbuch der Geologischen Bundesanstalt, Sonderband 9, p. 1-128, pls. 1-16.

Maync, Wolf, 1973, Lower Cretaceous foraminiferal fauna from Gorringe Bank, eastern North Atlantic, DSDP Leg 13, in Ryan, W. F., Hsu, K. J., and others, eds., Initial reports of the Deep Sea Drilling Project: Washington, D. C., v. 13, p. 1075-1111, pls. 1-4.

McGugan, Alan, 1964, Upper Cretaceous zone Foraminifera, Vancouver, British Columbia, Canada: Jour. Paleontology, v. 38, no. 5, p. 933-951, pls. 150-152.

Norris, Geoffrey, Jarzen, D. M., and Awai-Thorne, B. V., 1975, Evolution of the Cretaceous terrestrial palynoflora in western Canada, in Caldwell, W. G. E., ed., The Cretaceous system in the western interior of North America: Canada Geol. Assoc. Special Paper no. 13, p. 333-389, pls. 1-5.

Pessagro, E. A., Jr., 1977, Upper Jurassic Radiolaria and radiolarian biostratigraphy of the California Coast Ranges: Micropaleontology, v. 23, no. 1, p. 56-113, pls. 1-12.

Scott, J. A. B., 1974, The Foraminifera of the Haslan, Qualicum and Trent River Formations, Vancouver Island, British Columbia: Canada Petroleum Geology Bull., v. 22, no. 2, p. 119-176, pls. 1-6.

Sliter, W. V., 1968, Upper Cretaceous Foraminifera from southern California and northwestern Baja California, Mexico: Univ. Kansas Paleontol. Contr., ser. no. 49, art. 7, p. 1-141, pls. 1-24.

______1973, Upper Cretaceous foraminifera from the Vancouver Island area, British Columbia, Canada: Jour. Foraminiferal Res., v. 3, no. 4, p. 167-186, pls. 1-6.

Sliter, W. V., and Baker, R. A., 1972, Cretaceous bathymetric distribution of benthic foraminifera: Jour. Foraminiferal Res., v. 2, no. 4, p. 167-183, figs. 1-8.

Swain, F. M., 1973, Upper Cretaceous Ostracoda from the northwestern Pacific Ocean: Jour. Paleontology, v. 47, no. 4, p. 711-714, pl. 1.

Trujillo, E. F., 1960, Upper Cretaceous Foraminifera from near Redding, Shasta County, California: Jour. Paleontology, v. 34, no. 2, p. 290-346, pls. 43-50.

Wiggens, V. D., 1973, The dinoflagellate family Pareodiniaceae: Geoscience and Man, v. 11, p. 95-115.