Test Wells, Titaluk and Knifeblade Areas, Alaska

By FLORENCE M. ROBINSON

With Micropaleontologic Study of Test Wells in the Titaluk and Knifeblade Areas, Northern Alaska

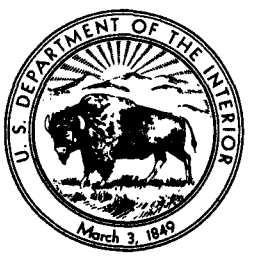
By HARLAN R. BERGQUIST

EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA, 1944–53

PART 5, SUBSURFACE GEOLOGY AND ENGINEERING DATA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 305-G

Prepared and published at the request of and in cooperation with the U. S. Department of the Navy, Office of Naval Petroleum and Oil Shale Reserves



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U. S. Geological Survey Library has cataloged this book as follows:

Robinson, Florence Marie, 1921–

Test wells, Titaluk and Knifeblade areas, Alaska. With Micropaleontologic study of test wells in the Titaluk and Knifeblade areas, northern Alaska, by Harlan R. Bergquist. Washington, U. S. Govt. Print. Off., 1959.

iii, 377–422 p. illus., maps, diagrs. (2 in pocket) tables. 30 cm. (U. S. Geological Survey. Professional paper 305–G. Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944–53, pt. 5, Subsurface geology and engineering data)

"References cited": p. 416. "Bibliography of micropaleontologic study": p. 419.

(Continued on next card)

Robinson, Florence Marie, 1921– Test wells, Titaluk and Knifeblade areas ... 1958. (Card 2)

1. Petroleum—Alaska. 2. Paleontology—Alaska. 3. Foraminifera, Fossil—Alaska. 4. Micropaleontology—Alaska. I. Bergquist, Harlan Richard, 1908– II. Title. III. Title: Titaluk and Knifeblade areas, Alaska. (Series: U. S. Geological Survey. Professional paper 305–G. Series: U. S. Geological Survey. Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944–53, pt. 5)

622.18282

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TEST WELLS, TITALUK AND KNIFEBLADE AREAS, ALASKA

By FLORENCE M. ROBINSON

ABSTRACT

The Titaluk and Knifeblade test wells were drilled in 1951 as a part of the exploration program of Naval Petroleum Reserve No. 4 in northern Alaska. Titaluk test well 1, which is 62 miles west of Umiat, was drilled to a depth of 4,020 feet. Knifeblade test wells 1, 2, and 2A, which are about 68 miles west-southwest of Umiat, were drilled to depths of 1,805, 373, and 1,805 feet, respectively. These wells were drilled on two different anticlines to test sandstone of the Grandstand formation of Cretaceous age (the principal oil and gas producing strata in the Umiat field, Alaska). Except for the few minor shows of gas and oil, the tests were dry.

This report includes lithologic descriptions, paleontologic determinations, and engineering and logistic information obtained in the drilling of these tests. Some of the data are presented graphically.

INTRODUCTION

In 1944 the U. S. Navy started exploration of Naval Petroleum Reserve No. 4 in northern Alaska. The U. S. Geological Survey participated in this program as a cooperating agency, undertaking a large part of the geological fieldwork and maintaining a laboratory in Fairbanks, Alaska, for the description and analysis of rock samples collected, particularly by drilling, in the Reserve.

The Kigalik River-Awuna River-Maybe Creek area in northern Alaska in which the Knifeblade and Titaluk anticlines are located was first traversed by Geological Survey reconnaissance field parties in 1924 under the leadership of Philip S. Smith and J. B. Mertie, Jr. In 1945, early in its new program for the exploration of Naval Petroleum Reserve No. 4, the U. S. Navy sent a field party down the entire length of Maybe Creek and the Ikpikpuk River for 15 miles. Finally, they moved south and examined the Colville River banks in the vicinity of Aupuk Creek (south of Knifeblade anticline). The Geological Survey field parties sent into the area mapped the Knifeblade, Titaluk, and other anticlines in 1946 and 1947. The Titaluk anticline was mapped in detail in 1949 by the Geological Survey to determine closure; seismic lines were run across part of the anticline by United Geophysical Co. Inc., in 1950. The Knifeblade anticline was later restudied from aerial photographs by the Geological Survey.

In the fall of 1950 several wildcat locations were selected in the general area of Maybe Creek. The Titaluk and Knifeblade anticlines were chosen to be drilled in the summer of 1951 although, of the other structural features, only the Wolf Creek anticline was eventually drilled.

Titaluk test well 1 is 62 miles due west of Umiat, and the Knifeblade test wells are within a mile of each other about 68 miles west-southwest of Umiat. (See fig. 28). Titaluk was drilled to a depth of 4,020 feet and penetrated the Ninuluk, Chandler, Grandstand, and Topagoruk formations of Late and Early Cretaceous age. The three shallower Knifeblade test wells penetrated only the Chandler and Grandstand formations. The tests had very poor shows of gas or oil in the Grandstand formation and were dry and abandoned.

Information on Titaluk and Knifeblade test wells was compiled from daily and final reports made to the U. S. Navy by Arctic Contractors, United Geophysical Co., Inc., The Schlumberger Well Surveying Corp., and the Geological Survey. Unless otherwise noted, all core analyses and sample descriptions were made by the staff of the Survey laboratory in Fairbanks, Alaska. Valuable structural information was given to the author by W. P. Brosgé and C. L. Whittington, who studied the surface geology in the Titaluk and Knifeblade areas, respectively. Microfossils were identified by Harlan R. Bergquist. The stratigraphic distribution of fossils in the test wells of northern Alaska will be presented by him in another chapter of this series. The pelecypods were identified by Ralph W. Imlay, and the heavy-mineral data are part of a regional study of the heavy-mineral zones by Robert H. Morris. Summaries of thermal investigations in Titaluk test well 1 and Knifeblade test well 2 have been furnished by Max C. Brewer.

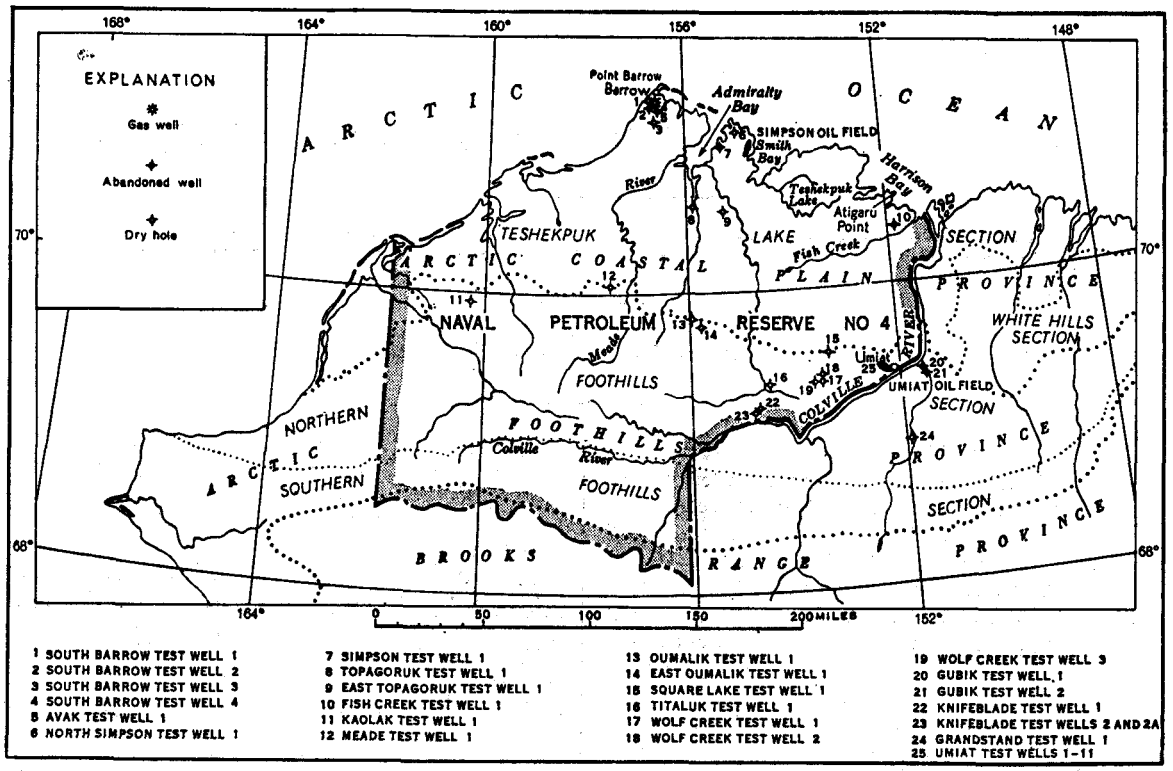


FIGURE 28.—Index map of northern Alaska showing location of test wells and oil fields.

The United States Bureau of Mines at Bartlesville, Okla., analyzed a gas sample from Titaluk test well 1.

The assistance of the personnels of the above organizations is gratefully acknowledged.

STRATIGRAPHY

Titaluk test well 1 penetrated the Ninuluk, Chandler, Grandstand, and Topagoruk formations of Cretaceous age (fig. 29). The much shallower Knifeblade test wells penetrated only the Chandler and Grandstone formations. Lithologically, however, the section drilled in the Knifeblade test wells is similar to the same formations in Titaluk test well 1.

ROCKS OF CRETACEOUS AGE

NANUSHUK GROUP

NINULUK FORMATION

The Ninuluk formation of Late Cretaceous age is the youngest formation drilled on both the Titaluk or the Knifeblade anticlines. In Titaluk test well 1, it is made up of about 65 percent of clay shale, 30 percent of sandstone and siltstone (primarily in 2 thick sandstone beds), and 3 percent of coal and carbonaceous material. The other 2 percent is bentonite and clay ironstone. The clay shale is medium light to medium gray but is darker gray where it contains an abundance of carbonaceous material. It is moderately hard to hard and has a sub-

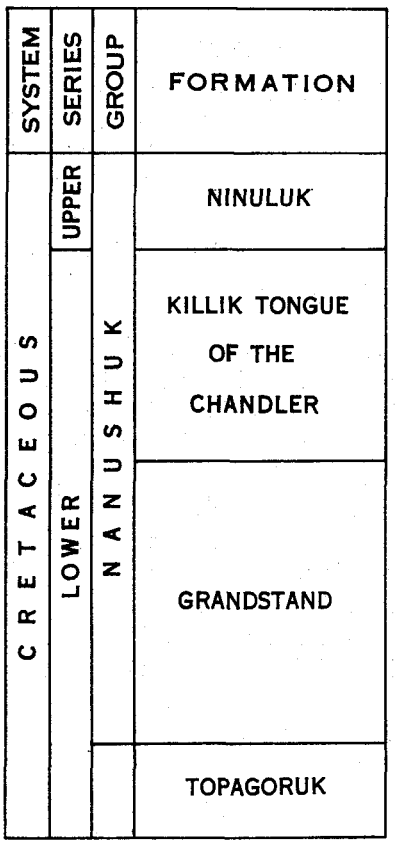


FIGURE 29.—Rocks of Cretaceous age penetrated by Titaluk test well 1.

conchoidal fracture or breaks irregularly along bedding planes but is finely laminated where interbedded with coal, carbonaceous shale, or bentonite.

The sandstone is light gray, hard, and massive where cored near the base of the formation; it is very fine to medium grained, and 80 percent of the grains are white and clear quartz, and the remainder are coal particles, dark chert, white chalky material (weathered feldspar or chert?), and rare mica. The siltstone is similar to the sandstone—medium light gray and hard.

The sandstones and siltstones are slightly to moderately calcareous. The cementing material is partly argillaceous, partly calcareous, and probably partly sideritic. The effective porosity in the sandstone beds near the base of the formation is 11.7–12 percent, and the beds are impermeable.

Coal beds as much as 5 feet thick are present at the top and at about 250 feet below the top of the Ninuluk formation. The coal is soft, shaly, dull to shiny, and black. In a few places it grades into dark-gray carbonaceous clay shale that contains black plant fragments.

Bentonite is interbedded with the coal but is rare elsewhere in the Ninuluk formation. The bentonite is light gray to white and contains some brown biotite plates. Yellowish-brown clay ironstone concretions are present in the Ninuluk, although they are not nearly as common as in the underlying Killik tongue of the Chandler formation.

The shallowest sample in Titaluk test well 1 examined by the Fairbanks laboratory was from a depth of 40 feet. This was from the Ninuluk formation and is essentially the top of the formation. (See p. 383.) The total thickness of the formation in the Titaluk area is about 550 feet. The Ninuluk formation was not found in the Knifeblade test wells, as older formations only are exposed along the axis of the Knifeblade anticline; the Ninuluk formation is present off the north flank of the anticline, according to C. L. Whittington (oral communication, 1956.)

Despite the presence of coal and carbonaceous beds, the Ninuluk formation is primarily marine as indicated by the repeated occurrence of marine microfossils. A few pelecypods were also found. The few nonmarine beds associated with the Ninuluk formation are fingers of the Niakogon tongue of the Chandler formation.

KILLIK TONGUE OF THE CHANDLER FORMATION

The Killik tongue of the Chandler formation, 1,260 feet thick, underlies the Ninuluk formation in Titaluk test well 1; at the type section it is mostly nonmarine (Detterman, 1956, p. 237). In the subsurface there is no good break between the two formations. The contact in the Titaluk test well is placed at the base of a thick sandstone where there is a diminution of microfossils which may be indicative of nonmarine beds.

The Killik tongue is composed of 85 percent of claystone and clay shale, 10 percent of sandstone and siltstone, and about 5 percent of coal, very carbonaceous clay shale, and clay ironstone. The claystone and clay shale are medium light to medium dark gray. The darker colors are more common. This rock has poor cleavage and subchoncoidal fracture, that is, primarily a claystone. Some of the carbonaceous beds are finely laminated.

The sandstone is light to medium light gray, hard, and the beds are rarely more than 20 feet thick. The grains are subrounded to subangular and range in size from very fine to medium. They are made up of 75–80 percent white and clear quartz, and varying amounts of dark chert, rock fragments, and carbonaceous and ironstone particles. The matrix in Titaluk test well 1 is slightly to moderately calcareous, whereas in the Knifeblade test wells it is particularly argillaceous. The siltstone is similar to the sandstone but is mostly slightly darker. The sandstone, siltstone, and claystone are gradational in places. Rare small-scale crossbedding is present.

The effective porosity of the sandstone and siltstone in both areas is low, ranging from 0.96 to 5.29 percent in the few samples tested. All plugs were impermeable. Except for a very small amount of gas found while drilling at 640 feet in Knifeblade test well 1, no oil or gas shows were found in the Killik tongue of the Chandler formation.

Coal, carbonaceous material, and plant fragments are scattered throughout the formation. The coal is black, shiny to dull, brittle, and thin bedded. Very rare small inclusions of clear greenish-yellow amber are present. Dark-gray carbonaceous shale is present above and below the coal and elsewhere in the section. Black plant impressions are found in both the claystone and sandstone, being abundant at some depths. These impressions are fragmentary, and the plants cannot be identified.

Very characteristic of the Killik tongue are clay ironstone (sideritic mudstone) concretions and laminae, particularly in the Knifeblade test wells. The clay ironstone is hard, has conchoidal fracture, and ranges from gray to yellowish brown. Brown dense dolomite (or siderite?) laminae as much as 2 inches thick are found near some of the thicker coal beds in Titaluk test well 1. Tiny vertical veins of yellowish-gray dolomite crystals are rare.

In the Knifeblade test wells and the subsurface in other places in the Reserve, there is a great deal of authigenic sericite in the Killik tongue. This mica

gives a silky sheen to fractured surfaces. The sericite is most common in the lower part of the Chandler formation although some is also found in the upper Grandstand formation.

GRANDSTAND FORMATION

The Chandler formation grades into the marine Grandstand formation; the top of the Grandstand formation is placed at the first common occurrence of the *Verneuilinoides borealis* marine fauna. This is also the approximate top of a very sandy section, the thickest sandstone bed of which occurs about 350 feet below the faunal top.

The Grandstand formation in Titaluk test well 1 is 1,650 feet thick. About 1,710 feet of this formation was drilled in Knifeblade test well 2A, but this is at least 10 percent in excess of the true thickness because of the steep dips. A comparison of thicknesses in the two wells suggests that the bottom of Knifeblade test well 2A is near the base of the formation.

The Grandstand contains about 700 feet of sandstone and siltstone in beds as much as 180 feet thick; the rest is clay shale and claystone. The sandstone is light gray (rarely medium light gray), hard, and massive. The grain size ranges from very fine to medium in the Titaluk test well and from very fine to very coarse in the Knifeblade test wells; grain size decreases with depth. A few thin beds of conglomerate were recorded at the top of the formation in Knifeblade test well 1. The conglomerate contains subrounded and rounded granules and pebbles of dark-gray, greenish-gray, and black chert, milky quartz, coal, medium- and medium-light-gray clay shale, yellowish-gray clay ironstone, and light-gray sandstone.

As is usual in the sandstones of the Nanushuk group, the predominant mineral making up the sand is white and clear quartz, ranging in quantity from 60 to 90 percent of the total. The other grains are mostly dark chert and carbonaceous particles with a few rock fragments. The proportion of dark grains is higher in the coarser standstone, which has a salt-and-pepper appearance. Most of the grains are subangular, and a few are subround; but the very coarse grains are round.

Where tested, the effective porosity of the Grandstand formation ranged from 4.58 to 20.9 percent in the Knifeblade test wells and from 0.56 to 12.45 percent in the Titaluk test well. The highest air permeabilities were 325 millidarcys and 17 millidarcys, respectively, although most samples tested "impermeable." The low range of porosity in the Titaluk test well is a result of calcareous material in the matrix. The content of carbonate minerals in the sandstone in Titaluk test well 1 is higher than that in the Knifeblade test wells, and 1 sample in the Titaluk test well had an exceptionally high reading that measured 30.4 percent by weight. Ordinarily the matrix of the sandstone of the Grandstand formation is argillaceous. A few feet of limestone (or possibly siderite or dolomite)—medium-dark-gray with a brownish cast, hard, argillaceous, with white vein calcite—was found in Titaluk test well 1, but none was found in the Knifeblade test wells.

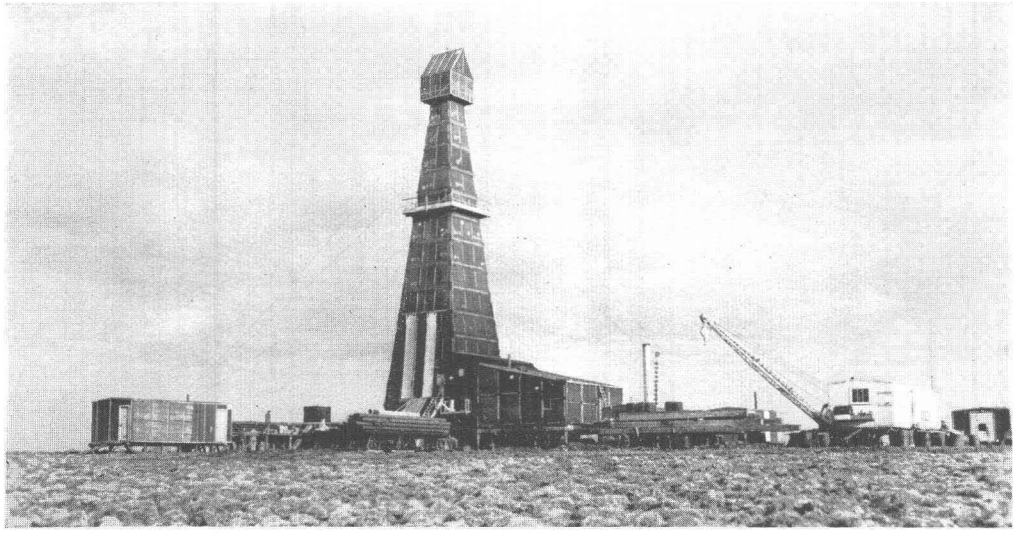
Most of the oil-producing zones in the Umiat field are in the Grandstand formation (Collins, 1957). In the Knifeblade test wells this formation contains numerous deposits of black bitumen or asphaltic residue suggesting that at one time the fault blocks that were drilled (see p. 413) did contain oil. The light fractions have long since escaped. The two deep Knifeblade holes yielded brackish water on bailing tests. In Titaluk test well 1, a little gas and a few oil shows were noted.

Siltstone in the Grandstand formation is light to medium light gray, and hard and is made up primarily of white and clear quartz grains. It is generally gradational with the sandstone beds and makes up less than 10 percent of the sandstone-siltstone bulk. Some swirly bedding and some small-scale crossbedding were noted in the siltstone near the top of the formation in Titaluk test well 1.

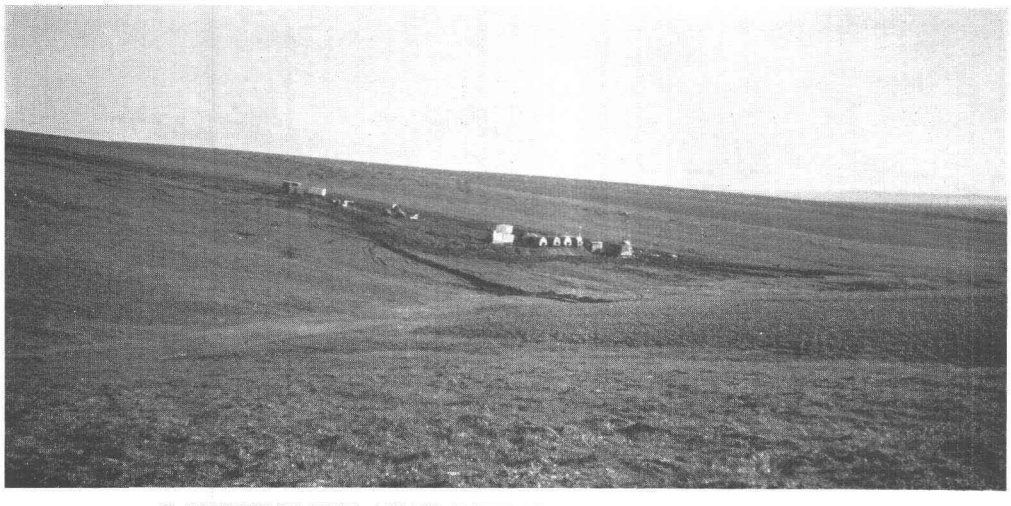
The clay shale and claystone are medium to dark gray and hard. The clay shale has fair to good cleavage, and the claystone has almost no cleavage but has irregular to conchoidal fracture. These clayey beds are mostly noncalcareous but are very silty in places and grade to siltstone. The clay shale has some micaceous-carbonaceous partings. Sericite is present but is not common in the formation.

There is considerably less coal and carbonaceous material in the Grandstand formation, particularly at Titaluk, than in the Chandler formation above. A few coal beds are near the top of the Grandstand in the Knifeblade test wells, but these beds interfinger with marine microfossil-bearing shales. The coal may represent nonmarine stringers of the Chandler formation. No thick coal beds were cored; the cutting chips are black and shiny to dull. Rare carbonaceous shale beds and a few plant fragments in the shale partings were noted. Clay ironstone is less common in the Grandstand formation than in the Chandler formation.

Marine microfossils (see p. 417) are present throughout the formation, as well as *Inoceramus* sp. (mostly prisms in the cuttings), *Ditrupa* sp., and crinoid fragments. The Knifeblade area was probably closer than the Titaluk to the source of the material that makes up the Grandstand formation as the sandstone is coarser grained, even conglomeratic, and there are more coaly beds.

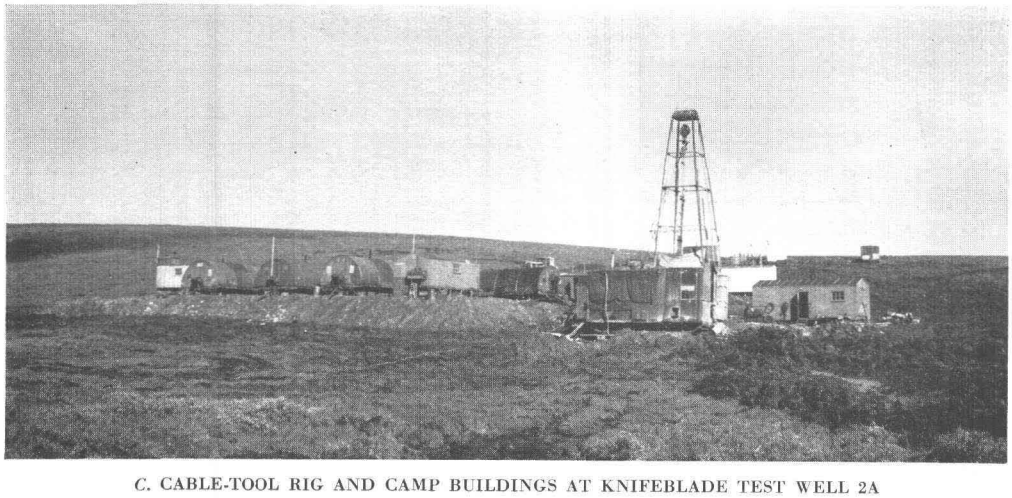


A. TITALUK TEST WELL 1, JUNE 6, 1951

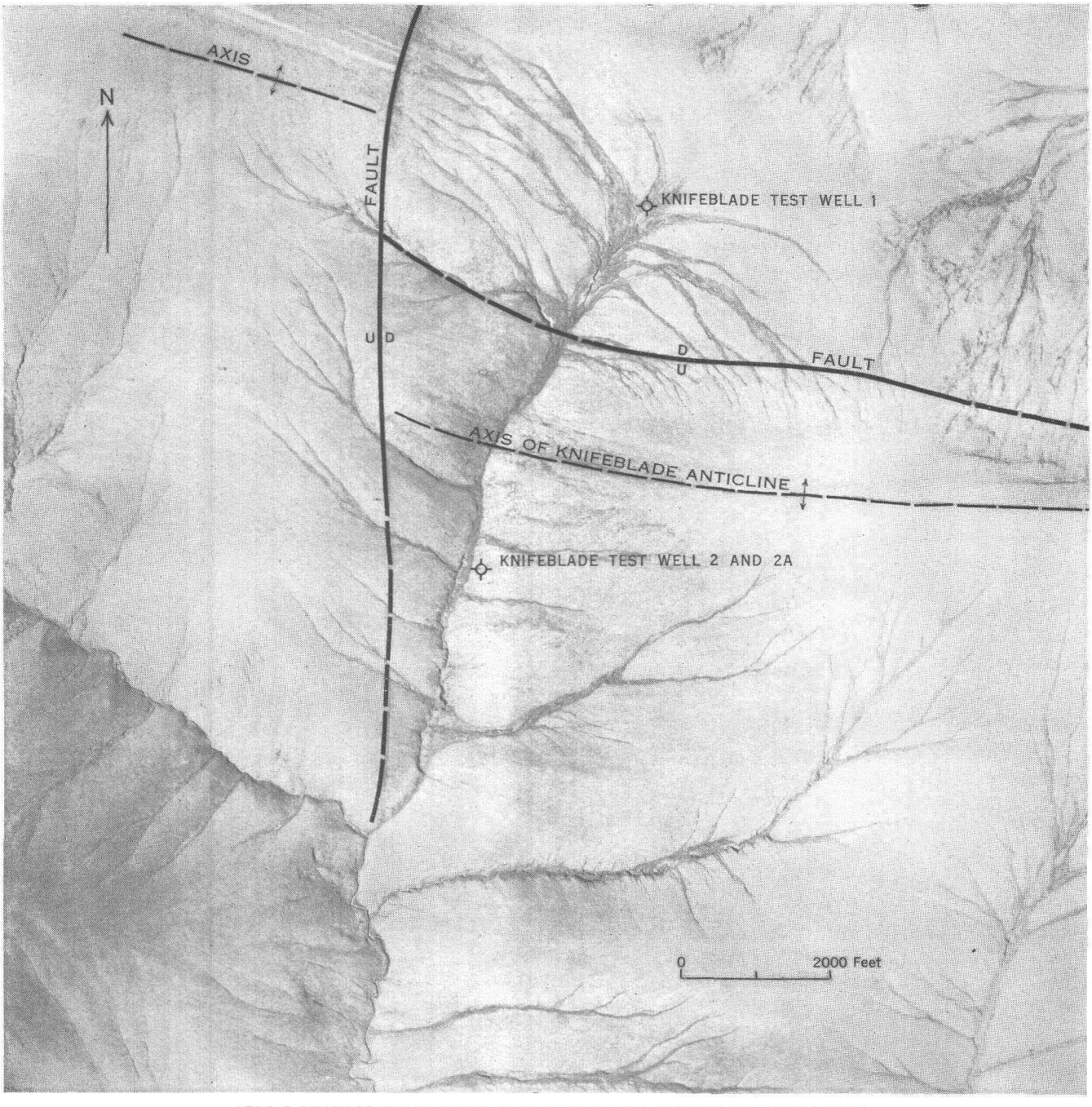


B. SOUTHEAST VIEW ACROSS SOUTH SLOPE NEAR KNIFEBLADE RIDGE

A view of the gentle rolling surface and barren Arctic tundra near Knifeblade test well 2A. The ridge is more rugged to the northwest.



C. CABLE-TOOL RIG AND CAMP BUILDINGS AT KNIFEBLADE TEST WELL 2A



AERIAL PHOTOGRAPH SHOWING LOCATION OF THE KNIFEBLADE TEST WELLS

The axis of the anticline trends northwest between tests 1, 2, and 2A.

TOPAGORUK FORMATION

Only 520 feet of the Topagoruk formation was penetrated by Titaluk test well 1. The Knifeblade tests were too shallow to reach it. In Titaluk test well 1, the division between the Grandstand and Topagoruk formations is a well-defined lithologic change. The base of the Grandstand (also the base of the Nanushuk group) is placed at the bottom of the thick sandstone group.

The Topagoruk formation is about 70 percent of clay shale and 30 percent of siltstone and a little sandstone. The clay shale is medium to medium dark gray and hard. The cleavage ranges from very good to very poor, and some of the rocks can be classified as claystone. Some of the claystone is calcareous.

The siltstone is light to medium light gray, slightly to moderately calcareous, hard, has fair to good cleavage parallel to the bedding and some carbonaceous and micaceous partings. There are a few thin beds of very fine- to fine-grained quartz sandstone. Effective porosity in the coarsest siltstone beds cored was between 4 and 6 percent, and the plugs tested were impermeable. A very pale cut of oil was obtained from one core near the top of the formation.

The siltstone and the clay shale are interbedded, some places in thin laminae. An inch-thick intraformational conglomerate made up of subangular clay shale fragments in siltstone was found 170 feet below the top of the formation. A small amount of swirly bedding and small-scale crossbedding is also present.

The Topagoruk formation contains the same microfossils and megafossils as the Grandstand formation.

TITALUK TEST WELL 1

Location: Lat 69°25'21" N., long 154°34'04" W.
Approximate elevation: Ground, 822 feet; kelly bushing, 840 feet.
Spudded: April 22, 1951.
Completed: July 6, 1951, dry and abandoned.
Total depth: 4,020 feet.

Titaluk test well 1 is on the Titaluk anticline about 62 miles west of Umiat. The test is on the top of a ridge 7 miles northeast of the junction of Maybe Creek and the Titaluk River and about 650 feet above the streams. The area has rolling hills and intrenched streams near the north edge of the Arctic Foothills province. Fifteen miles north of the test site the land flattens to the monotonous lake-covered Arctic coastal plain.

The purpose of the hole was to test the oil and gas possibilities of the formations of the Nanushuk group to the extent of completely penetrating the lowest sandstone or reaching the capacity of the rig (approximately 4,000 feet). The hole was drilled to 4,020 feet, at which depth it penetrated the Topagoruk formation which underlies the Nanushuk group. Only a few minor shows of oil and gas were found. (See page 394.)

The formation contacts as determined in this test are as follows:

Ninuluk	40–590 feet.
Chandler	590–1,850 feet.
Grandstand	1,850–3,500 feet.
Topagoruk	3,500–4,020 feet, total depth.

Field investigations by W. P. Brosgé, C. L. Whittington, and A. L. Kover, U. S. Geological Survey, show that the Seabee formation of the Colville group of late Cretaceous age is present on the surface at the rig site. Samples representing the top 22 feet of rock were not received by the Fairbanks laboratory, but W. P. Brosgé [1] believes that this interval of rock, based on the well geologist's description, represents the Seabee formation. The uppermost sample from 40–50 feet received in the laboratory contained a few microfossils which are distinctive of the Ninuluk formation.

The elevation of Titaluk test well 1 has been adjusted by W. P. Brosgé to the Umiat datum.[2] All elevations and locations in the Umiat-Maybe Creek area are subject to correction, pending the results of new topographic surveys.

STRUCTURE

The Titaluk anticline is a long and narrow structure extending from a point southeast of the Meade River at lat 69°35′ N., long 157°05′ W. about 80 miles east to a point near the headwaters of Maybe Creek at lat 69°20′ N. and long 153°30′ W. Near its midpoint the Titaluk anticline is crossed by the river from which it derives its name.

Titaluk test well 1 was drilled on a local closure near the east end of the anticline. The minimum closure on top of the Seabee formation as shown by structure contouring by Brosgé and Kover and by United Geophysical Co. (fig. 30) is about 180 feet, and the area covered is about 13 square miles. The actual closure on such a large anticline could be well in excess of these figures. Contours on figure 30 are projected over the top of the anticline where the Seabee formation is eroded. Surface geological control is lacking on the northwest side but it has been supplemented by seismic lines (United Geophysical Co., party 144, 1950) which indicate closure at depth (phantom seismic horizon A in shallow rocks of Cretaceous age).

The test well is just south of, and 70 feet below, the apex of the anticline. The strata drilled in the test are flat lying to a depth of about 2,000 feet, indicating that the test was drilled near the apex to this depth at least.

[1] William Brosgé, personal communication.
[2] Datum used on the Umiat Special Map, a topographic sheet published by the U. S. Geological Survey in 1948.

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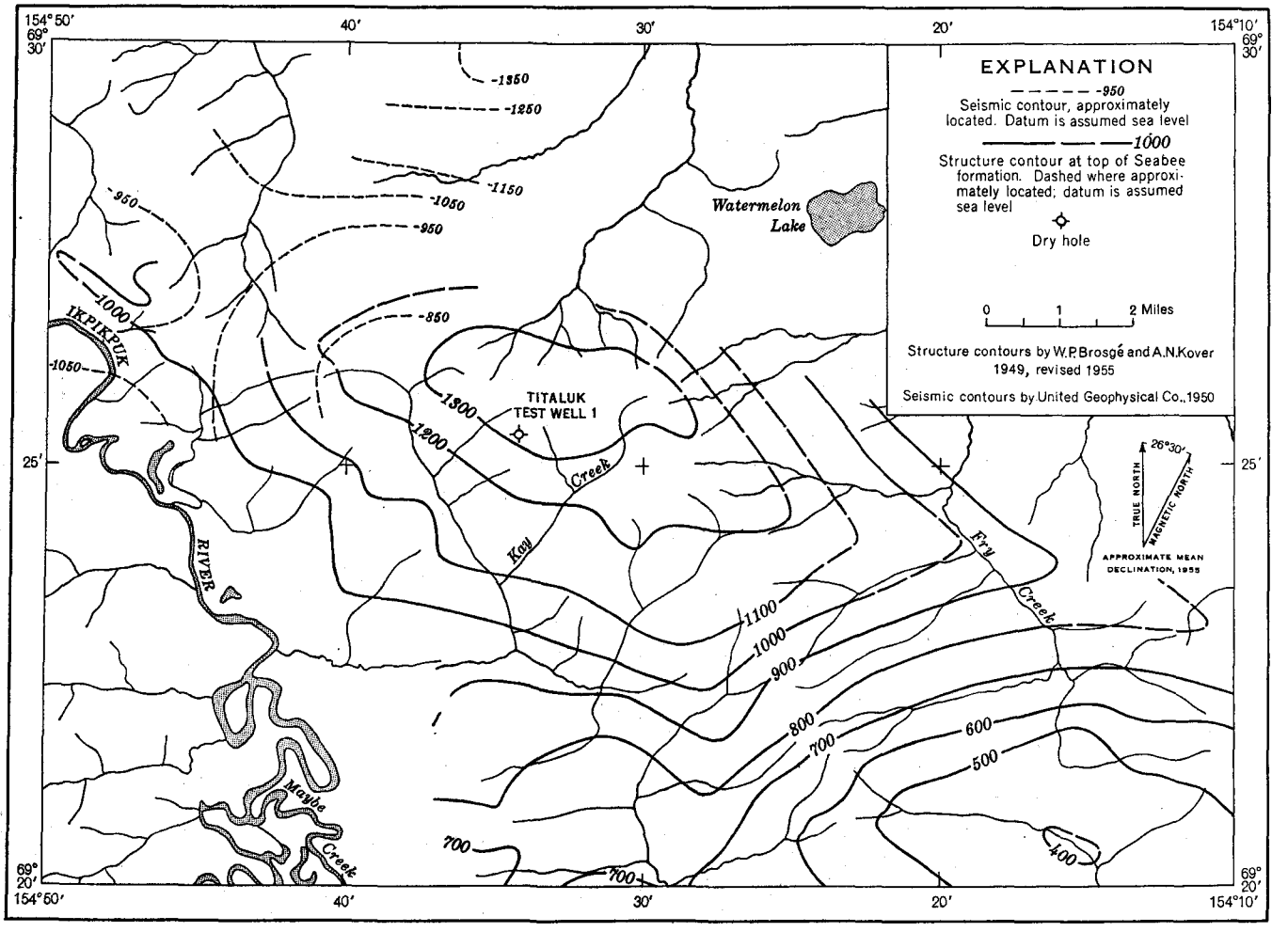

FIGURE 30.—Map showing location of Titaluk test well 1 and structure contours of a part of the Titaluk anticline. Seismic contours are on phantom horizon *A* in shallow rocks of Cretaceous age.

Below 2,000 feet the dip averages a little more than 1°, direction unknown. Surface dips on the north and south flanks of the anticline are 1°–2°.

There is no evidence of faults on the local closure although Fossil Creek anticline, a continuation of the Titaluk anticline to the east, may be separated from Titaluk anticline by faulting.[3]

DESCRIPTION OF CORES AND CUTTINGS

The following lithologic description was made by the author using cores, well cuttings, and the well geologist's report. With the exception of some cement contamination, the well cuttings were of good quality.

All material was described when dry; colors were determined by comparison with the National Research Council Rock Color Chart (Goddard, and others, 1948). Depths were measured from the top of the kelly bushing. The term "trace" as used in this report is defined as less than 3 percent and in most cases is less than 1 percent. Clay ironstone is a sideritic dense and rather hard muddy rock that generally effervesces very slowly in cold dilute hydrochloric acid.

In a few instances the lithology as indicated by the samples does not correspond to that shown by the electric log. The author assumes that these discrepancies are the result of poor or contaminated samples. Where obvious discrepancies exist the graphic lithologic column was corrected to match the electric log. The "no sample recovered" symbol is used only where intervals of rock more than 5 feet thick are missing.

[3] William Brosgé, oral communication, 1956.

Lithologic description

[Where no core is listed, description is based on cutting samples]

Core	Depth (feet)	Remarks
----	0–18	Kelly bushing to ground level.
----	18–40	No samples received in the laboratory. Well geologist described interval as: "Shale, buff, hard; with calcareous concretions."
----	40–50	Siltstone, medium-light-gray, hard; some very fine- to fine-grained slightly calcareous sandstone, 40 percent. Black dull to shiny coal, 30 percent. Medium-light-gray clay shale, 30 percent. Trace of pale-yellowish-brown clay ironstone and trace of white bentonite.
----	50–80	Clay shale, medium-light-gray; and as much as 20 percent siltstone; as much as 30 percent coal; much clay ironstone; trace of sandstone.
----	80–90	Siltstone, 60 percent, and 20 percent very fine- to fine-grained moderately calcareous sandstone; clay ironstone.
----	[1] 65–115	Clay ironstone, siltstone, some sandstone, some carbonaceous shale, and coal.
----	115–120	No sample.
----	120–150	Clay shale, medium-light-gray; some siltstone and sandstone. Maximum of 25 percent white bentonite containing brown biotite plates. Trace of coal and yellowish-brown clay ironstone.
----	150–170	Sandstone, light- and light-yellowish-gray, fine- to medium-grained; hard; subangular to subrounded grains are 80 percent white and clear quartz; some coal particles, dark chert, white chalky mineral (tripolitic chert or feldspar (?)), rare mica. Yellowish color of some chips probably due to siderite—these chips effervesce with HCl. Trace of clay shale and clay ironstone.
----	170–180	Clay shale, medium-gray and very rarely medium-dark-gray. Trace of sandstone.
----	180–210	Sandstone, as in interval 150–170 ft, slightly calcareous.
----	210–300	Clay shale, medium- to medium-light-gray. Trace of very fine sandstone at 220–230 ft and 270–290 ft, trace of siltstone at 280–290 ft, trace of brown clay ironstone at 230–240 ft, one chip of coal at 280–290 ft.
1	300–320	Recovered 20 ft: Microfossils very rare. 5 in., coal, soft, shaly. 4 ft 7 in., clay shale, medium-gray, noncalcareous, moderately hard, very finely laminated; breaks irregularly along bedding planes; bedding flat. 3 in., clay shale, medium-dark-gray, with thin irregular laminae of coal. A few nearly complete fossil leaves from a dicotyledonous plant. 3 ft 11 in., clay shale, medium-gray, and medium-light-gray very finely interlaminated noncalcareous siltstone that breaks irregularly along bedding planes. 5 in., coal, as above. 7 in., clay shale, with laminae of coal, as above. 1 ft 9 in., coal, as above. 1 ft 5 in., clay shale, with laminae of coal, as above. 1 in., coal. 9 in., bentonite, white to light-gray, pure. 1 ft 2 in., clay shale, with laminae of coal, as above. 4 ft 6 in., coal, as above. 2 in., bentonite, medium-light-gray-brown; clay admixed.
----	320–330	Clay shale, medium-light- to dark-gray, carbonaceous; also black plant fragments; 20 percent black dull and shiny coal; very small amount of amber; moderate yellowish-brown clay ironstone; trace of bentonite.
----	330–340	Coal, black, dull to shiny, 70 percent. medium- to dark-gray clay shale; trace of bentonite; many free biotite plates (probably washed out of bentonite).
----	340–360	Clay shale, medium- to medium-light-gray; trace to 20 percent light-gray siltstone; trace of coal and clay ironstone.
----	360–370	Sandstone, light-gray, very fine-grained, hard; mostly white and clear quartz but also numerous coal grains; moderately calcareous cement. Partings with plant impressions; 20 percent medium-light- to medium-dark-gray clay shale.
----	370–440	Clay shale, medium- to rarely medium-dark-gray. Trace of siltstone at 380–400 ft and 430–440 ft, trace of very fine sandstone at 380–390 ft and 400–410 ft, trace of clay ironstone at 430–440 ft.
----	440–450	Siltstone, light-gray, moderately calcareous. Contains plant impressions.
----	450–510	Clay shale, medium-light- to medium-dark-gray; trace of coal and siltstone.
----	510–520	Sandstone, medium-gray, very fine grained, very calcareous, very soft. A few small chips of very light-gray clay shale.

[1] Single sample covering this interval.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	520–522	No sample.
2	522–542	Recovered 20 ft: Microfossils very rare. 13 ft 9 in., clay shale, medium-dark-gray, noncalcareous, hard; subconchoidal fracture parallel to bedding planes; few pelecypods, embedded mostly in cone-in-cone structure; three interbeds (about 1 in. thick) of slightly calcareous silty hard clay ironstone. Bedding flat. 3 in., siltstone, medium-light-gray, finely and sparsely micaceous, very slightly calcareous, extremely hard. 6 ft, sandstone, light-gray, very slightly calcareous, massive; fine subangular grains; bedding planes indiscernible; clay ironstone nodule. At 539 ft effective porosity parallel to bedding 12.0 percent and 11.7 percent normal to bedding. The rock is impermeable to air.
----	542–544	No sample.
----	544–550	Sandstone, light-gray, fine-grained; composed mostly of white and clear quartz, rare dark minerals with subrounded to subangular grains; slightly to moderately calcareous; 40 percent medium-gray clay shale.
----	550–570	Clay shale, medium-gray; maximum of 40 percent light-gray, fine-grained slightly calcareous sandstone; sand is mostly in lower half of sample.
----	570–590	Sandstone, fine-grained, mostly quartz. Medium-gray clay shale; trace of brownish-gray clay ironstone.
----	590–630	Clay shale, medium- to medium-light-gray. Trace of clay ironstone at 620–630 ft, trace of siltstone at 600–620 ft, trace of coal at 620–630 ft. *Inoceramus* prisms and chunks of prisms throughout. Abundant white mollusk shell fragments at 590–620 ft. Top of the Chandler formation at 590 ft.
----	630–640	Sandstone and siltstone, medium-light-gray; also clay shale and clay ironstone.
----	640–720	Clay shale, medium- to rarely medium-dark-gray. Most of these samples contain traces of siltstone, coal, clay ironstone, and rarely sandstone. They seem to be of poor quality, particularly from 630–680 ft; cement contamination at 650–670 ft. White mollusk fragments at 690–720 ft.
----	720–730	Siltstone, light-gray, sandy, moderately calcareous. Some medium-gray clay shale.
----	730–850	Clay shale, medium- to medium-light-gray. Some dark-gray carbonaceous shale at 790–800 ft, and 830–840 ft; trace of slightly to moderately calcareous siltstone at 760–770 ft, 780–790 ft, 810–820 ft, and 840–850 ft; trace of brownish-gray clay ironstone at 730–750 ft, 770–780 ft, and 830–840 ft. Mollusk fragments at 780–790 ft. Clump of *Inoceramus* prisms at 760–770 ft and 820–830 ft.
3	850–870	Recovered 20 ft: Microfossils very rare. 1 ft, claystone, medium-gray, noncalcareous, hard; breaks in irregular angular chips. 2 in., clay shale, dark-gray, thinly laminated; almost a plant-leaf "coquina." 3 ft, silty claystone, medium-light-gray, noncalcareous, hard; subconchoidal fracture; abundant plant fossils; bedding indistinct. 10 in., claystone, as above. 8 in., silty claystone, as above. 6 in., claystone, as above. 5 ft, 4 in., silty claystone, as above. Grades into unit below. 1 ft 2 in., siltstone, medium-light-gray, noncalcareous, hard; few thin carbonaceous laminae; some small-scale crossbedding. 7 ft 4 in., silty claystone, as above. Beds lie flat (?).
----	870–910	Clay shale, medium-light- to medium-dark-gray; trace of slightly calcareous to noncalcareous light-gray siltstone at 870–880 ft, and 890–910 ft; trace of coal at 870–890 ft, and 900–910 ft; very rare pyrite at 880–890 ft; and trace of brownish-gray clay ironstone at 880–890 ft. *Inoceramus* at 870–880 ft.
----	910–920	Siltstone, light-gray, slightly calcareous; some very fine sandstone; also medium-gray clay shale with a trace of dark carbonaceous shale.
----	920–940	Sandstone, light-gray, fine- to medium-grained, slightly calcareous, rather soft; grains are subangular to subrounded; mostly white and clear quartz, some coal particles; also quite a large amount of medium-gray clay shale; trace of white calcite.
----	940–990	Clay shale, medium-light- to medium-dark-gray; trace of light-gray slightly calcareous siltstone at 960–970 ft, trace of clay ironstone at 980–990 ft. *Inoceramus* prisms at 960–970 ft.
----	990–1, 000	Sandstone, light-gray, fine-grained, rather soft; white and clear quartz, some dark chert; trace of brownish-gray clay ironstone; some clay shale.
----	1, 000–1, 020	Clay shale, medium- to medium-dark-gray, very finely micaceous; trace of black shiny coal at 1,000–1,010 ft.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	1, 020–1, 030	Siltstone, medium-gray, very argillaceous, slightly micaceous, slightly calcareous; also some clay shale; trace of yellowish-gray clay ironstone.
----	1, 030–1, 090	Clay shale, medium- to medium-dark-gray; trace of dark-gray clay shale at 1,030–1,040 ft, and 1,070–1,080 ft; also trace of coal at 1,060–1,080 ft. *Inoceramus* prisms at 1,070–1,080 ft.
----	1, 090–1, 110	Sandstone, light-gray, very fine- to fine-grained; moderately calcareous cement; as much as 70 percent medium-gray clay shale. Plant impressions in both shale and sandstone.
----	1, 110–1, 136	Clay shale, medium- to medium-dark-gray; trace of carbonaceous dark-gray clay shale. *Inoceramus* at 1,110–1,120 ft.
4	1, 136–1, 151	Recovered 10 ft: Microfossils abundant. 2 ft 6 in., claystone, medium-dark-gray, noncalcareous, hard; breaks irregularly approximately parallel to bedding planes. 4 ft 2 in., claystone, as above; but with some tendency to develop shaly fracture; some thin coaly laminae; few sideritic (?) mudstone concretions around which cone-in-cone structure has developed. Abundant plant remains. 3 ft 4 in., silty claystone, medium-gray, noncalcareous, hard; very finely micaceous with thin laminae of siltstone; small-scale crossbedding; at 2 ft from bottom of recovered core is a fault plane (34° dip) with well-developed slickensides and calcite fill. Beds lie flat (?).
----	1, 151–1, 160	No sample.
----	1, 160–1, 170	Clay shale, medium- to dark-gray; a few shell fragments; trace of coal and clay ironstone.
----	1, 170–1, 180	Coal, and black carbonaceous shale, 80 percent; coal is mostly dull and black; 5 percent brown dolomite; also lighter-colored clay shale.
----	1, 180–1, 190	Clay shale, medium- to medium-dark-gray; trace of coal; < 5 percent brown dolomite. *Inoceramus* prisms.
----	1, 190–1, 300	Clay shale, medium- to medium-dark-gray; trace to 5 percent black shiny coal and black shale. Trace of light-gray siltstone and sandstone at 1,210–1,220 ft. *Inoceramus* prisms at 1,290–1,300 ft.
5	1, 300–1, 307	Recovered 7 ft. Microfossils absent. 9 in., sandstone, light-gray, very fine- to fine-grained, hard; mostly white quartz and some clear quartz, with dark chert and other minerals; grains subangular to subrounded; black carbonaceous plant fragments in partings; moderately calcareous cement. At 1,300 ft rock was impermeable to air and had an effective porosity of 1.5 percent parallel to bedding and of 2.1 percent normal to bedding. Carbonate content at the same depth was 21.3 percent by weight. 2 ft 5 in., clay shale or claystone, medium-gray, hard, poor cleavage; rocks tend to fracture conchoidally. Contains scattered black noncalcareous carbonaceous plant impressions. Grades into unit below. 3 ft 10 in., claystone, silty, and argillaceous siltstone, medium-light-gray, hard; rock grades from one to the other; scattered laminae of light-gray sandstone; contains numerous black plant impressions throughout; ⅛-inch layer of coal at very base. Irregular fracture about parallel to bedding; dip low, probably less than 5°; bedding not clearly defined; slickensides noted at 1,301 ft and 1,304 ft, latter at an angle of 40°. No shows.
----	1, 307–1, 330	Clay shale, medium-gray; trace of fine- to medium-grained sandstone with moderately calcareous matrix; trace to 5 percent black shiny coal.
----	1, 330–1, 340	Coal, black, shiny to dull; mostly in small pieces; also much dark-gray carbonaceous shale. Trace of very fine- to fine-grained sandstone and of medium-gray clay shale.
----	1, 340–1, 350	Siltstone, and some very fine-grained sandstone, argillaceous, slightly micaceous, "dirty"; coal grains; brownish-gray clay ironstone common.
----	1, 350–1, 360	Clay shale, medium-light- to medium-dark gray; trace of siltstone and coal. *Inoceramus* prisms.
----	1, 360–1, 370	Coal, black, dull to shiny, 30 percent; and medium-light- to medium-dark-gray clay shale; trace of brownish-gray clay ironstone.
----	1, 370–1, 380	Clay shale, medium-light- to dark-gray; 10 percent, slightly micaceous siltstone; trace to 5 percent coal.
----	1, 380–1, 390	No sample.
----	1, 390–1, 400	Clay shale, medium- to medium-light-gray; 30 percent light-gray argillaceous siltstone; trace of coal.
6	1, 400–1, 420	Recovered 18 ft: Microfossils absent. 1 ft 9 in., coal, interbedded with dark-gray carbonaceous clay shale. Coal is black, shiny to dull, and brittle. Also laminae (maximum 2 in. thick)

Lithologic description—Continued

Core	Depth (feet)	Remarks
		of medium-dark-gray dense very hard dolomite with conchoidal fracture; has thin almost vertical veins of yellowish-gray dolomite crystals.
		8 ft 2 in., siltstone, closely interbedded with some sandstone and claystone, light- to medium-light-gray—lighter gray with increasing grain size, hard; cleavage poor where present; contains black plant fragments on partings; sandstone is very fine grained, mostly white and clear quartz; does not effervesce with cold dilute HCl. At 1,409 ft the rock was impermeable to air and had an effective porosity of 0.96 percent parallel to bedding and 1.2 percent normal to bedding. Carbonate content at that depth 10.2 percent by weight.
		9 in., clay shale, medium-dark-gray; numerous plant fragments; shale is interbedded with thin laminae of coal.
		2 ft 11 in., sandstone, light- to medium-light-gray, very fine- to fine-grained, hard; subrounded to subangular grains are primarily white and clear quartz; some dark chert and coal particles. Partings and stringers of dark carbonaceous material; small amount of crossbedding; some siltstone and claystone. Does not effervesce with cold dilute HCl; beds lie approximately flat.
		2 ft 5 in., claystone and clay shale, interbedded with a small amount of siltstone. Shale is medium-dark to medium-light-gray, hard; cleavage poor where present; abundant black plant fragments; a few thin laminae of coal. Siltstone is light-gray and occurs as irregular lenses in the shale.
		2 ft, coal and clay shale. Coal is black, dull to shiny, thin-bedded, rather brittle; contains rare small inclusions of clear amber. Clay shale is dark-gray to grayish black, thin bedded, and very carbonaceous. Some nodules of yellowish-gray clay ironstone and scattered slickensided surfaces throughout core; no shows.
----	1, 420–1, 450	Clay shale, medium-gray; as much as 10 percent sandy siltstone, and 5 percent coal. *Inoceramus* prisms at 1,420–1,430 ft.
----	1, 450–1, 480	Sandstone, light-gray, fine- to medium-grained (mostly the latter), moderately calcareous; grains are 60 percent white and clear quartz; numerous coal particles, very rare glauconite (?); as much as 20 percent medium-dark- to dark-gray clay shale.
----	1, 480–1, 500	Clay shale, medium-gray to grayish-black; trace of black shiny coal.
7	1, 500–1, 512	Recovered 12 ft: Microfossils absent. Clay shale or claystone, medium-dark to dark-gray, medium-hard; entire core is badly broken; only rare pieces are thicker than an inch; poor cleavage, conchoidal fracture; scattered (particularly in lowest 5 ft of core) very thin lenses of coal; ¼-inch layer of clear, greenish-yellow amber at approximately 1,508 ft; rare slickensides; noncalcareous; bedding obscure, probably almost flat.
----	1, 512–1, 570	Clay shale, medium- to medium-dark-gray. Trace of sandstone at 1,512–1,520 ft; trace of siltstone at 1,560–1,570 ft; trace to 10 percent of coal at 1,530–1,540 ft and 1,550–1,560 ft; trace of dark-yellowish-brown clay ironstone at 1,540–1,550 ft.
----	1, 570–1, 590	Siltstone; and some very fine light-gray sandstone; also a large amount of medium to medium-dark-gray clay shale; plant impressions; trace of coal; pelecypod fragments.
----	1, 590–1, 610	Clay shale, medium- to medium-dark-gray; trace of siltstone and coal; one piece of amber at 1,600–1,610 ft. *Inoceramus* prisms at 1,590–1,600 ft.
----	1, 610–1, 620	Siltstone, light-gray, noncalcareous, 80 percent; also medium- to medium-light-gray clay shale.
----	1, 620–1, 660	Clay shale, medium- to medium-dark-gray, rarely dark-gray; trace of coal at 1,640–1,650 ft.
----	1, 660–1, 720	Clay shale, medium- to medium-light-gray. Trace of siltstone, trace of fine-grained sandstone at 1,660–1,670 ft, trace of coal at 1,680–1,690 ft and 1,710–1,720 ft, light-olive-gray clay ironstone at 1,710–1,720 ft.
----	1, 720–1, 740	Sandstone, light-gray, fine-grained; grains subangular to subrounded; primarily white and clear quartz; remainder is dark chert and black coal grains, also scattered grains of a greenish mineral; plant impressions; trace of coal; noncalcareous.
----	1, 740–1, 790	Clay shale, medium- to medium-dark-gray, some medium-light-gray and some dark-gray. Trace to 5 percent siltstone at 1,740–1,780 ft; 30 percent light-gray very fine- to fine-grained noncalcareous sandstone at 1,750–1,760 ft.
----	1, 790–1, 800	Clay shale, medium-light-gray, 50 percent; and 50 percent, light-gray, noncalcareous siltstone; trace of coal and some clay ironstone. *Inoceramus* prisms.
----	1, 800–1, 802	No sample.

Lithologic description—Continued

Core	Depth (feet)	Remarks
8	1, 802–1, 812	Recovered 9 ft: Microfossils absent. Clay shale, 90 percent; and 10 percent siltstone. Clay shale is medium dark gray, hard; has poor to fair cleavage; contains scattered plant fragments the larger of which have changed to coal. Siltstone is medium light gray, approximately same hardness as the clay shale, and is present as irregular laminae and lenses in the shale; slight suggestion of small-scale cross bedding; very rare slightly yellowish-gray clay ironstone nodules; slickensides dipping 45° at 1,806 ft; siltstone is slightly calcareous. Dip 1°.
----	1, 812–1, 830	Clay shale, medium- to medium-light-gray; trace of siltstone and very fine sandstone.
----	1, 830–1, 840	Sandstone, light-gray, very fine- to fine-grained, noncalcareous, 45 percent; and medium-gray clay shale.
----	1, 840–1, 860	Clay shale, medium- to medium-light-gray; trace of very fine sandstone. Top of the Grandstand formation is placed at 1,850 ft.
----	1, 860–1, 880	Clay shale, medium-gray; 40 percent light-gray very fine-grained noncalcareous sandstone contains coal fragments; trace of coal and brownish-gray clay ironstone.
----	1, 880–1, 890	Sandstone, light-gray, fine- to medium-grained, hard; grains are subangular to subround; 80 percent white and clear quartz; remainder is carbonaceous particles and dark chert; argillaceous matrix; carbonaceous partings; also 15 percent medium-gray clay shale.
----	1, 890–1, 900	Clay shale, medium-gray; trace of siltstone and coal.
----	1, 900–1, 910	Siltstone, light-gray, argillaceous, 60 percent; and medium-gray clay shale.
----	1, 910–1, 950	Clay shale, medium- to medium-dark-gray; trace of coal at 1,940–50 ft.
----	1, 950–1, 980	Clay shale, medium-light- to medium-dark-gray; also siltstone and very fine-grained slightly calcareous sandstone. Trace of brownish-gray clay ironstone; some slightly to moderately calcareous white material which is probably fault gouge; slickensides are at 1,960–1,970 ft.
----	1, 980–2, 000	Clay shale, medium- and dark-gray, carbonaceous; 5 percent coal; trace of siltstone.
----	2, 000–2, 020	Siltstone, and very fine-grained sandstone, 30–80 percent; light- to medium-gray noncalcareous clay shale; trace of coal.
----	2, 020–2, 030	Clay shale, medium-gray; 10 percent black shiny coal; trace of sandstone and siltstone.
----	2, 030–2, 040	Siltstone, medium-light-gray; and light-gray very fine-grained argillaceous noncalcareous sandstone; grades to medium-gray clay shale; trace of coal.
----	2, 040–2, 080	Clay shale, medium- to medium-light-gray; 20–60 percent light-gray sandstone and siltstone; sandstone is fine to medium grained, slightly calcareous; made up mostly of white and clear quartz; coal particles.
9	2, 080–2, 092	Recovered 12 ft: Microfossils very rare. Siltstone, 25 percent, interbedded with clay 75 percent claystone (or clay shale). Claystone is medium dark gray, hard; poor cleavage; some conchoidal fracture; small amount of clay ironstone. Siltstone is light to medium light gray, hard, slightly sandy; some swirly bedding in the upper 2 ft; siltstone is slightly to moderately calcareous; dip 1°; no shows.
----	2, 092–2, 100	Clay shale, medium-gray; 20 percent siltstone; trace of sandstone; trace of light-brownish-gray clay ironstone.
----	2, 100–2, 170	Clay shale, medium- to medium-dark-gray; trace to 20 percent siltstone or sandstone except in the interval 2,140–2,160 ft; carbonaceous plant impressions at 2,130–2,140 ft and 2,160–2,170 ft; trace of clay ironstone.
----	2, 170–2, 190	Clay shale, medium- to medium-dark-gray; as much as 30 percent slightly calcareous light-gray siltstone and fine-grained sandstone.
----	2, 190–2, 200	Siltstone; and 60 percent very fine- to fine-grained light-gray slightly to moderately calcareous sandstone. Also medium-gray clay shale.
----	2, 200–2, 230	Clay shale, medium- to medium-dark-gray; a trace to 30 percent sandstone in the lower part of the interval.
----	2, 230–2, 290	Sandstone, light-gray, fine- to medium-grained; subangular to subrounded grains, rare rounded coarse grains; mostly white and clear quartz; some brownish chert and siderite particles; coal particles; plant impressions; slightly calcareous except for the interval 2,270–2,280 ft which is moderately calcareous; fairly porous to drop test. Also some medium- to medium-dark-gray clay shale in each sample; brownish-gray clay ironstone at 2,260–2,270 ft.
----	2, 290–2, 300	Sandstone, as above; and as much as 65 percent medium- to medium-dark-gray clay shale.
----	2, 300–2, 330	Sandstone, as above, fine- to medium-grained; clay ironstone at 2,300–2,310 ft.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	2, 330–2, 340	Clay shale, medium- to dark-gray; also some sandstone.
----	2, 340–2, 360	Sandstone, as in interval 2,230–2,290 ft, fine- to medium-grained, noncalcareous to slightly calcareous; rather porous to drop test; some clay shale.
----	2, 360–2, 370	Sandstone, 50 percent, and 50 percent clay shale.
----	2, 370–2, 378	No sample.
10	2, 378–2, 393	Recovered 12 ft: Microfossils abundant. 4 ft 6 in., clay shale, medium- to dark-gray, hard; fair to good cleavage; conchoidal fracture. Very rare carbonaceous plant impressions. 7 ft 6 in., siltstone, 65 percent, interbedded with 20 percent sandstone, and 15 percent clay shale. Siltstone and sandstone are medium light gray, hard, tight, silt size to very fine grained; consists of mostly white and clear quartz; a small amount of small-scale crossbedding. Clay shale is medium gray, noncalcareous, hard, with poor to fair cleavage; dip 1°–4°.
----	2, 393–2, 410	Clay shale, medium- to medium-dark-gray; 15 percent medium-light-gray siltstone.
----	2, 410–2, 420	Siltstone, light-gray, 50 percent; also 50 percent medium-gray clay shale; trace of clay ironstone.
----	2, 420–2, 480	Clay shale, medium- to rare medium-dark-gray; trace of brownish-gray clay ironstone at 2,430–2,450 ft and 2,460–2,470 ft; trace of black shiny to dull coal at 2,420–2,430 ft, 2,440–2,450 ft and 2,460–2,470 ft; siltstone or sandy siltstone at 2,440–2,480 ft.
----	2, 480–2, 490	Sandstone, light-gray, fine- to medium-grained; 70 percent; subangular to subrounded grains are 80 percent white and clear quartz; also dark chert, coaly particles, rock fragments; slightly calcareous; also 30 percent medium-gray clay shale; trace of clay ironstone.
----	2, 490–2, 520	Clay shale, medium- to medium-dark-gray; as much as 30 percent fine-grained light-gray sandstone; trace of dull to shiny black coal at 2,500–2,510 ft.
----	2, 520–2, 540	Sandstone, light-gray, fine-grained; grains are subangular to subrounded; mostly white and clear quartz; also dark chert, rock fragments, coal particles; trace of siltstone, clay shale, clay ironstone, pyrite, and coal.
----	2, 540–2, 560	Clay shale, medium-dark- and dark-gray; maximum of 30 percent sandstone as above; trace of clay ironstone. Crinoid ossicle at 2,540–2,550 ft.
----	2, 560–2, 580	Sandstone, light-gray, fine- to medium-grained; probably rather soft; subangular to subrounded grains are 85 percent white and clear quartz; remainder is dark chert, dark rock particles, coal particles; noncalcareous; also about 15 percent, medium-dark-gray clay shale.
----	2, 580–2, 620	Clay shale, medium- to medium-dark-gray; 20 to 30 percent slightly calcareous siltstone and sandstone; trace of clay ironstone at 2,580–2,590 ft and 2,610–2,620 ft.
----	2, 620–2, 630	Limestone (or possible siderite or dolomite), medium-dark-gray, argillaceous, hard; some chips with a brownish cast; reacts slowly at first with dilute hydrochloric acid but vigorously later; white vein calcite present; trace of clay shale.
----	2, 630–2, 640	Sandstone, light-gray, fine- to rare medium-grained; subangular to subrounded grains are 70 percent white and clear quartz; also dark chert, coal, and rock fragments. Medium-dark-gray clay shale; and siltstone; trace of coal.
----	2, 640–2, 650	Clay shale, medium-dark-gray, 70 percent; 20 percent sandstone; 10 percent siltstone; trace of clay ironstone.
----	2, 650–2, 657	No sample.
11	2, 657–2, 670	No recovery.
12	2, 670–2, 676	Recovered 16 ft: Microfossils rare. Recovery included part of core 11. 3 ft 3 in., sandstone, light- to medium-light-gray, very fine- to fine-grained, hard; subangular to rare subrounded grains are 80 percent white and clear quartz; remainder is mostly dark carbonaceous particles, dark chert, and rock fragments. Contains irregular coaly streaks and carbonaceous plant impressions. Also includes a few small yellowish-gray clay ironstone nodules. Slightly calcareous cement; no shows. 7 ft, clay shale, medium-dark- to dark-gray, hard; fair cleavage; subconchoidal fracture; contains very rare coaly inclusions and numerous small (about one-quarter inch in diameter) incipient cone-in-cone structures. About a foot from the base of this interval of rock is a rough broken zone of 6 in. infiltrated with drilling mud; noncalcareous; dip 2° or less. Grades into unit below. 3 ft 5 in., claystone, medium-dark-gray, hard; similar to above but with smoother texture, poorer cleavage, and more conchoidal fracture. Some small brownish-gray clay ironstone nodules; incipient cone-in-cone struc-

Lithologic description—Continued

Core	Depth (feet)	Remarks
		tures; near vertical slickensides at the very base of the interval. 2 ft 4 in., sandstone, light-gray, massive, hard; grains subangular to subrounded; fairly well sorted; intermediate between fine and medium size ranges; 90 percent or more clear and white quartz, some dark chert and coal particles; light-colored argillaceous(?) cement. Fleeting to fairly good oil odor on fresh break at 2,675 ft—odor suggestive of light fractions. Very pale-straw-colored cut and pale-yellow residue at 2,675 ft. At 2,675 ft the effective porosity and air permeability parallel to bedding 12.45 percent and 17 millidarcys, respectively; normal to bedding 11.3 percent and 8 millidarcys, respectively. At the same depth the carbonate content 5.7 percent by weight.
----	2, 676–2, 690	Sandstone, light-gray, fine- to medium-grained, noncalcareous. Medium-dark-gray clay shale; trace of yellow-gray clay ironstone.
----	2, 690–2, 700	Clay shale, 70 percent; and sandstone as above.
----	2, 700–2, 710	Sandstone, as above; a maximum of 50 percent medium- to medium-dark-gray clay shale.
----	2, 710–2, 770	Clay shale, medium-dark-gray; varying amounts of siltstone and sandstone; trace of coal at 2,750–2,760 ft, trace of clay ironstone at 2,760–2,770 ft.
----	2, 770–2, 820	Sandstone, light-gray, between fine- and medium-grained; grains are 85 percent white and clear quartz; remainder is dark chert and dark rock particles; very slightly calcareous; trace of clay shale.
----	2, 820–2, 890	Clay shale, medium-dark-gray; varying amounts of slightly calcareous fine-grained sandstone (40 percent in interval 2,830–2,850 ft), trace of brownish-gray clay ironstone at 2,860–2,870 ft and 2,880–2,890 ft; trace of dull to shiny black coal at 2,880–2,890 ft.
----	2, 890–2, 900	Sandstone, light-gray, fine-grained; grains are mostly white and clear quartz; also dark chert, rock fragments, carbonaceous material, and rare pyrite; very calcareous cement.
----	2, 900–2, 960	Clay shale, medium-dark-gray; traces of siltstone and sandstone.
----	2, 960–2, 983	Sandstone, light-gray, fine- to medium-grained; grains are subangular to subround; 80 percent white and clear quartz; remainder is mostly dark chert and carbonaceous-coaly particles. Also some medium-dark-gray clay shale.

Lithologic description—Continued

Core	Depth (feet)	Remarks
13	2, 983–3, 003	Recovered 20 ft: Microfossils absent. Sandstone, light-gray, uniform, massive, hard; irregular fractures; fine-grained with rare medium-sized grains; grains are subangular to subrounded; as much as 90 percent white and clear quartz; remainder is mostly dark chert and coal particles; slightly to moderately calcareous; dip 1°. At 2,987 ft the effective porosity parallel the bedding 8.1 percent, and normal the bedding 7.8 percent; at 2,997 ft it is 7.32 percent and 7.96 percent, respectively. All the samples were impermeable. Very pale-straw-colored cut and very pale-brownish-yellow residue from 2,987 ft. Very pale-brownish-yellow residue from 2,997 ft. No cut.
14	3, 003–3, 014	Recovered 10 ft: Microfossils absent. Sandstone, as above, slightly calcareous; very rare coaly plant impressions; slickensides dipping 30° with white coating at 3,007 ft and at 3,008 ft; dip 1°. Impermeable at 3,004 ft; effective porosity parallel to bedding 8.25 percent, normal to bedding 9.96 percent. Very pale-straw colored cut and very pale-brownish-yellow residue from 3,004 ft.
15	3, 014–3, 027	Recovered 10 ft: Microfossils absent. Sandstone, as above; fine- to medium-grained; 1 pale-brown clay ironstone concretion 2 in. in diameter at 3,017 ft; slightly calcareous; dip 1°. At 3,015 ft effective porosity parallel to bedding 4.26 percent, normal to bedding 6.31 percent; impermeable to air. Extremely faint cut and very pale-brownish-yellow residue from 3,015 ft.
----	3, 027–3, 030	No sample.
----	3, 030–3, 102	Clay shale, medium-dark-gray; small amounts of very fine- to fine-grained sandstone; 50 percent sandstone at 3,060–3,070 ft.
16	3, 102–3, 122	Recovered 20 ft: Microfossils common. 13 ft, clay shale, medium-dark-gray, medium-hard; fair to good cleavage; subconchoidal fracture; rare very thin lighter-colored silty streaks; and rare coaly plant fragments; thin, ¼-in. layers of shiny black coal at 3,103 ft and 3,114 ft. 7 ft, clay shale, 60 percent; and 40 percent siltstone. Clay shale is medium gray, hard; poor to fair cleavage. Light-gray hard slightly calcareous siltstone grades in places into the clay shale and in others alternates with the

Lithologic description—Continued

Core	Depth (feet)	Remarks
		shale in very thin beds; some dark carbonaceous partings; some tiny crossbeds; dip 3°.
17	3, 122–3, 137	Recovered 14 ft: Microfossils abundant. Clay shale, medium-dark-gray, very slightly micaceous, noncalcareous, hard; fair cleavage; slight tendency to conchoidal fracture; about 5 percent of light-gray very silty laminae and lenses; dip 1°.
----	3, 137–3, 210	Clay shale, medium-dark-gray; 30 to 50 percent light-gray fine- to medium-grained siltstone and sandstone; subangular to subrounded grains are 80 percent white and clear quartz; remainder is dark chert and coal particles; trace of clay ironstone at 3,160–3,170 ft and 3,200–3,210 ft.
----	3, 210–3, 214	No sample.
18	3, 214–3, 233	Recovered 15 ft: Microfossils very rare. Sandstone, light-gray, fine-grained; hard; mostly massive with no bedding apparent; subangular to subrounded grains are 90 percent white and clear quartz; remainder is mostly dark chert and some coal particles; very rare carbonaceous partings; calcareous cement; dip 2½°; slight odor at very base of core. Saturation test at 3,233 ft showed rock to contain 0.51 percent petroleum and 1.54 percent basal sediment and water with total percent by volume of 2.05. Effective porosity at 3,244 ft 2.44 percent parallel to bedding, and 1 percent normal to bedding. Porosity at 3,232 ft 0.80 and 0.56 percent, respectively. Samples all impermeable. Carbonate-mineral content at 3,214 ft 17.5 percent by weight and at 3,232 ft 30.4 percent.
----	3, 233–3, 240	Sandstone, as in core immediately above; also some medium-dark-gray clay shale.
----	3, 240–3, 280	Clay shale, medium-dark-gray; numerous laminae of fine-grained sandstone.
----	3, 280–3, 289	No sample.
19	3, 289–3, 309	Recovered 20 ft: Microfossils abundant. 3 ft, clay shale, medium-dark to dark-gray, noncalcareous, medium-hard; fair to good cleavage; dip 2°. 1 ft, coal and shale, dark-gray to grayish-black, carbonaceous, brittle; flaky cleavage. 1 ft, claystone, medium-dark-gray; fractures irregularly; abundant shiny black coal particles; abundant plant fragments. 15 ft, sandstone, light-gray, medium-hard; fractures approximately parallel to bedding; grain size between fine

Lithologic description—Continued

Core	Depth (feet)	Remarks
		and medium; grains subangular to subround; 85 percent white and clear quartz, dark chert, rarely other minerals make up remainder. Rare black carbonaceous partings; moderately to very calcareous (probably cement); dip 1½°; slight odor in sandstone. Effective porosity at 3,297 ft 11.05 percent; air permeability 4 millidarcys; carbonate-mineral content 14.9 percent by weight. At 3,306 ft porosity parallel to bedding 8.98 percent and normal to bedding 8.83 percent. Samples at 3,306 ft impermeable, and carbonate content 11.9 percent.
----	3, 309–3, 390	Clay shale, medium-dark-gray; as much as 50 percent light-gray fine-grained sandstone.
----	3, 390–3, 410	Sandstone, light-gray, fine- to medium-grained; consists of 85 percent quartz; also chert and coal particles; also some medium-dark-gray clay shale.
----	3, 410–3, 420	Clay shale, medium-dark-gray, and some sandstone.
20	3, 420–3, 435	Recovered 12 ft: Microfossils absent. Sandstone and some very sandy limestone, light- to medium-light-gray, fine- to medium-grained, hard; subangular to rare subrounded grains; consists of 70 percent white and clear quartz, as much as 25 percent dark-brown and black chert; moderately to very calcareous cement. Upper 2 ft shows at least 3 distinct fracture planes with slickensided surfaces coated with hard white calcareous material. Cracks filled with white material also noted in unbroken parts of core. Fracture planes dip 35° to nearly vertical. Slickensides noted also at 3,430 ft and 3,431 ft. Very rare black carbonaceous laminae; dip difficult to distinguish because of massive beds but probably very low. Fairly good odor, yellow cut, and brownish-yellow residue from 3,428 ft. At 3,431 ft rock impermeable to air and effective porosity to 10.5 percent parallel to bedding, 12.0 percent normal to bedding. Carbonate content 51.9 percent by weight.
21	3, 435–3, 450	Recovered 15 ft: Microfossils absent, Sandstone, medium-light-gray, massive, hard; irregular fracture; grains subangular to subrounded; fine to slightly larger than fine size; 85 percent white and clear quartz; remainder is dark-gray and brown chert, rock fragments, and rarely

Lithologic description—Continued

Core	Depth (feet)	Remarks
		other minerals; very rare clayey laminae or lenticles; dip 1½°; no odor; no cut but a yellowish greasy stain from 3,435 ft and 3,448 ft. At 3,435 ft effective porosity parallel to bedding is 8.42 percent and normal to bedding is 10.12 percent. Porosities at 3,448 ft are 9.04 and 4.58 percent, respectively. Carbonate-mineral content at 3,435 ft is 20.48 percent by weight, and 9.82 percent at 3,448 ft. All four samples are impermeable.
----	3, 450–3, 490	Sandstone, light-gray, fine- to medium-grained; 85 percent is white and clear quartz, also chert and coal particles; slightly calcareous; as much as 40 percent medium-dark-gray clay shale.
----	3, 490–3, 500	Siltstone and clay shale; and a rather large amount of sandstone.
----	3, 500–3, 550	Clay shale, medium-dark-gray, 60-75 percent; also siltstone and sandstone. Top of Topagoruk formation placed at 3,500 ft.
22	3, 550–3, 560	Recovered 7 ft: Microfossils abundant. Siltstone, 30 percent, interbedded with 70 percent clay shale. Siltstone is medium light gray, slightly calcareous, and hard; good cleavage parallel to bedding, and carbonaceous-micaceous partings. Clay shale is medium to medium dark gray, silty, and hard; fair cleavage: partly pyritized *Ditrupa* sp. found at 3,551 ft; dip variable up to 4°; no shows. *Inoceramus* prisms in microfossil cut.
----	3, 560–3, 600	Clay shale, medium dark gray, 60 percent; remainder is medium-light-gray siltstone and some very fine sandstone. Trace of clay ironstone at 3,570–3,580 ft; trace of coal at 3,590–3,600 ft.
----	3, 600–3, 620	Siltstone, medium-light-gray; some sandstone and clay shale.
----	3, 620–3, 630	Clay shale, medium-dark-gray, 70 percent; and light-gray fine- to medium-grained slightly salt and pepper sandstone; 70 percent is quartz, remainder is dark chert and coal particles; noncalcareous; trace of clay ironstone.
----	3, 630–3, 650	Clay shale, medium-dark-gray, small amount of siltstone and sandstone; trace of clay ironstone at 3,640–3,650 ft.
23	3, 650–3, 677	Recovered 10 ft: Microfossils common. Siltstone, light-gray, hard; good to excellent cleavage parallel to bedding; beds frequently grade into laminae containing very fine- to fine-grained quartz sand; dark carbonaceous partings common. Less than 5 percent of total recovery made up of irregular lenses of medium-gray clay shale; at top of bottom 5 ft of core inch-thick layer of subangular clay shale fragments in the silt—a very local intraformational conglomerate. Fragments are as much as an inch in diameter and lie with their long flat dimensions parallel to bedding. *Ditrupa* tubes, a pelecypod cast (too poorly preserved to identify), and crinoid fragments found at approximately 3,676 ft; *Ditrupa* and crinoid fragments also noted at 3,672 ft; carbonate content at 3,671 ft is 20.1 percent by weight. Effective porosity at this depth 6.07 percent parallel to bedding and 6.67 percent normal to bedding. Rock is impermeable to air. Dip 2°–6°; no odor; very pale cut and yellowish greasy stain in evaporating dish at 3,671 ft. *Inoceramus* prisms in microfossil cut.
24	3, 677–3, 689	Recovered 15 ft: Microfossils very rare. Recovery includes 3 ft of core 23. 8 ft, siltstone, as in core 23; carbonate content at 3,677 ft 26.2 percent by weight. Effective porosity at this depth 4.66 percent parallel to bedding and 5.57 percent normal to bedding; impermeable; dip 2°; no odor or cut but faint greasy residue in evaporating dish at 3,677 ft. Grades into unit below. 7 ft, claystone, medium-light- to medium-gray, very silty, moderately calcareous, hard; cleavage poor where present.
----	3, 689–3, 762	Clay shale, medium-dark-gray; trace to 10 percent sandstone and (or) siltstone; trace of brownish-gray clay ironstone at 3,720–3,730 ft and 3,740–3,760 ft.
25	3, 762–3, 782	Recovered 17 ft: Microfossils very rare. Siltstone, 90 percent; and 10 percent clay shale. Siltstone is light to medium light gray, hard, has fair to good shaly cleavage. Clay shale is medium gray to medium dark gray, moderately to very calcareous, hard; occurs as laminae no thicker than 2 in. in the silt; poor cleavage; dip 2°–4°; no shows.
----	3, 782–3, 790	Clay shale, medium-dark-gray; trace to 5 percent siltstone, trace of clay ironstone and sandstone.
----	3, 700–3, 800	Siltstone, medium-light-gray, 80 percent; and medium-gray clay shale.
----	3, 800–3, 820	Clay shale, medium to medium-dark-gray, 60 percent; and 40 percent siltstone.
----	3, 820–3, 850	Clay shale, medium- to medium-dark-gray 70–90 percent; remainder is siltstone or very fine sandstone; trace of brownish-

Lithologic description—Continued

Core	Depth (feet)	Remarks
		gray clay ironstone; several slickensided chips and one crinoid stem ossicle at 3,830–3,840 ft.
----	3, 850–3, 930	Clay shale, medium- to medium-dark-gray; trace to 8 percent siltstone and sandstone.
----	3, 930–4, 001	Clay shale, medium-dark-gray; trace of medium-light-gray siltstone. *Inoceramus* prisms at 3,950–3,960 ft.
26	4, 001–4, 020	Recovered 19 ft: Microfossils common. Siltstone, interbedded with clay shale with all gradations between these. Core is generally slightly more silty than argillaceous. Siltstone is light gray to medium gray, finely micaceous, moderately to very calcareous, moderately hard; has good cleavage parallel the bedding, rare slightly sandy streaks, and traces of small-scale crossbedding. Clay shale is medium to medium dark gray, noncalcareous, medium hard, and has good cleavage; some swirly bedding in the top foot; beds dip 1° or less; no shows when core reached laboratory, but well geologist reported slight odor in the silt at time core was taken.

Core analyses of Titaluk test well 1

Core	Depth [1]	Effective porosity (percent)	Air permeability (millidarcys)	Carbonate minerals (percent by weight)
2	539P	12. 0	0	Not tested.
	539N	11. 7	0	
5	1300P	1. 5	0	21. 3
	1300N	2. 1	0	
6	1409P	0. 96	0	10. 2
	1409N	1. 2	0	
12	2675P	12. 45	17	5. 7
	2675N	11. 30	8	
13	2987P	8. 1	0	Present, not determined.
	2987N	7. 8	0	
	2997P	7. 32	0	Present, not determined.
	2997N	7. 96	0	
14	3004P	8. 25	0	Trace, not determined.
	3004N	9. 96	0	
15	3015P	4. 26	0	Trace, not determined.
	3015N	6. 31	0	
18	3214P	2. 44	0	17. 5
	3214N	1. 00	0	
	3232P	0. 80	0	30. 4
	3232N	0. 56	0	
19	3297	11. 05	4	14. 9
	3306P	8. 98	0	11. 9
	3306N	8. 83	0	
20	3431P	10. 5	0	51. 9
	3431N	12. 0	0	
21	3435P	8. 42	0	20. 48
	3435N	10. 12	0	
	3448P	9. 04	0	9. 82
	3448N	4. 58	0	
23	3671P	6. 07	0	20. 10
	3671N	6. 67	0	
24	3677P	4. 66	0	26. 20
	3677N	5. 57	0	

[1] P is parallel to the bedding.
N is normal to the bedding.

CORE ANALYSES

The following table contains analyses made in the Fairbanks laboratory of the Geological Survey on plugs cut from the sandy cores of Titaluk test well 1. The effective porosity was determined by the Barnes (vacuum) method, and the air permeability was determined by a standard permeameter whose requirements are detailed in API Code 27, second edition, April 1942.

HEAVY-MINERAL ANALYSIS

Robert H. Morris of the Geological Survey has made a study of the heavy minerals of Naval Petroleum Reserve No. 4 from samples collected both in the field and in the test wells. The sandstone samples were disaggregated and treated with HCl to remove the carbonates. The disaggregate was sieved, and the material passing the 80-mesh and retained on the 235-mesh screens was separated in bromoform (sp gr 2.70) and methylene iodide (sp gr 3.0) into light, medium, and heavy fractions. Slides of the heavy fractions (sp gr 3.0) were prepared with Canada balsam or aroclor.

The opaque heavy minerals were found to be nondiagnostic for zonation purposes. The following criteria were found useful in delimiting zones of the nonopaque heavy minerals: Relative abundance of certain minerals; proportion of garnet grains etched in contrast to garnet grains with conchoidal fracture; presence of diagnostic minerals or mineral suites; degree of rounding of mineral grains; and grain form, such as euhedral or anhedral.

Nine samples from Titaluk test well 1 were examined and only the zoned zircon zone was recognized. (See fig. 31.) This zone ranges from 2,660 to 3,460 feet. The sample at 3,660 feet is nondiagnostic.

OIL AND GAS

OIL AND GAS SHOWS

The oil and gas shows in the Titaluk test are poor. Cuts were made in the Fairbanks laboratory with carbon tetrachloride immediately after the cores had been shipped from the Reserve.

The best oil shows in Titaluk test well 1 were in the sandstones between 3,200 and 3,450 feet. A little gas was found at 3,000 feet but most of the sands are too thin and are lacking in permeability to have much

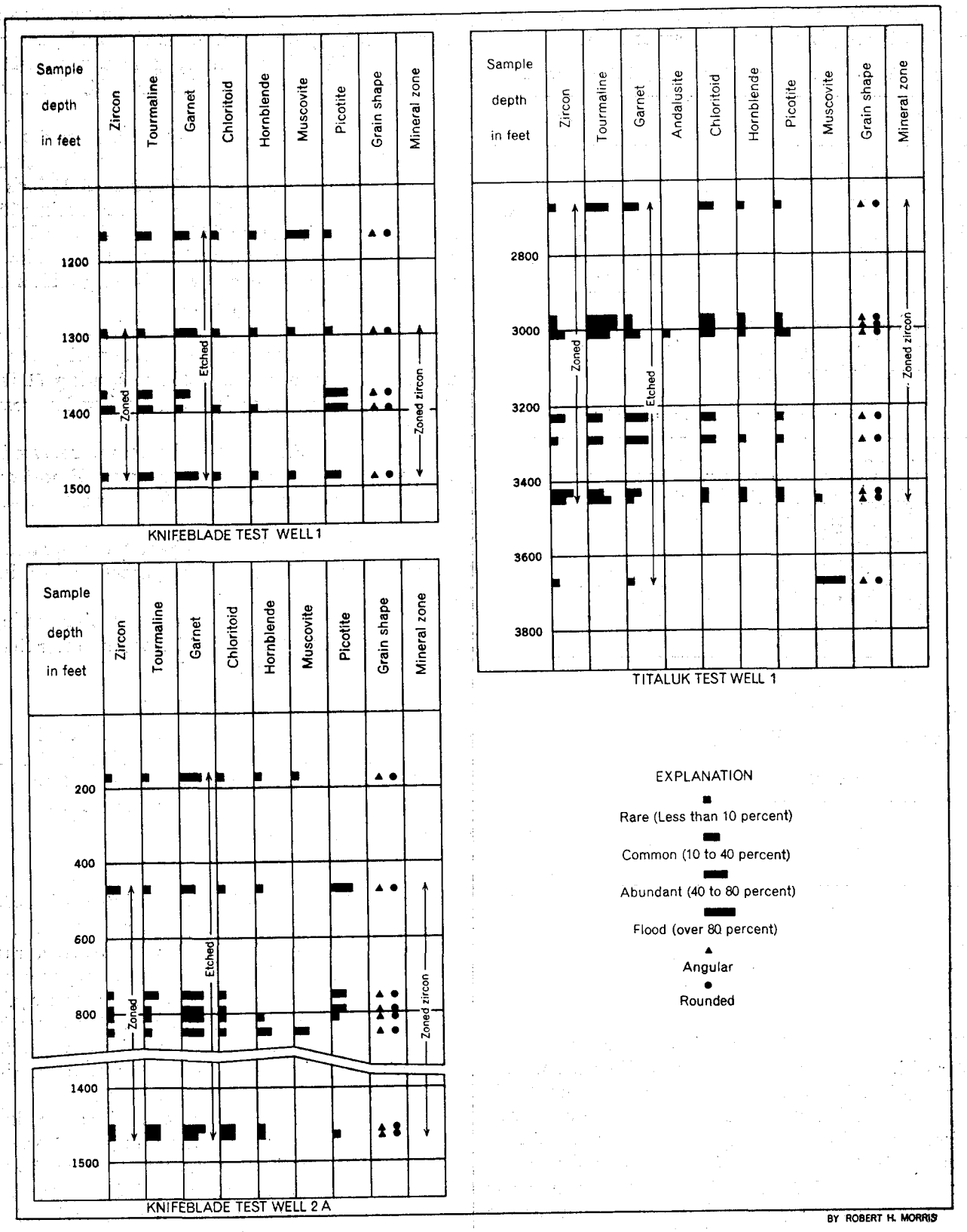

FIGURE 31.—Relative abundance of heavy minerals in the Titaluk and Knifeblade test wells.

merit as reservoirs of oil and gas. The results of tests for oil stain are given in the following table.

Tests for oil stain in carbon tetrachloride, Titaluk test well 1

Core	Depth (feet)	Cut	Residue
12	2,675	Very pale straw colored	Pale yellow.
13	2,987	Very pale straw colored	Pale brownish yellow.
13	2,997	None	Very pale brownish yellow.
14	3,004	Very pale straw colored	Yellow.
15	3,015	Extremely faint	Very pale brownish yellow.
20	3,428	Yellow	Brownish yellow.
21	3,435	None	Yellowish greasy stain.
21	3,448	None	Yellowish greasy stain.
23	3,671	Very pale	Yellowish greasy stain.
24	3,677	None	Faint greasy film.

Oil and gas shows reported by R. D. Rutledge, Arctic Contractors' well geologist, during the drilling are given in the following table.

Oil and gas shows, Titaluk test well 1

Core	Depth (feet)	Show
13	2,983–3,003	Slight show of gas, slight cut, slight fluorescence.
14	3,003–3,014	Slight odor and fluorescence, no cut.
15	3,014–3,027	Slight odor, fluorescence, no stain or cut.
16	3,116–3,122	Slight fluorescence and cut.
18	3,214–3,233	Slight fluorescence and odor.
19	3,294–3,309	Good odor, very slight fluorescence, no cut.
	3,340–3,471	Gas bubbles in ditch throughout interval.
20	3,425–3,435	Good odor, stain, fluorescence and slight cut.
21	3,435–3,450	Fair to good odor, slight fluorescence and cut.
23	3,657–3,677	Very slight fluorescence and odor.
24	3,677–3,689	Very slight fluorescence and odor.
25	3,762–3,782	Slight odor.
26	4,001–4,020	Slight odor.

In addition, a few saturation tests from sealed samples were made in the laboratory, and the results of these tests are given in the following table.

Saturation tests, Titaluk test well 1

Core	Depth (feet)	Petroleum (percent)	Basal sediment and water (percent)	Total (percent by volume)
18	3,233	0.51	1.54	2.05
20	3,422	None	1.60	1.60
20	3,424	1.19	9.53	10.72
20	3,428	1.04	6.25	7.29
20	3,430	Trace	6.76	6.76
20	3,431	None	.56	.56

FORMATION TESTS

Test 1, 2,984–3,027 feet.—A Johnston formation tester with a 6⅝-inch open-hole side-wall packer was set in the 7⅝-inch hole at 2,984 feet with a 6¼-inch rat hole from 2,986–3,037 feet. A ¼-inch bean was used with 43 feet of tail pipe, including 25 feet of perforated pipe from 2,996–3,021 feet, and 2 pressure bombs on the bottom at 3,021–3,027 feet. The tester was open 1 hour and 26 minutes, producing a light steady blow of gas and 90 feet of gas-cut mud. The bottom-hole pressure and the flowing pressure could not be determined from the pressure chart.

Test 2, 3,415–3,762 feet.—A Johnston formation tester with a 8¾-inch open-hole side-wall packer was set in the 9⅝-inch hole at 3,415 feet, using 241 feet of tail pipe. The packer failed to hold. No test was obtained.

Test 3, 3,658–3,762 feet.—A Johnston formation tester with an 8¾-inch open-hole side-wall packer was set in the 9⅝-inch hole at 3,658 feet. A ¼-inch bean was used with 104 feet of tail pipe, including 15 feet of perforated pipe from 3,658–3,673 feet, and 2 pressure bombs on bottom from 3,756–3,762 feet. The tester was open 1 hour and produced only a light blow of air and no fluid. The pressure was zero.

Test 4, 3,400–3,471 feet.—A Johnston formation tester with a 8¾-inch open-hole side-wall packer was set in the 9⅝-inch hole at 3,400 feet, using 71 feet of tail pipe. The packer failed to hold and no test was obtained.

Test 5, 3,408–3,471 feet.—The test was repeated with the packer set at 3,408 feet and using 63 feet of tail pipe. The packer failed to hold and no test was obtained.

Test 6, 3,423–3,471 feet.—The test was repeated with packer set at 3,423 feet but the packer again failed to hold. No test was obtained.

Tests 4–6 were made with the tail pipe resting on a cement plug at 3,471 feet, which was set after the total depth of 4,020 feet was attained.

GAS ANALYSIS

The U. S. Bureau of Mines at Bartlesville, Okla., made an analysis of a gas sample taken in formation test 1 and found 2.6 percent of nitrogen, 92.9 percent of methane, 2.0 percent of ethane, and 2.5 percent of propane plus present.

LOGISTICS

Transportation.—During the winter of 1950–51, 1,100 tons of drilling equipment and supplies were moved to the site of Titaluk test well 1 by tractor trains from Barrow. A winter airstrip was prepared on the ridge near the test; during the summer, float-equipped planes used a small lake about 5 miles to the northeast.

Housing.—A camp consisting of 7 jamesway huts and 13 wanigans (see pl. 27*A*) was set up near the rigsite. Four of the jamesways were used for sleeping quarters, 1 for a galley, 1 for a mess hut, and 1 for a combination radio room and store. Of the wanigans, 1 was used for an office, 1 for a boiler room, 2 for storage of cementing material, 2 for water storage, 1 for the mechanics, 1 for the mess storage room, 1 for the latrine, 1 for a power room, 1 for a utility room, 1 for Schlumberger equipment, and 1 for sleeping quarters for the cat-train crew.

Personnel.—There was a permanent force of 25 men at the rig during drilling, including 1 tool pusher, 1 petroleum engineer, 1 geologist, 2 drillers, 2 derrickmen, 6 floormen, 2 firemen, 2 heavy-duty equipment mechanics, and 1 oiler who made up the rig crew; and 2 cooks, 1 cook's helper, 2 bulldozer operators, 1 warehouseman-storekeeper, and 1 laborer for camp maintenance. Other employees included an electrician, an LVT (landing vehicle, tracked) operator, laborers, a carpenter, a Schlumberger engineer, and a cementer who were brought in from the main camps at Barrow or Umiat when needed.

Vehicles and drilling equipment.—At the rig site 2 weasels (military vehicle, fully tracked), 1 TD9 International tractor with crane (cherrypicker), 1 D8 Caterpillar bulldozer, 1 swing crane, and 1 LVT were used. One of each of the major items of the drilling equipment listed below was used by Arctic Contractors:

Ideco Standard derrick, 87 ft high with a 24-ft base.
120-ton Ideal type D–12 crown block with five 34-in. sheaves grooved for a 1 in. line.
120-ton Ideal type D–12 traveling block with four 34-in. sheaves grooved for a 1 in. line.
125-ton Byron Jackson type 4125, Triplex hook with bail capacity.
Ideal type FE–17½-inch. rotary table.
150-ton Ideal type D swivel.
Cardwell model H drawworks, skid mounted, complete with cat heads and rotary-drive assembly.
Caterpillar diesel engine, model D–8800 on drawworks.
General Motors quad diesel engine model 24103, series 671 on slush pump.
Ideal power duplex slush pump, type C–250, 7¼ by 15 in.
60-bbl divided mud truck.
Shaffer double gate blowout preventer.
Kewanee boiler, 35 hp.
Halliburton cementing unit.
Schulumberger automatic recorder and deep winch.

Fuel, water, and lubricant consumption.—During the drilling of Titaluk test well 1 the following materials were used: 44,960 gallons of diesel fuel, 929 gallons of 72 octane gasoline, 372,000 gallons of water, 96 pounds of grease No. 00, 297 pounds of thread lubricant, 586 gallons of 9170 lubricant, 196 gallons of 9500 lubricant, and 215 gallons of GO–75 lubricant.

DRILLING OPERATIONS

The rig used to drill Titaluk test well 1 was one of 2 Cardwells unitized by Arctic Contractors for greater mobility. Both the derrick and the pumphouse were mounted on Athey tracks.

DRILLING NOTES

The following table contains selected notes from the drilling records of the Arctic Contractors' petroleum engineer.

Notes from drilling record

Depth (feet)	Remarks
0	Well was spudded on April 22, 1951.
87	Lost circulation. Pumped in 33 sacks of gel and 300 lb of Fibertex. Regained circulation.
112	Set and cemented casing; 13⅜-in., 54.5 lb muck string (jacketed with 16½-in. casing from 22 to 88 ft) using 108 sacks of Cal-Seal.
502	Set and cemented casing; 10¾-in. 55.5-lb surface casing with 100 sacks of Hi-Early cement. Later the electric log indicated that this casing had separated at the float collar at 479 ft and settled 5 ft, placing the bottom at 510 ft. By using care in coming in and out of the hole, the separated casing gave no trouble. Cut off 13⅜-in. casing and landed 10¾-in. casing with 1½ sacks of Cal-Seal after finding the top of the cement 8 ft below the cellar floor.
2,092	Pulled out and found one cutter missing from the core bit. Drilled it out of the hole.
2,914	Twisted off drill collar tool joint. Pulled out leaving two 30-ft drill collars, sub and bit in hole. Top of fish at 2,848 ft. Made up and ran 5¾-in. Bowen overshot. Recovered fish.
3,042	Twisted off and pulled out leaving four drill collars and bit in hole. Ran 5¾-in. Bowen overshot and recovered fish.
4,020	A cement plug was set at 3,470–3,511 ft and drilled out to 3,471 ft. The hole was left full of 92-lb mud. A 10¾-in. riser extended 2½ in. above the ground level. A box covered the well head, and the bottom of the box was frozen into the cellar. Thermistors were installed.

During the drilling of the test the following temperature extremes were noted: Maximum outdoor 73°F, minimum outdoor −8°F, maximum indoor 77°F, and minimum indoor 30°F.

DRILL AND CORE BITS

A total of 52 bits was used in drilling Titaluk test well 1. A 22-inch hole opener and a 17½-inch bit were used to open the hole in order to set the 112-foot muck string. Five bit sizes were used that ranged from 22 inches to 7⅞ inches. Generally the bits were very worn when pulled.

All coring was done with Reed conventional core barrels using 6 ⅛-inch and 6 ¼-inch soft and hard formation core heads. A total of 25 core bits was used. Of the total penetration, 402 feet or 10 percent, was cored, with a recovery of 360 feet or 89.5 percent. Core bit 8 is not listed on plate 25 as it was run only to recover a lost cutter from core bit 6.

DRILLING MUD

The hole was spudded with 77 pounds per cubic foot of Aquagel water mud. Fibertex and Aquagel were found to be very effective in restoring circulation when it was lost at 87 feet. By treating the mud with water, acid pyro, and quebracho, the average characteristics

down to the surface casing point of 505 feet were as follows: Weight, 77 pounds per cubic foot; viscosity, 38 Marsh funnel seconds; water loss, 3.5 cc per 30 minutes; cake, 2/32 inch; sand content, 5 percent; gel strength, 3–10; and pH, 7.5.

Before cementing, the mud was treated with acid pyro; but this pretreating proved to be unsuccessful as the mud became highly flocculated after drilling. With the addition of quebracho and water, however, the drilling mud was stabilized.

In general, the nature of the formations in this hole made treatment of the mud relatively simple. The high degree of induration of the sands resulted in a low sand content, the shale sections showed no tendency to heave or cave, and balling of the bit was seldom a problem. The average properties of the mud from the casing at 505 feet to the bottom of the hole at 4,020 feet were as follows: Weight, 92 pounds per cubic foot; viscosity, 46 Marsh funnel seconds; water loss, 3.4 cc per 30 minutes; cake, 2/32 inch; sand content, 3 percent; gel strength, 0–0; and pH, 8.

Fifty-five sacks of Aquagel, 542 pounds of quebracho, 300 pounds of Fibertex, 602 pounds of sodium acid pyrophosphate, and 150 pounds of Driscose were used in drilling Titaluk test well 1. The drilling mud characteristics and additives are given in detail in the following table.

Drilling-mud characteristics and additives, Titaluk test well 1

Depth (feet)	Weight (lb per cu ft)	Viscosity (Mfs [1])	Filtration loss (cc per 30 min)	Drilling fluid temperature (°F)	Additives
18–117	67	52	5.0	56	39 sacks Aquagel.
300	77	38	4.0	52	90 lb sodium acid pyrophosphate.
505	79	36	3.0	55	300 lb Fibertex.
635	80	40	6.0	60	
843	78	32	7.0	68	9 sacks Aquagel.
1,010	81	38	4.5	73	120 lb sodium acid pyrophosphate.
1,245	85	45	2.5	84	160 lb quebracho.
1,337	87	40	3.0	76	50 lb Driscose.
1,445	87	41	3.0	88	
1,513	87	40	3.0	82	
1,627	86	38	3.0	90	
1,770	87	40	2.5	84	4 sacks Aquagel.
1,830	88	42	2.5	82	50 lb quebracho.
1,905	87	38	2.5	84	50 lb Driscose.
2,005	87	39	2.0	78	
2,080	89	39	2.5	80	
2,097	89	42	2.5	75	
2,173	89	47	2.5	78	
2,265	89	48	2.5	80	127 lb quebracho.
2,343	89	46	3.0	82	72 lb sodium acid pyrophosphate.
2,393	90	44	3.0	80	
2,440	90	45	3.0	78	
2,510	90	44	3.0	80	
2,573	90	45	3.0	76	
2,618	90	44	3.5	78	
2,667	92	47	3.0	78	50 lb Driscose.
2,700	90	42	3.5	75	40 lb quebracho.
2,765	92	50	3.0	72	110 lb sodium acid pyrophosphate.
2,840	92	49	3.0	73	
2,895	92	46	3.0	74	
2,913	92	48	3.0	70	
2,945	92	46	3.0	72	3 sacks Aquagel.
2,993	92	46	3.0	73	30 lb quebracho.
3,013	92	45	3.0	70	30 lb sodium acid pyrophosphate.
3,027	91	47	3.0	64	

Drilling-mud characteristics and additives, Titaluk test well 1—Con.

Depth (feet)	Weight (lb per cu ft)	Viscosity (Mfs [1])	Filtration loss (cc per 30 min)	Drilling fluid temperature (°F)	Additives
3,042	92	46	3.0	65	
3,095	93	48	3.0	68	
3,120	92	44	3.0	67	15 lb quebracho.
3,148	91	45	3.0	67	
3,180	----------	46	2.5	----------	80 lb sodium acid pyrophosphate.
3,200	91	----------	3.0	----------	
3,225	----------	47	----------	69	
3,270	92	45	3.0	68	
3,345	93	46	3.0	68	35 lb quebracho.
3,415	90	46	3.0	69	15 lb sodium acid pyrophosphate.
3,475	92	45	3.5	69	
3,570	92	46	3.5	70	10 lb quebracho.
3,585	90	45	3.5	70	45 lb sodium acid pyrophosphate.
3,647	92	45	3.5	69	
3,735	92	46	2.0	69	
3,790	92	47	1.0	68	
3,860	92	45	0.5	67	75 lb quebracho.
3,935	92	46	1.0	69	40 lb sodium acid pyrophosphate.
4,003	92	46	1.0	69	
4,017	92	46	1.0	69	

[1] Marsh funnel seconds.

HOLE-DEVIATION RECORD

The hole deviation throughout the test was low—mostly less than 1° except from 1,290–1,427 feet, at 2,600 feet, from 3,365–3,490 feet and from 3,760–3,850 feet, where it was 1° or a little more. (See pl. 25.)

ELECTRIC LOGGING

The electric logs were made by Schlumberger Well Surveying Corp. The following table indicates the intervals tested; the electric log is shown on plate 25. Also included in the table are the temperatures recorded by the well surveyors.

Electric-log runs and temperature surveys

Run	Depth (feet)	Temperature (°F)
1	505–112	36
2	2, 092–510	64
3	2, 982–2, 092	73
4	3, 657–2, 982	73
5	4, 020–3, 657	----------

TEMPERATURE-MEASUREMENT STUDIES

Max C. Brewer made temperature studies on the test wells. He reports that (written communication, 1956) on July 10, 1951, 4 days after the test well was completed, 4 thermal cables containing 77 thermistors placed at depths from 5 to 1,350 feet were installed. Frequent readings were made in the summer and fall of 1951, but no readings were obtained after November 11th of that year.

The top two cables (the longest reaching to a depth of 600 feet) failed about a month after installation because of ice expansion within the casing. The data available from the bottom cables indicate a depth of permafrost (temperature continuously below 0°C.) of slightly more than 800 feet. The geothermal gradient

was not determined by Mr. Brewer as thermal equilibrium had not been reestablished when the last readings were obtained. The minimum temperature in the well could not be obtained because of the loss of the upper cables.

KNIFEBLADE TEST WELLS 1, 2, 2A

Knifeblade 1:
Location: Lat 69°09'04" N., long 154°53'21" W.
Elevation: Ground, 993 feet; derrick floor, 999 feet.
Spudded: October 13, 1951.
Completed: December 22, 1951; dry and abandoned.
Total depth: 1,805 feet.

Knifeblade 2:
Location: Lat 69°08'19" N., long. 154°44'12" W.
Elevation: Ground, 871 feet; derrick floor, 876 feet.
Spudded: July 26, 1951.
Completed: August 5, 1951; junked and abandoned.
Total depth: 373 feet.

Knifeblade 2A:
Location: Lat 69°08'19" N., long 154°44'12" W.
Elevation: Ground, 869 feet; derrick floor, 874 feet.
Spudded: August 6, 1951.
Completed: October 7, 1951; dry and abandoned.
Total depth: 1,805 feet.

The Knifeblade test wells were drilled to test the oil and gas possibilities of the Grandstand and Tuktu formations. Knifeblade test wells 1, 2, and 2A are on Knifeblade ridge, a prominent topographic and structural high in the Arctic foothills province, about 3 miles north of the Colville River and 68 miles west-southwest of Umiat, Alaska. (See fig. 28.) This structural feature is a little over 20 miles south of the Titaluk test well; the Titaluk rig could be seen from Knifeblade ridge on clear days. The name "Knifeblade" was given to the sharp-crested ridge by a pilot flying over the area.

Knifeblade test well 2 and 2A are near the bottom of a shallow valley of an intermittent stream on the south side of the ridge. (See pls. 27*B* and 28.) The test well on the south side of the main thrust fault (see Structure) was thought to offer the best possibilities for finding oil; so it was drilled first. The number previously assigned to this test was "2," and this number was retained to prevent confusion in the records, although it was actually the first hole drilled. Knifeblade test well 2 was drilled to a depth of 373 feet, at which point the hole was junked when the drilling tools were lost and not recovered; at this depth the hole was still in permafrost and was completely dry. The formations drilled in this and the succeeding Knifeblade tests are as follows:

	Killik tongue of the Chandler formation (depth in feet)	*Grandstand formation (depth in feet)*
Knifeblade test well 1	6–820	820–1,805 T. D.
Knifeblade test well 2	5–105	105– 373 T. D.
Knifeblade test well 2A	15–90	90–1,805 T. D.

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The rig was skidded 28 feet due north and Knifeblade test well 2A was drilled to a depth of 1,805 feet. Good shows were absent in the sandstones of the Grandstand formation, although an asphaltic residue was noted. The hole produced some brackish water. (See page 414.)

Knifeblade test well 1 is 4,865 feet N. 23°13′ E. of 2A in a bowllike depression that opens to the south near the top of Knifeblade Ridge. This test well was on a different fault block and started higher in the Chandler formation than the other two tests. Bitumen was also found in the Grandstand formation, but shows of oil or gas were negligible. This test well gave some brackish water.

No pronounced lithologic change from sandstone to shale was noted (possibly because of sand-contaminated samples) near the bottom of Knifeblade test well 2A, although the bottom of this test must be close to the base of the Grandstand formation, by comparison of thicknesses with Titaluk test well 1. The grain size of the Grandstand formation sandstones becomes finer with depth and is very fine to silty near the bottom in Knifeblade test well 2A. This may represent the transition to the Topagoruk formation found in other test wells. The holes could not be drilled deep enough (the capacity of the drilling rig was 1,800 feet) to check for the presence of the Tuktu formation. However, it is very unlikely the Tuktu formation would have been found here. The decreasing sand size near the base of the Grandstand does not preclude but suggests, that there is no thick underlying sandstone formation. None is described by C. L. Whittington (oral communication) from the outcrop nearby.

Elevations in the Knifeblade area were determined by reconnaissance altimeter traverses by C. L. Whittington and have been tied to the Umiat datum. (See page 381.) The well elevations are accurate with respect to each other, although they may not be accurate with reference to sea level. Latitude and longitude are derived from planimetric maps compiled from trimetrogon aerial photographs.

STRUCTURE

The following brief discussion of a structure in the Knifeblade anticline is based on the work of C. L. Whittington (written communication, 1956). The anticline is about 14 miles long and 4 miles wide, although it can be traced for many more miles as a low fold. A major thrust fault, thrust from the south, is north of and approximately parallel to the axis at the east end of the anticline. (See fig. 32.) Beds of the Chandler and Grandstand formations are pushed over strata of the Chandler formation. On the surface this fault is marked by an abrupt change in strike be-

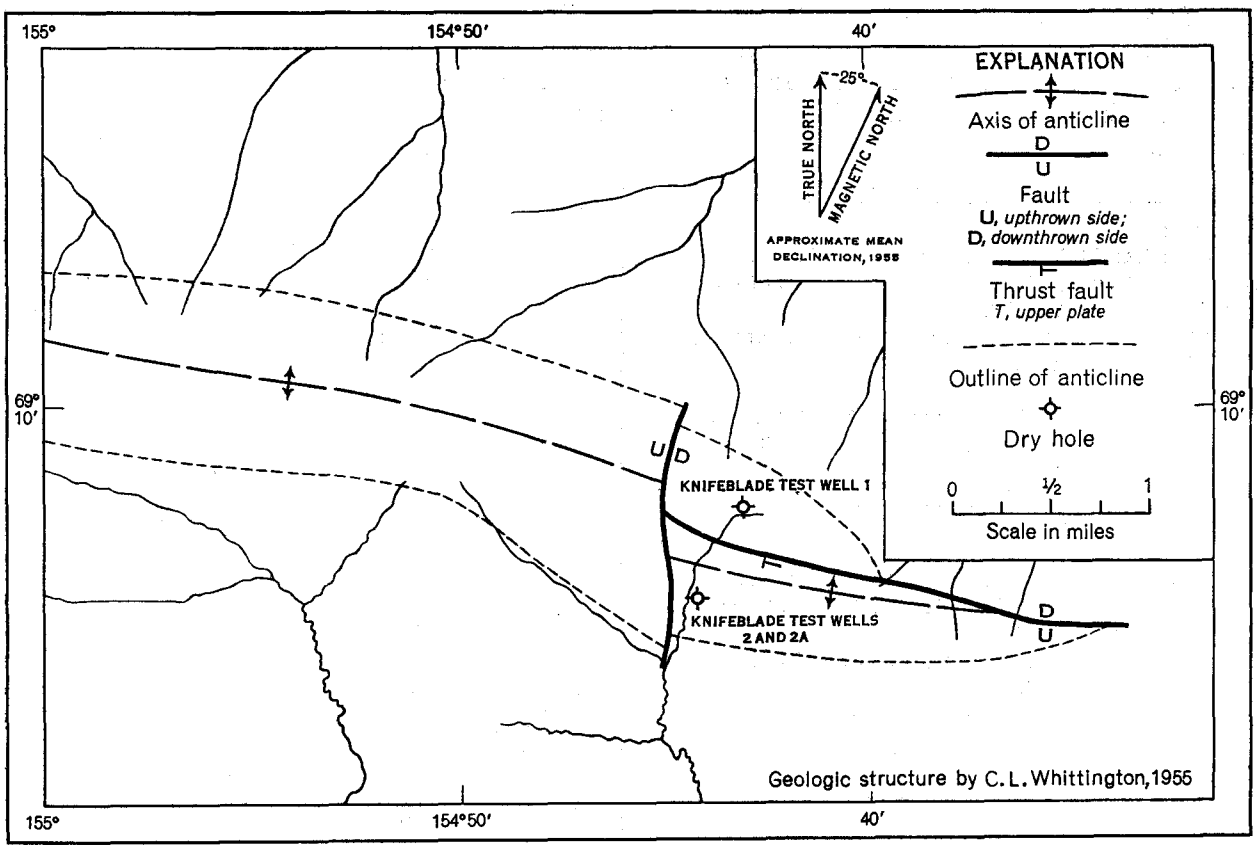

FIGURE 32.—Outline of part of the Knifeblade anticline, showing the closure on an imaginary horizon in the Chandler formation and the relation of the test wells to important faults. The west end of the anticline, not shown on this map, is complexly faulted.

tween the northeast and southeast blocks. Dips are very steep, as much as 70° on the north side in the vicinity of the fault. A major transverse fault, probably older than the thrust fault, offsets the axis in the eastern third of the anticline. Other minor transverse faults are indicated.

This anticline appears to have a large area of closure, but surface exposures are not sufficient to permit a definite interpretation. No geophysical work was done in the area.

Knifeblade test wells 2 and 2A were located on the southeast block, on the hanging wall of the major thrust. There is no evidence in either of the two holes to suggest that they penetrated this thrust fault. Because they are so close together, correlation between 2 and 2A is excellent. The top of the Grandstand formation is at 766 feet above sea level in test well 2 and at 779 feet above sea level in test well 2A, a difference of 13 feet, indicating that the beds dip 25° on that zone, assuming 1 hole is directly down dip from the other. A dip measured on the surface nearby is 19°S. as the fault is approached. Dip measured on the cores in Knifeblade test well 2A decreases from about 40° in the upper 2 cores (171 and 365 ft) to 20° or less in the deepest cores. The 1,805 feet of beds drilled in test well 2A represents an actual thickness of approximately 1,625 feet because of the inclined beds.

Knifeblade test well 1 was located on the north side on the footwall of the thrust fault. Original plans called for drilling this test well about 1,000 feet south of its actual location, but the plans were changed when it became apparent that this more southerly site was on or very close to the big thrust. A surface dip near the trace of the fault is 70°NE., and near the well site it is 18°NE. Dips measured on cores range from 5° to 15°, much less than in Knifeblade 2A. There is no evidence of faulting in Knifeblade test well 1.

The top of the Grandstand formation in Knifeblade test well 1 is at 179 feet above sea level, or 600 feet lower than in Knifeblade test well 2A on the overthrust sheet. Correlation between the two holes is good both lithologically and paleontologically after taking into consideration differences in thickness due to dip.

The test wells are dry, possibly because they are too low on the anticline, but it is more likely that the cause is due to an unfavorable structural history.

DESCRIPTION OF CORES AND CUTTINGS

The following descriptions of cores and cuttings of the Knifeblade tests were made by the author on the material shipped to Fairbanks from the Reserve at the time of drilling. All samples were described dry, and the colors can be referred to the National Research Council's Rock Color Chart (Goddard and others, 1948). See plate 26 for a graphic representation of the lithology of the Knifeblade tests.

KNIFEBLADE TEST WELL 1

The quality of the well cuttings was good, but there may be loose sand contamination in the lower 250 feet.

Lithologic description

[Where no core is listed, description is based on cutting samples]

Core	Depth (feet)	Remarks
----	0–6	Height of derrick floor above ground level.
----	6–40	Sandstone, light-gray very fine to coarse-grained, very slightly calcareous; yellowish iron stain near the surface; grains subangular to subrounded; 15 percent is white and clear quartz; remainder is dark-gray and brownish chert, dark rock fragments and carbonaceous particles, ironstone particles and other rare minerals; some black carbonaceous plant impressions. As much as 5 percent moderate yellowish brown and light-olive-gray clay ironstone.
----	40–45	Clay shale, medium- to medium-dark-gray; trace of medium-dark-olive-gray ironstone.
----	45–55	Coal, black, shiny to dull; blocky fracture; trace of medium-light-gray clay shale and clay ironstone.
----	55–60	Sandstone, light-gray; mostly white and clear quartz, some carbonaceous particles, dark chert and rock particles; outstanding in abundance of interstitial sericite which makes up 25 percent of total volume of rock and gives rock chips a silky sheen; trace to 5 percent moderate yellowish-brown clay ironstone.
----	60–65	Clay shale, light- to medium-light-gray, micaceous; trace of sandstone.
----	65–70	Coal, black, shiny to dull, thin-bedded, brittle; 5 percent medium-light-gray clay shale.
----	70–90	Clay shale, medium-light-gray, sericitic, silty; 10 percent coal and trace of clay ironstone at 70–75 ft.
----	90–95	No sample.
----	95–105	Clay shale, medium-light-gray; also 15 percent very fine-grained noncalcareous sericitic sandstone and siltstone; trace of dark-gray carbonaceous shale.
----	105–130	Clay shale, medium-light-gray; trace to 10 percent dark-gray shale at 105–110 ft and 115–120 ft; trace of sandstone at 105–110 ft and 125–130 ft; trace of ironstone at 120–125 ft.
----	130–140	Clay shale, medium-light-gray, micaceous, and sandstone, light-gray, sericitic; trace of light-brownish-gray clay ironstone.
----	140–155	Clay shale, medium- to medium-light-gray; 5 percent dark carbonaceous shale and black coal at 140–145 ft; 10 percent medium-light-gray siltstone and sandstone; as much as 5 percent brownish-gray clay ironstone.
----	155–160	Sandstone, light-gray, medium-grained; grains subangular to subrounded; 80 percent white and clear quartz; also carbonaceous particles, dark chert and rock fragments; 5 percent grayish-brown ironstone, 10 percent medium-grey clay shale.
----	160–165	Coal and carbonaceous shale, black, dull to shiny; 20 percent sandstone as above; 10 percent clay ironstone.
----	165–170	Clay shale, medium- to medium-light-gray, 60 percent; 30 percent coal and carbonaceous clay shale, 10 percent clay ironstone, trace of pyrite.
----	170–185	Clay shale, medium-light- to medium-dark-gray, sericitic; 30 percent siltstone and some very fine-grained sandstone at 170–175 ft, 15 percent black shiny coal at 180–185 ft.
----	185–190	Siltstone, and very fine-grained sandstone, 60 percent; 30 percent medium-light-gray clay shale; 10 percent coal and carbonaceous shale.
1	190–194	Recovered 4 ft: Microfossils absent. 1 ft, sandstone, medium-light-gray, fine-grained, hard; grains subangular to rarely subrounded; 80 percent white and clear quartz; fairly large amount of carbonaceous particles; some dark chert, rock fragments and mica; much sericitic mica in the matrix gives silky sheen to fractured surfaces; very rare carbonaceous partings; noncalcareous; dip possibly 10°–15°(?). No shows. 2 ft, clay shale, medium- to medium-light-gray, noncalcareous, medium-hard; fair cleavage; dip undetermined. 1 ft, clay shale, medium-dark-gray, moderately soft; fair cleavage; carbonaceous particles and fragments in partings. Several laminae as much as one-half inch thick of black shiny brittle platy coal. Dip undetermined.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	194–205	Clay shale, medium-light- and medium-dark-gray; 5–10 percent siltstone and sandstone, as much as 10 percent black shale and coal.
----	205–210	Sandstone and siltstone, light-gray fine-grained to silty; 70 percent white and clear quartz; ironstone and carbonaceous particles common; also dark chert and rock fragments, sericite is abundant in matrix and gives sheen to chips noncalcareous; 5 percent dark-gray carbonaceous shale; trace of coal.
----	210–265	Clay shale, medium- to dark-gray; trace of siltstone at 215–225 ft, carbonaceous partings at 220–225 ft, 10–20 percent black shiny coal at 230–240 ft, trace of coal at 255–260 ft.
----	265–267	Sandstone, light-gray, medium-grained, 70 percent; grains subangular; 65 percent white and clear quartz; 30 percent medium-gray clay shale; abundant black coal particles; some brownish and some gray chert; no sericite; slightly calcareous cement.
2	267–271	Recovered 4 ft: Microfossils absent. 1 ft, sandstone, light-gray, very fine- to fine-grained; represented in core box by chips up to three-quarter inch in diameter and a few larger pieces; 75 percent white and clear quartz; abundant black coal particles and some dark-gray chert and rock fragments, rare white mica; argillaceous cement; dark carbonaceous partings; very slightly calcareous; at 267 ft the effective porosity is 4.42 percent and the sample is impermeable; no shows. 3 ft, clay shale, medium- to medium-light-gray, very silty; grades to noncalcareous hard siltstone, poor cleavage; dip 13°.
----	271–290	Clay shale, medium-light- to dark-gray, 50–80 percent; as much as 40 percent light-gray medium-grained salt and pepper sandstone, with 40 percent dark minerals; noncalcareous, also 40 percent black coal at 283–287 ft; trace of brownish-gray clay ironstone.
----	290–295	Sandstone, light-gray, fine-grained, sericitic; also medium-dark-gray clay shale rarely medium light gray.
----	295–305	Clay shale, medium-light-gray, silty, sericitic; 5 percent medium-dark-gray clay shale.
----	305–311	Siltstone and sandstone, as in core below; 30 percent medium- to medium-light-gray clay shale.
3	311–315	Recovered 4 ft: Microfossils absent. Sandstone, light-gray, massive, fine- to rare medium-grained, hard; subangular grains 75 percent white and clear quartz; also rock fragments, dark chert, carbonaceous particles, white mica, and tan earthy particles; micaceous-argillaceous-noncalcareous cement; dip 8°; no shows. At a depth of 314 ft the effective porosity 5.29 percent; and the sample is impermeable.
----	315–360	Clay shale, medium- to medium-light-gray; trace to 15 percent sandstone at 315–320 ft, 340–345 ft, and 355–360 ft; 5 percent black shiny coal at 330–335 ft; trace of ironstone throughout.
----	360–365	Sandstone, light-gray, medium-grained; subangular grains; 85 percent white and clear quartz; 15 percent medium-dark-gray clay shale; also dark chert, carbonaceous particles, rock fragments and some white mica; slightly calcareous.
4	365–368	Recovered 6 in.: Microfossils absent. Sandstone, medium-light-gray, fine-grained, hard; angular to subangular; 85 percent white and clear quartz; also rock fragments, coal particles, dark chert, some white mica; argillaceous cement; noncalcareous; dip undetermined; no shows.
----	368–380	Sandstone, as in core above, noncalcareous; carbonaceous impressions at 375–380 ft.
----	380–405	Clay shale, medium- to medium-dark-gray; 10 percent very fine-grained sandstone and siltstone at 380–385 ft; trace of siltstone at 385–390 ft; 20 percent light-gray fine- to medium-grained salt and pepper sericitic sandstone at 395–405 ft; trace of clay ironstone at 395–400 ft.
----	405–415	Clay shale, medium- to medium-light-gray; trace of siltstone.
----	415–420	Sandstone and siltstone, medium- to medium-light-gray, very fine- to fine-grained; 75 percent quartz; some ironstone particles.
----	420–450	Clay shale, medium-light- to medium-dark-gray; trace to 10 percent sandstone and siltstone at 420–435 ft; 5 percent brownish-gray clay ironstone at 420–430 ft; and trace of black shiny coal and carbonaceous shale at 420–435 ft; 15 percent siltstone at 445–450 ft.
----	450–455	Sandstone, light-gray, fine-grained; grains subangular to subrounded; 70 percent white and clear quartz; remainder is dark chert, rock, clay ironstone and carbonaceous particles; abundant interstitial mica; noncalcareous; trace of siltstone; 10 percent clay shale.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	455–475	Clay shale, medium- to medium-light-gray; 5–40 percent silty sandstone as in the above 455–465 ft; trace of black shiny coal at 465–470 ft, 20 percent light-gray siltstone at 470–475 ft.
----	475–480	Coal, black, shiny, 30 percent; 30 percent carbonaceous dark-gray shale; 30 percent medium-gray clay shale; 10 percent siltstone.
----	480–500	Clay shale, medium- to medium-light-gray; trace of medium-dark-gray clay shale; trace to 10 percent sandstone and siltstone; trace of yellowish-brown clay ironstone at 480–485 and 490–500 ft.
----	500–505	Clay shale, medium- to medium-light-gray; 75 percent; and 25 percent sandstone made up of 70 percent quartz, quite sericitic, very slightly calcareous; trace of ironstone.
----	505–535	Clay shale, medium- to medium-light-gray; 10 to 15 percent siltstone at 505–515 ft, and trace of siltstone at 520–525 and 530–535 ft, trace of coal and carbonaceous shale at 510–520 ft, trace of grayish-brown ironstone at 505–510 and 515–520 ft, 5–10 percent olive-gray and yellowish-brown ironstone at 525–535 ft.
----	535–540	Siltstone, medium-light-gray; and medium- to medium-light-gray clay shale; 5 percent ironstone.
----	540–567	Clay shale, medium- to medium-dark-gray, some dark-gray; 10 percent very fine-grained light-gray sandstone; trace of ironstone at 540–545 ft.
5	567–570	Recovered 2 ft: Microfossils absent. Claystone, medium-dark- to dark-gray, dense, hard to very hard; grades downward through siltstone into 6 in. of medium-gray very fine-grained silty sandstone; dark carbonaceous plant impressions in sandstone; noncalcareous. Dip possibly 10°.
----	570–575	Clay shale, medium- to medium-dark-gray; 20 percent medium-light-gray very fine- to medium-grained sandstone; much carbonaceous material; sericitic; very slightly calcareous; trace of brownish-gray clay ironstone.
----	575–605	Clay shale, medium- to medium-dark-gray; carbonaceous partings at 590–595 ft; trace of medium-dark-gray siltstone at 580–585 ft; 5–20 percent medium- to medium-light-gray siltstone; very fine- to fine-grained very slightly calcareous sandstone; trace of dark-yellowish-brown clay ironstone at 590–595 ft; 10 percent black shiny coal at 600–605 ft.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	605–610	Coal, black, dull to shiny; blocky fracture; and dark-gray carbonaceous shale; 15 percent medium-gray clay shale; 5 percent dark-yellowish-brown clay ironstone.
----	610–640	Clay shale, medium- to medium-dark-gray, rarely dark-gray; trace to 5 percent coal at 610–620 ft; trace to 5 percent yellowish-brown and brown clay ironstone at 615–620 and 630–640 ft; 5–10 percent fine-grained medium-light-gray sandstone at 625–630 and 635–640 ft.
----	640–645	Sandstone, medium-light-gray, fine-grained; 70 percent white and clear quartz; remainder is carbonaceous particles, dark chert, and ironstone particles; coaly partings, slightly calcareous; 10 percent medium-dark- to dark-gray clay shale; olive-gray ironstone quite common.
----	645–660	Clay shale, medium- to medium-dark-gray; trace of ironstone at 645–650 ft.
----	660–665	Clay shale, medium-dark- to dark-gray; 20 percent black shiny coal.
----	665–700	Clay shale, medium- to medium-dark-gray; trace of siltstone at 665–670 ft; trace of dark-gray carbonaceous shale; black dull and shiny coal at 670–680 ft.
----	700–710	Clay shale, medium- to medium-dark-gray; 10–20 percent medium- to medium-light-gray sandstone and siltstone; much carbonaceous material; moderately calcareous; trace to 5 percent olive-gray ironstone.
----	710–745	Clay shale, medium- to medium-dark-gray, rarely dark-gray; 10 percent medium- to medium-light-gray very fine-grained slightly to moderately calcareous sandstone and siltstone; 5 percent black dull coal and carbonaceous shale at 735–745 ft; trace of brownish-gray clay ironstone at 710–715 and 730–735 ft.
----	745–750	Clay shale, medium-dark-gray; many plant fragments; also 30 percent black shiny coal.
----	750–768	Clay shale, medium-light- to medium-dark-gray; trace of coal and carbonaceous partings; trace of ironstone at 750–760 ft, trace of siltstone at 765–768 ft.
6	768–773	Recovered 5 ft: Microfossils absent. Clay shale, medium-dark-gray, noncalcareous, hard; fair cleavage; very rare slightly silty streaks; dip not determined.
----	773–780	Clay shale, medium-gray with trace of dark-gray; 10 percent black shiny coal.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	780–785	Coal, black, shiny, 40 percent; and medium-gray clay shale; trace of ironstone.
----	785–795	Sandstone, medium-light-gray, fine-grained; made up of 65–70 percent white and clear quartz; fairly large amounts of carbonaceous or coaly material, dark chert, much sericite; very slightly calcareous; 10 percent clay shale; trace of ironstone.
----	795–815	Clay shale, medium-light- to medium-dark-gray; 5 percent dark-gray carbonaceous shale at 800–805 ft.
----	815–820	No sample.
----	820–826	Sandstone, light-gray, fine-grained, 80 per cent; composed of 75 percent white and clear quartz; also carbonaceous fragments, dark chert, rock fragments; no sericite; very slightly calcareous; 20 percent medium-dark-gray clay shale. The top of the Grandstand formation is placed at 820 ft.
7	826–830	Recovered 4 ft: Microfossils absent. Sandstone, light-gray, salt and pepper, very fine- to very coarse-grained, hard; subangular to rounded grains; up to 50 percent dark material—coal particles, rock fragments and dark-gray chert; remainder is mostly white and clear quartz and light-earthy particles. Several streaks of conglomerate up to 2 in. thick contain subrounded to rounded granules and pebbles of dark-gray greenish-gray and black chert, milky quartz, coal, medium- and medium-light-gray clay shale, yellowish-gray ironstone and light-gray sandstone; noncalcareous; at a depth of 828 ft the effective porosity is 10.58 percent, and the sample is impermeable; dip 9°(?).
----	830–845	Sandstone, as in core above, medium- to coarse-grained; 5 percent very pale-orange clay ironstone and trace of dark-gray clay shale at 830–835 ft.
8	845–846	Recovered 1 ft: Microfossils absent. 6 in., sand, fine- to medium-grained, loose; and very small chips of light-gray sandstone, highly rust-stained from metal chips from the bit; grains angular to subangular; 90 percent white and clear quartz; remainder is dark chert and coal particles. 6 in., sandstone, light-gray, very hard; possibly siliceous cement; composition as above, but with larger proportion of dark materials; noncalcareous; dip undetermined; no shows.
----	846–850	Sandstone, as above.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	850–878	Clay shale, medium-light- to medium-dark-gray; 5–25 percent medium-grained sandstone at 850–860 ft; trace of fine-grained sandstone containing much carbonaceous material at 865–875 ft; 35 percent medium-light-gray fine-grained moderately calcareous sandstone at 875–880 ft; trace of olive-gray ironstone at 875–880 ft.
9	878–882	Recovered 3 ft 6 in.: Microfossils absent. 1 ft 6 in., sandstone, medium-light-gray, very fine-grained to silty, medium-hard; subangular to subrounded; largely white and clear quartz; some dark chert, rock fragments; dark micaceous-carbonaceous partings; very slightly calcareous; dip undetermined; no shows; becomes siltier toward base. Grades into unit below. 2 ft, clay shale, medium-dark-gray, noncalcareous medium-hard, poor cleavage; dip undetermined.
----	882–910	Clay shale, medium-dark-gray; silty at 900–910 ft; slightly to moderately calcareous at 895–910 ft.
10	910–915	Recovered 3 ft: Microfossils absent. Clay shale and claystone, medium-gray, slightly silty, noncalcareous, medium-hard; poor to fair cleavage; some micaceous-carbonaceous partings; a few black plant impressions in partings; dip 5°–10°(?).
----	915–930	Clay shale, medium-light- to dark-gray; trace ironstone at 920–930 ft; trace black shiny coal at 925–930 ft; 5 percent medium-light-gray very fine-grained sandstone.
----	930–935	Sandstone, medium-light-gray, silty to fine-grained; composed of 75 percent white and clear quartz; also carbonaceous particles, dark chert, some sericite, slightly calcareous; 20 percent black dull to shiny coal and carbonaceous shale; trace of medium-gray clay shale; trace of grayish-brown ironstone.
----	935–940	Sandy siltstone, medium-light-gray; and 40 percent medium-gray clay shale; trace of coal.
----	940–945	Clay shale, medium- to medium-light-gray.
----	945–950	No sample.
----	950–955	Siltstone, and very fine grained sandstone, medium-light-gray, 40 percent; and medium- to medium-dark-gray clay shale; trace of dark-yellow-brown clay ironstone.
11	955–960	Recovered 3 ft 9 in.: Microfossils absent. Siltstone and sandstone, medium-light-gray, hard, tight; fairly good cleavage;

Lithologic description—Continued

Core	Depth (feet)	Remarks
		dark carbonaceous coaly partings; sandstone is very fine grained; subangular grains consist primarily of opaque grayish-white quartz; also rock fragments and carbonaceous particles; much sericitic material in the matrix gives sheen to the hand specimen; noncalcareous; dip 8° (?).
----	960–965	Siltstone and clay shale, medium- to medium-dark-gray; trace of coal and ironstone.
----	965–1,000	Clay shale, medium- to medium-dark-gray, rarely medium-light- and dark-gray; trace of coal at 970–975 and 990–995 ft, trace of ironstone at 990–995 ft, 10 percent black dull and shiny coal at 995–1,000 ft.
----	1,000–1,010	Clay shale and coal, 60 percent. Shale is dark gray and carbonaceous; also medium- and medium-dark-gray clay shale; 5 percent slightly calcareous sandy siltstone; trace of pyrite.
----	1,010–1,020	Coal, black, shiny, 10–20 percent; blocky fracture; 20 percent dark-gray clay shale; 70 percent medium-dark-gray clay shale, trace of pyrite, ironstone, and siltstone; pelecypod fragments and ostracod impression at 1,015–1,020 ft.
----	1,020–1,030	Clay shale, medium- to medium-dark-gray; 20 percent dark-gray clay shale.
----	1,030–1,040	Coal, black, dull to shiny, 30–80 percent; medium- to dark-gray clay shale; 10 percent medium-dark-gray sandy siltstone; one piece of siltstone with bitumen stain.
----	1,040–1,085	Clay shale, medium-dark- to dark-gray; trace of siltstone and sandy siltstone at 1,040–1,050 ft, trace of medium-dark-olive-gray calcareous siltstone with bitumen at 1,065–1,075 and 1,080–1,085 ft; 5–10 percent coal at 1,075–1,085 ft; trace of pyrite at 1,075–1,080 ft.
----	1,085–1,100	Coal, black, shiny, 20–30 percent, and clay shale, medium-dark to dark-gray; trace brownish-gray ironstone.
----	1,100–1,145	Clay shale, medium-dark- to dark-gray; trace to 10 percent of coal at 1,100–1,125 ft; 5 percent coal at 1,140–1,145 ft; trace of sandy siltstone at 1,135–1,140 ft; trace of pyrite at 1,120–1,125 and 1,140–1,145 ft; shell fragments at 1,100–1,105, 1,110–1,120, and 1,130–1,135 ft; *Inoceramus* prisms at 1,110–1,120 ft.
----	1,145–1,149	Sandstone, light- to medium-light-gray, salt and pepper, medium-grained, loose, soft; grains subangular with a few subrounded; 60 percent white and clear quartz; many coaly particles, dark chert, rock fragments, some white mica,

Lithologic description—Continued

Core	Depth (feet)	Remarks
		noncalcareous; 10 percent medium-dark-gray clay shale.
12	1,149–1,152	Recovered 1 ft: Microfossils common. Core consists almost entirely of mud containing a few chips of medium-gray clay shale.
----	1,152–1,155	Sandstone as in interval 1,145–1,149 ft; few coarse sand grains.
----	1,155–1,160	Sandstone as in interval above core 12, medium- to coarse-grained.
13	1,160–1,165	Recovered 3 ft 4 in.: Microfossils absent. Sandstone, medium-light-gray, thin-bedded(?), medium-grained; moderately hard; grains subangular; 75 percent white and clear quartz; many dark rock fragments and chert, some mica and a few other minerals. Noncalcareous; no shows; dip probably 5° or less; at 1,162 ft the effective porosity 11.5 percent and the air permeability $<$ 1 millidarcy.
----	1,165–1,195	Sandstone, medium-light-gray, salt and pepper, loose, medium- to rarely coarse-grained; fine to medium grained at base of interval; 70 percent white and clear quartz; remainder largely dark chert, some coaly particles and rock fragments. Noncalcareous; 5–20 percent medium- to medium-dark-gray clay shale.
----	1,195–1,200	Clay shale, medium- to medium-dark-gray, 60 percent; also some loose sand as above.
----	1,200–1,220	Siltstone, medium-dark-gray; slightly sandy at 1,200–1,210 ft; argillaceous (40 percent near base of interval) at 1,210–1, 220 ft; trace of coal at 1,200–1,205 ft.
----	1,220–1,245	Clay shale, medium-dark-gray; trace to 15 percent siltstone with bitumen stain.
----	1,245–1,250	Siltstone, medium-light-gray, sandy, noncalcareous, 80 percent; bitumen stain; and medium-dark-gray clay shale.
----	1,250–1,255	Clay shale, medium-dark-gray, 60 percent; also 15 percent medium-light-gray sandstone and medium-gray siltstone; chunk of stubby *Inoceramus* prisms; bitumen stain.
----	1,255–1,265	Sandstone, medium-light-gray, very fine- to coarse-grained, 75 percent; also medium- to medium-dark gray clay shale; very rare bitumen in cracks. Constituents as in core below.
14	1,265–1,270	Recovered 3 ft: Microfossils absent. Sandstone, medium-light-gray, salt and pepper, medium-grained, hard, massive; rare coarse grains; 75 percent white and clear quartz; much dark chert and some rock fragments; calcareous cement; very rare brownish plant impressions; dip undetermined;

Lithologic description—Continued

Core	Depth (feet)	Remarks
		no shows. At 1,269 ft the effective porosity 13.06 percent and the air permeability < 1 millidarcy. Carbonate content at the same depth 19.64 percent by weight.
----	1, 270–1, 295	Sandstone, as above, mostly unconsolidated; medium- to coarse-grained at 1,265–1,280 ft, fine- to medium-grained at 1,280–1,295 ft, slightly calcareous slightly harder, interval of rock at 1,280–1,285 ft; sericite in matrix; rare bitumen on broken surfaces at 1,285–1,295 ft.
15	1, 295–1, 298	Recovered 1 ft: Microfossils absent. Sandstone, medium-light-gray, fine-grained, hard; subangular to rare subrounded; 80 percent white and clear quartz; remainder is dark chert, coal particles, rock fragments, and mica. Noncalcareous to very calcareous; no shows; at 1,297 ft the effective porosity 8.16 percent and the sample is impermeable.
----	1, 298–1, 325	Sandstone, as above, fine-grained; slightly calcareous at 1,295–1, 300 ft, moderately calcareous at 1,310–1,315 ft, slightly calcareous at 1,315–1,325 ft; very fine grained and composed of 90 percent white and clear quartz at 1,320–1,325 ft.
----	1, 325–1, 335	Siltstone, and very fine-grained sandstone, slightly calcareous; some clay shale near base of interval.
----	1, 335–1, 355	Clay shale, medium- to medium-dark-gray; 20 percent siltstone at 1,335–1,340 ft. *Ditrupa* fragments throughout.
----	1, 355–1, 365	Sandstone, light-gray, fine- to medium-grained, 50 percent; 85 percent white and clear quartz; remainder is mostly dark chert and some rock fragments, slightly calcareous; also 30 percent medium-dark-gray clay shale; *Ditrupa*.
----	1, 365–1, 375	Sandstone, as above; mostly loose sand, noncalcareous. Trace of clay shale; *Ditrupa* at 1,365–1,370 ft.
16	1, 375–1, 379	Recovered 3 ft: Microfossils absent. Sandstone, medium- to medium-light-gray, very fine- to medium-grained, hard subangular grains; 75 percent white and clear quartz; remainder is rock fragments, dark-gray chert, mica, pyrite, and other minerals rare; rare partings of coal. Very few pieces of core have bitumen or a tarry residue on broken surfaces, also a very small amount of medium-gray, noncalcareous to slightly calcareous claystone. Dip undetermined, possibly low; no cut or residue from 1,377 ft. At 1,377 ft

Lithologic description—Continued

Core	Depth (feet)	Remarks
		effective porosity 4.58 percent and air permeability 2.72 millidarcys.
----	1, 379–1, 390	Sandstone, as in core above, medium-grained; very slightly calcareous at 1,385–1,390 ft.
17	1, 390–1, 395	Recovered 3 ft: Microfossils absent. Sandstone, medium- to medium-light-gray, medium- to coarse-grained salt and pepper, hard; subangular grains; 70 percent white and clear quartz; remainder is mostly dark-gray and black rock fragments and chert; noncalcareous; argillaceous cement and much interstitial bitumen; dip 12° (?). Trace of an odor, brownish-yellow cut and blackish-yellow-brown residue from 1,394 ft. At 1,394 ft effective porosity 6.08 percent, and air permeability 2.66 millidarcys.
----	1, 395–1, 435	Sandstone, as in core above, fine- to medium-grained; mostly loose sand; slightly calcareous at 1,415–1, 420 ft, moderately calcareous at 1,395–1,400 and 1,430–1,435 ft, much rust stain from bit at 1,425–1,435 ft, chunk of *Inoceramus* prisms at 1,430–1,435 ft, 5–25 percent medium-dark-gray clay shale at 1,405–1,420 ft.
----	1, 435–1, 445	Sandstone, medium-light-gray, fine- to medium-grained, salt and pepper; grains subangular to subrounded; 60 percent white and clear quartz; much dark chert and some rock fragments; slightly to moderately calcareous cement. Rare *Inoceramus* prisms.
----	1, 445–1, 465	Sandstone, medium-light-gray, fine- to medium-grained; 75 percent white and clear quartz; sericitic in part; very slightly calcareous at 1,450–1,455 ft, very calcareous cement at 1,455–1,465 ft.
----	1, 465–1, 485	Sandstone, light- to medium-light-gray, very fine- to fine-grained, silty, 50 percent; very calcareous cement at 1,465–1,470 ft; chunk of *Inoceramus* prisms; also as much as 50 percent medium-dark-gray shale; trace of coal and pyrite at 1,475–1,480 ft.
18	1, 485–1, 490	Recovered 2 ft 6 in. Microfossils absent. Sandstone, medium-light-gray, thin-bedded, very fine grained to silty, hard; subangular to subrounded grains; 90 percent white and clear quartz; also dark chert and rock fragments; noncalcareous; dip undetermined; no shows. At 1,486 ft effective porosity 11.1 percent, and air permeability < 1 millidarcy.
----	1, 490–1, 495	Sandstone, as in core above, silty, noncalcareous.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	1,495–1,505	Siltstone, medium-light-gray; and very fine light-gray sandstone; very calcareous cement; also 30 percent medium-gray clay shale.
----	1,505–1,510	Sandstone, medium-light-gray, fine-grained; grains subangular to subrounded; 90 percent white and clear quartz; remainder is dark chert and rock fragments, some sericite, carbonaceous patches; moderately calcareous cement.
----	1,510–1,515	Siltstone, and very fine sandstone; moderately to very calcareous cement.
----	1,515–1,550	Clay shale, medium-dark-gray; trace of medium-gray noncalcareous siltstone and very fine-grained sandstone at 1,515–1,520 and 1,530–1,540 ft; 25 percent very fine sandstone and siltstone; *Ditrupa* at 1,535–1,540 ft.
----	1,550–1,580	Sandstone, light- to medium-light-gray, very fine-grained; grains subangular to subrounded; 90 percent white and clear quartz; trace of dark-yellowish-brown clay ironstone at 1,555–1,560 ft, trace of bitumen throughout.
----	1,580–1,590	Siltstone, medium-light-gray; trace of clay shale.
----	1,590–1,600	Sandstone, light-gray, fine- to medium-grained, salt and pepper, soft and friable; 65 percent white and clear quartz; subangular to rarely angular.
----	1,600–1,660	Sandstone, light-gray, mostly loose sand, fine-grained, rarely medium-grained; 75–85 percent white and clear quartz; some siltstone and clay shale; trace of carbonaceous shale at 1,615–1,620 ft, trace of bitumen in siltstone at 1,625–1,630 ft, *Ditrupa* at 1,605–1,620 ft. *Inoceramus* prisms at 1,625–1,630 ft.
----	1,660–1,685	Clay shale, medium-dark-gray; 30–40 percent medium-gray sandy siltstone at 1,660–1,675 ft; 30–50 percent sandstone at 1,675–1,685 ft.
----	1,685–1,710	Sandstone, light- to medium-light-gray, very fine-grained; grains subangular; 90 percent white and clear quartz; dark chert and a minor amount other minerals; slightly calcareous; trace medium-dark-clay shale.
19	1,710–1,712	Recovered 8 in.: Microfossils very rare. Siltstone, medium-gray, very slightly calcareous, very hard; dip undetermined.
----	1,712–1,715	Siltstone, medium- to medium-light-gray, sandy, noncalcareous; trace medium-dark-gray clay shale.
----	1,715–1,730	Clay shale, medium- to medium-dark-gray, silty.
----	1,730–1,735	Siltstone, medium- to medium-light-gray; 20 percent medium-dark-gray clay shale; rare bitumen coating.
----	1,735–1,750	Clay shale, medium- to medium-dark-gray, very silty.
----	1,750–1,755	Siltstone, and very fine sandstone, medium-light-gray, slightly calcareous: 30 percent medium-dark-gray clay shale.
----	1,755–1,760	Clay shale, medium-dark-gray, 75 percent; 30 percent medium-dark-gray slightly calcareous siltstone.
----	1,760–1,765	Siltstone, medium-light-gray, slightly calcareous, slightly micaceous, 80 percent; also clay shale; *Ditrupa*.
----	1,765–1,770	Sandstone, light-gray, very fine-grained to silty; grains subangular with some subrounded; 90 percent white and clear quartz; also carbonaceous and micaceous particles, dark chert and rock fragments; 10 percent medium-dark-gray clay shale. Slightly calcareous.
----	1,770–1,785	Siltstone, and very fine sandstone, slightly calcareous; trace of clay shale.
----	1,785–1,795	Clay shale, medium-gray, silty, trace of coal; *Ditrupa* at 1,780–1,790 ft.
20	1,795–1,800	No recovery.
----	1,800–1,801	No sample.
21	1,801–1,805	Recovered 1 ft 2 in.: Microfossils common. Clay shale, medium-dark-gray, finely micaceous; noncalcareous, moderately hard; fair cleavage; dip undetermined.

KNIFEBLADE TEST WELL 2

The quality of well cuttings from this test was good.

Lithologic description

Core	Depth (feet)	Remarks
----	0–5	Height of derrick floor above ground.
----	5–15	Clay shale, medium- to medium-light-gray, slightly silty; carbonaceous plant impression; trace of dark-yellowish-brown clay ironstone; trace of black shiny coal.
----	15–25	Coal, black, shiny, 50 percent; and medium- to dark-gray carbonaceous clay shale; 5 percent clay ironstone.
----	25–65	Clay shale, medium- to dark-gray; plant impressions, 3–5 percent coal in the upper 10 ft; trace to 20 percent siltstone at 40–55 ft.
----	65–75	Coal, black, shiny to dull, 35 percent; 35 percent dark-gray carbonaceous clay shale; and medium-light-gray fine-grained sandstone.

Lithologic description—Continued

Core	Depth (in feet)	Remarks
----	75–85	Sandstone, light-gray, fine- to medium-grained, salt and pepper, soft; 75 percent white and clear quartz; also coal particles, dark chert and mica (muscovite or sericite).
----	85–95	Clay shale, medium- to medium-dark-gray, 40 percent; 40 percent sand as above; remainder is black shiny coal.
----	95–105	Siltstone, 50 percent; and 40 percent light- to medium-light-gray very fine-grained sandstone; trace of clay shale.
----	105–145	Sandstone, very light- to light-gray, medium- to coarse-grained, salt and pepper, soft to hard; grains subangular to subrounded; 80 percent white and clear quartz, 10 percent coal particles, 10 percent mica (muscovite or sericite); light-colored slightly calcareous cement; carbonaceous plant impressions and light-olive-gray clay ironstone. The top of the Grandstand formation is placed at 105 ft.
----	145–155	Clay shale, medium-gray, 60 percent; 20 percent siltstone, and about 20 percent micaceous sandstone.
----	155–165	Sandstone, light-gray, medium-grained, soft; grains subangular to subrounded; 70 percent white and clear quartz; remainder is dark chert, coal particles, rock fragments, and mica; slightly calcareous.
----	165–185	Clay shale, medium-gray; also 40 percent sandstone as below in the lower half of the interval; trace olive-gray ironstone.
----	185–205	Sandstone, medium-light-gray, medium-grained, rare fine-grained, salt and pepper, very soft to medium-soft; grains subangular; 60 percent white and clear quartz; remainder mostly dark chert with abundant coal particles in places, some coaly partings; noncalcareous; trace of clay ironstone at 185–190 ft.
----	205–210	Siltstone, medium-light-gray, noncalcareous; carbonaceous partings; trace of sandstone.
----	210–225	Clay shale, medium-light- to medium-dark-gray, silty near top; trace of coal, pyrite, and olive-gray clay ironstone.
----	225–235	Clay shale, medium- to medium-dark-gray; 15–30 percent black shiny to dull coal.
----	235–245	Clay shale, medium- to medium-dark-gray, slightly silty, micaceous.
----	245–250	Siltstone, and small amount of very fine-grained sandstone, light- to medium-light-gray, micaceous; plant impressions.
----	250–265	Sandstone, light- to medium-light-gray; very fine-grained in upper part of interval and medium-grained in the lower; 75 percent white and clear quartz; remainder is dark chert, coal particles; sericite in matrix; slightly calcareous.
----	265–280	Clay shale, medium-light- to medium-gray, trace of finely micaceous siltstone.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	280–295	Clay shale, medium-dark- to medium-gray; trace of pyrite, coal, and brownish-gray clay ironstone.
----	295–300	No sample.
1	300–303	Recovered 1 ft: Microfossils abundant. Clay shale, medium- to medium-dark-gray, medium-hard; good cleavage; one 1½ in. thick hard slightly brownish-gray clay ironstone concretion at the bottom of the interval; shale contains pyrite nodules; dip undeterminable.
----	303–305	Coal, black, shiny, 50 percent; and dark-gray to grayish-black clay shale.
----	305–315	Clay shale, medium- to dark-gray; 5 percent coal at 305–310 ft.
----	315–320	Clay shale, medium-gray; and 30 percent very fine-grained argillaceous slightly calcareous sandstone; bitumen in sandstone.
----	320–370	Clay shale, medium- to medium-dark-gray; 10 percent medium-light-gray very fine-grained sandstone at 355–360 ft.
----	370–373	No sample.

KNIFEBLADE TEST WELL 2A

The well cuttings from Knifeblade test well 2A were of good quality to a depth of 1,500 feet. Below this depth there appeared to be a considerable amount of loose sand contamination. No samples were taken from 190 to 335 feet as the section was duplicated by nearby Knifeblade test well 2.

Lithologic description

Core	Depth (feet)	Remarks
----	0–5	Height of derrick floor above ground.
----	5–15	No sample.
----	15–20	Clay shale, medium- to dark-gray; 5 percent coal and moderate yellowish-brown clay ironstone.
----	20–30	Clay shale, medium- to medium-light-gray; also 10–20 percent medium-light-gray medium-grained very tight sandstone; brownish sideritic matrix; also some mica; 20 percent moderate yellowish-brown noncalcareous clay ironstone; trace of coal.
----	30–47	Clay shale, medium-light-gray, slightly silty; trace of sandstone.
----	47–49	Sandstone, medium- to medium-light-gray, fine- to medium-grained; 70 percent white and clear quartz; remainder is rock fragments, dark chert, coal particles, and mica; trace medium-gray clay shale.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	49–56	Coal, black, shiny to dull, and clay shale, medium- to dark-gray, 40 percent; 10 percent of the clay shale is light brownish gray.
----	56–61	Clay shale, medium-light-gray, slightly silty and sandy; trace to 10 percent coal.
----	61–64	Siltstone, medium-light-gray, and clay shale; trace of dirty sandstone.
----	64–69	Clay shale, medium-light-gray.
----	69–75	Coal, black, shiny; 10 percent grayish-black clay shale.
----	75–80	Clay shale, medium- and dark-gray; 15 percent coal; trace of ironstone.
----	80–87	Clay shale, medium-light-gray, very silty; 5 percent dark-gray clay shale.
----	87–90	Sandstone; as below but some with yellowish sideritic cement; 15 percent black dull to shiny coal, 5 percent moderate yellowish-brown clay ironstone.
----	90–113	Sandstone, light-gray, probably quite soft; medium grained with scattered coarse grains; subangular grains; 85 percent white and clear quartz; remainder is coal particles and dark chert, some mica, slightly calcareous in part; trace of coal at 97–99 ft, trace of ironstone at 108–113 ft. The top of the Grandstand formation is placed at 90 ft.
----	113–123	Clay shale, medium- to medium-light-gray; some sandstone; trace of light-olive-gray clay ironstone.
----	123–128	Sandstone, fine-grained, slightly calcareous, 60 percent; also medium-gray clay shale; trace of clay ironstone.
----	128–130	Siltstone, light-gray, and medium-gray clay shale.
----	130–137	Clay shale, medium-light-gray, silty and slightly sandy.
----	137–144	Sandstone, medium-light-gray, very fine- to rarely medium-grained, very dirty, silty, composed of 70 percent white and clear quartz, some coal, chert, mica (sericitic); as much as 10 percent clay ironstone particles; trace of clay shale.
----	144–148	Clay shale, medium-gray; trace sandstone; 5 percent light-olive-gray clay ironstone.
----	148–152	Sandstone, medium-light-gray, silty to fine-grained, slightly calcareous, hard; 75 percent white and clear quartz; 20 percent dark chert, coal particles, some mica, ironstone particles.
----	152–168	Clay shale, medium- to medium-light-gray; trace of siltstone; trace of pyrite.
----	168–171	Sandstone, as in core below; 10 percent medium-light-gray clay shale, 5 percent dark-yellowish-brown clay ironstone.
1	171–174	Recovered 2 ft 9 in.: Microfossils absent. Sandstone, light-gray, medium-grained, salt and pepper, medium-hard; platy fracture; subangular grains; 75 percent white and clear quartz; remainder is mostly dark-gray and black chert, very rare white chert and rare coal particles; argillaceous cement; noncalcareous; carbonaceous partings with 40° dip; sand contains very rare blebs of bitumen. At 172 ft effective porosity 16.0 percent, and air permeability 41 millidarcys.
----	174–185	Sandstone, as in core above.
----	185–190	Clay shale, medium-light-gray.
----	190–335	No samples were taken in this interval. See Knifeblade test well 2, 210–355 ft.
----	335–355	Clay shale, medium- to medium-light-gray, medium-dark-gray; carbonaceous partings at 340–345 ft.
----	355–365	Sandstone, medium-light-gray, fine- to rare medium-grained; 65 percent white and clear quartz; black coal particles common; dark chert; as much as 10 percent interstitial sericite; slightly calcareous; also as much as 40 percent medium-light- to medium-dark-gray clay shale.
2	365–368	Recovered 1 ft 6 in.: Microfossils absent. Siltstone, medium- to medium-light-gray, argillaceous, medium-hard; poor to fair shaly cleavage; many partings contain black carbonaceous plant impressions; some streaks of very fine sand; noncalcareous; some indication of dip as much as 40°.
----	368–370	Siltstone, medium-gray, 80 percent, and medium-gray clay shale or claystone; with conchoidal fracture.
----	370–375	Clay shale, medium- to medium-dark-gray.
----	375–385	Clay shale, dark-gray, carbonaceous; 5–10 percent black shiny coal; some medium-light-gray clay shale; as much as 20 percent medium-dark-gray siltstone.
----	385–455	Clay shale, medium- to dark-gray, rarely medium-light-gray; carbonaceous at 405–410 ft, silty and sandy at 430–435 ft, trace of pyrite at 445–455 ft, one shell fragment at 420–425 ft.
----	455–464	Sandstone, medium-gray, medium- to coarse-grained; grains subangular to subrounded; 50 percent white and clear quartz, 40 percent dark-gray chert and black coal; noncalcareous; bitumen in sand; also some clay shale in upper 5 ft of this interval.
3	464–467	Recovered 9 in.: Microfossils absent. Sandstone, light-gray, medium-hard, fine- to medium-grained, salt and

Lithologic description—Continued

Core	Depth (feet)	Remarks
		pepper; angular to subangular grains; 60 percent white and clear quartz; remainder almost entirely dark-gray and black chert; argillaceous cement; in some fragments the interstices are filled with a dark-brown tarry material; noncalcareous; dip undetermined; at 465 ft effective porosity 10.07 percent and the sample is impermeable.
----	467–470	Sandstone, light-gray, as in core above; also 15 percent medium-dark-gray clay shale.
----	470–545	Sandstone, light- to medium-gray, salt and pepper, rather soft except for calcareous streaks; fine grained at the base of the interval becoming coarse near the top, a few of the coarse grains are rounded, the rest are subangular to subrounded; 40 percent white and clear quartz, 30 percent coal particles and dark chert; about 30 percent of total rock is sericitic material—probably in matrix—which gives a sheen to rock chips. Very calcareous in interval at 495–500 ft, slightly to moderately calcareous at 505–515 ft. Traces of bitumen throughout.
----	545–560	Siltstone, medium-light-gray; sandy near top of interval, argillaceous near base.
----	560–570	Clay shale, medium-gray; as much as 10 percent medium-light-gray siltstone.
----	570–645	Sandstone, light- to medium-light-gray, fine- to medium-grained, mostly rather soft; 75 percent white and clear quartz; remainder is dark chert, rock and coal particles; sericitic material in matrix; noncalcareous except for very calcareous at 580–585 and 615–620 ft. *Inoceramus* prisms at 570–580 ft. Traces of bitumen throughout.
----	645–655	Siltstone, and very fine-grained sandstone, medium-light-gray, 60–80 percent; and medium- to medium-dark-gray clay shale.
----	655–665	Clay shale, medium-gray, silty in upper 5 ft. *Inoceramus* prisms.
4	665–667	Recovered ½ in.: Microfossils absent. Clay shale, medium-gray, slightly to moderately calcareous, hard; fairly good cleavage.
----	667–670	Clay shale interbedded with siltstone, dark-gray, hard, moderately to highly calcareous.
----	670–705	Clay shale, medium- to medium-dark-gray, silty; trace of very fine sandstone toward the base of the interval. *Ditrupa* at 695–705 ft.
----	705–730	Sandstone, medium- to medium-dark-gray, medium-grained; subangular grains; 70 percent white and clear quartz; remainder is dark chert and quite a large amount of carbonaceous material.
----	730–750	Clay shale, medium- to medium-dark-gray, silty. Trace of coal at 730–735 ft.
----	750–755	Sandstone, light- to medium-light-gray, fine- to medium-grained; grains subangular, 80 percent white and clear quartz; remainder is rock fragments, dark chert, coal particles, some mica and pyrite; noncalcareous; some bitumen in siltstone.
5	755–758	Recovered 2 ft 10 in.: Microfossils absent. Sandstone, medium-light-gray, fine- to medium-grained, salt and pepper, medium-hard; grains subangular; 60 percent white and clear quartz; remainder is dark-gray and black chert; other minerals rare; noncalcareous; dip undetermined; no shows. At a depth of 758 ft effective porosity 10.25 percent. The pieces of core were too small to drill a plug for permeability.
----	758–771	Sandstone, as in core above; some coarse grains; trace of bitumen.
6	771–773	Recovered 10 in.: Microfossils absent. Sandstone, medium- to medium-light-gray, medium-hard, fine- to medium-grained; some coarse grains; 80 percent white and clear quartz; remainder mostly dark chert and some coal particles; rare partings of angular black clastic coarse-grained coal particles; very slightly calcareous; dip undetermined; no shows.
----	773–789	Sandstone, as in core above, medium-grained, slightly calcareous.
7	789–792	Recovered 1 ft 10 in.: Microfossils absent. Sandstone, medium-light-gray, medium-grained, salt and pepper, medium-hard; subangular grains; 70 percent white and clear quartz; remainder is dark chert, coal particles, other minerals rare; argillaceous cement; noncalcareous; dip undetermined; no shows. At 792 ft effective porosity 14.2 percent, and air permeability 1.3 millidarcys.
----	792–805	Sandstone, medium-light-gray, salt and pepper; grains subangular to subrounded with some coarse rounded dark chert; 70 percent white and clear quartz; remainder is mostly dark-gray and black chert; pyrite common; trace of dark-gray clay shale and coal toward the base.
8	805–807	No recovery.

Lithologic description—Continued

Core	Depth (feet)	Remarks
9	807–809	Recovered 10 in.: Microfossils absent. Sandstone, medium-light-gray, medium- to coarse-grained, salt and pepper, medium-hard; composition essentially the same as in core 7 above; 65 percent white and clear quartz; very slightly calcareous to noncalcareous; no shows. At 807 ft effective porosity 20.9 percent, and air permeability 325 millidarcys.
----	809–815	Sandstone, light-gray, medium-grained, as above; trace of clay shale.
----	815–825	Siltstone, medium- to medium-light-gray, as much as 20 percent noncalcareous to very calcareous sandstone.
----	825–835	Clay shale, medium-gray; 5–25 percent moderately calcareous siltstone.
----	835–840	Siltstone, and very fine-grained sandstone, medium-light-gray, moderately calcareous; and medium-gray clay shale.
----	840–845	Sandstone, light-gray, fine- to medium-grained; 85 percent white and clear quartz; remainder is dark chert, coal particles, and rare rock fragments; very calcareous; also as much as 25 percent medium-gray clay shale.
10	845–846	Recovered 1 ft: Microfossils absent. Siltstone, light-gray, hard; some fine-grained sandy laminae; also about 40 percent medium-gray silty moderately to very calcareous hard clay shale with fair cleavage; possible dip of 18°.
----	846–850	Siltstone, medium-light-gray, moderately calcareous; carbonaceous partings; trace of very fine-grained sandstone.
----	850–860	Sandstone, light-gray, very fine-grained, hard; grades to siltstone; 85 percent white and clear quartz; very calcareous; also as much as 50 percent medium-gray clay shale.
----	860–893	Clay shale, medium- to medium-dark-gray; trace to 20 percent siltstone at 860–865 and 880–893 ft; slightly to moderately calcareous at 880–893 ft.
11	893–894	Recovered 7 in.: Microfossils very rare. Sandstone, light-gray, very silty, hard; grades to fine-grained argillaceous siltstone with irregular fracture; primarily white and clear quartz; some slightly carbonaceous and micaceous dark chert; one very small fragment of a mollusk shell. Very slightly calcareous; dip about 20°; no odor, no cut (well geologist reports slight fluorescence); slight greasy stain in evaporating dish of sample from 893 ft. At 893 ft effective porosity 8.93 percent and sample is impermeable.
----	894–903	Sandstone, light-gray, very fine-grained to silty; 90 percent white and clear quartz; also dark chert, rare rock fragments; 10–50 percent medium-gray clay shale.
12	903–905	Recovered 1 ft 4 in.: Microfossils common. Siltstone, medium-light-gray, argillaceous, very hard; streaks of sand; recovery consists mostly of flat chips up to 1 in. in diameter; about 40 percent of these chips are medium-gray noncalcareous clay shale; dip 27°; no shows.
----	905–915	Siltstone, medium-light-gray, 50–60 percent, and clay shale, medium- to medium-dark-gray; some very slightly calcareous very fine-grained sandstone.
----	915–920	Sandstone, light-gray, very fine-grained to silty, moderately calcareous, 80 percent; primarily white and clear quartz; also 20 percent medium-dark gray clay shale.
----	920–950	Siltstone and sandstone, in varying amounts; moderately calcareous at 925–930 ft, very slightly calcareous at 935–940 ft; as much as 50 percent medium-gray clay shale. *Inoceramus* prisms at 930–940 ft.
----	950–1, 000	Clay shale, medium- to medium-dark-gray, rarely medium-light- and dark-gray; very silty and moderately calcareous at 950–960 ft, silty at 990–1,000 ft. *Ditrupa* fragments at 955–960 and 995–1,000 ft, *Ditrupa* and *Inoceramus* at 970–975 ft.
----	1, 000–1, 010	Siltstone, medium-gray; and very fine-grained sandstone, slightly calcareous to noncalcareous; 5 percent medium-gray clay shale.
----	1, 010–1, 035	Clay shale, medium-dark- to dark-gray, silty; trace of very calcareous siltstone at 1,020–1,025 ft. 5 percent medium-light-gray very slightly calcareous siltstone at 1,030–1,035 ft.
----	1, 035–1, 040	Sandstone, light-gray, very fine-grained hard; 85 percent white and clear quartz; remainder is dark chert and coal particles; slightly calcareous; some medium-gray clay shale.
13	1, 040–1, 042	Recovered 2 in.: Microfossils very rare. Sandstone, light-gray, very fine-grained, hard; grains subangular; 80 percent white and clear quartz; remainder mostly dark chert, carbonaceous particles, and some biotite; very slightly calcareous; dip undetermined; exceedingly faint odor (?). Well geologist reports cores 13–15 bled gas.

Lithologic description—Continued

Core	Depth (feet)	Remarks
----	1, 042–1, 066	Sandstone, as in core above; 5–15 percent medium-gray clay shale.
14	1, 066–1, 070	Recovered 9 in.: Microfossils very rare. Sandstone, light-gray, very fine-grained to silty, very slightly calcareous, hard; composition as in core 13 above; dip approximately 23°; very faint odor; very pale-yellow cut and greasy residue in evaporating dish. At 1,066 ft effective porosity 9.45 percent, and the sample was impermeable to air.
----	1, 070–1, 084	Sandstone, as above; trace of clay shale at 1,080–1,085 ft.
15	1, 084–1, 086	Recovered 9 in.: Microfossils very rare. Siltstone, medium-light-gray, hard; irregular fracture; scattered sand grains; rare black carbonaceous plant impressions; very slightly to moderately calcareous; dip undetermined.
----	1, 086–1, 095	Sandstone, very fine-grained, and slightly calcareous siltstone; 15 percent medium-gray clay shale.
----	1, 095–1, 100	Siltstone, medium- to medium-dark-gray; 40–60 percent clay shale.
----	1, 100–1, 120	Clay shale, medium- to medium-light-gray; as much as 40 percent noncalcareous siltstone.
----	1, 120–1, 150	Siltstone, medium- to medium-light-gray, argillaceous; 10–50 percent medium- to medium-dark-gray clay shale; plant impressions at 1,140–1,145 ft.
----	1, 150–1, 155	Clay shale, medium-dark-gray.
----	1, 155–1, 160	Silty clay shale, and argillaceous siltstone, medium-light- to medium-dark-gray. *Ditrupa* fragments and *Inoceramus* prisms.
----	1, 160–1, 185	Clay shale, medium-dark-gray, trace of siltstone at 1,165–1,170 ft. One piece of aragonite stained with bitumen at 1,180–1,185 ft.
----	1, 185–1, 200	Siltstone, and very fine-grained sandstone, medium- to medium-light-gray, noncalcareous to moderately calcareous; also 10–30 percent silty clay shale.
----	1, 200–1, 210	Sandstone, medium-gray, very fine-grained, hard; composed of 70 percent white and clear quartz; many carbonaceous particles; some black chert and mica; argillaceous, silty, slightly to very calcareous; some interstitial bitumen present.
----	1, 210–1, 220	Siltstone; some very fine-grained sandstone and clay shale.
----	1, 220–1, 245	Clay shale, medium-dark-gray, silty.
----	1, 245–1, 265	Sandstone, medium- to medium-light-gray, very fine grained to silty, hard; grains subangular to subrounded; primarily white and clear quartz; also dark chert, coal particles; very calcareous in interval at 1,260–1,265 ft.
----	1, 265–1, 270	Siltstone and sandstone, medium- to medium-light-gray, slightly calcareous in part.
----	1, 270–1, 281	Clay shale, medium-dark-gray, very silty; some siltstone and sandstone.
16	1, 281–1, 283	Recovered 8 in.: Microfossils absent. Siltstone, medium-gray, argillaceous, hard; fair shaly cleavage; also some very fine-grained sand; carbonaceous micaceous partings; pyrite has replaced the matrix through one-half inch of the core; small amount of brownish crystalline calcite in partings; slightly calcareous; dip 27°.
----	1, 283–1, 305	Sandstone, medium-light-gray, silty to fine-grained, rather soft; 85 percent white and clear quartz; remainder is rock fragments and dark chert; 5–15 percent medium-dark-gray clay shale.
----	1, 305–1, 310	Clay shale, medium-dark-gray, 70 percent; and very fine-grained sandstone and siltstone.
----	1, 310–1, 325	Sandstone, medium-light-gray, very fine-grained, very soft; grains subangular to subrounded; 90 percent white and clear quartz, also dark chert, coal fragments; trace of clay shale.
----	1, 325–1, 335	Siltstone, medium- to medium-light-gray, noncalcareous to slightly calcareous; mostly white and clear quartz, rock fragments; also 20 percent medium-dark-gray clay shale. *Ditrupa* fragment.
----	1, 335–1, 340	Sandstone, light- to medium-light-gray, very fine- to fine-grained; mostly white and clear quartz, rock fragments; slightly calcareous in part; also 20 percent medium-dark-gray clay shale; crinoid stem ossicles and *Ditrupa*.
----	1, 340–1, 355	Clay shale, medium- to medium-dark-gray; 20–50 percent sandstone in the lower part of the interval; very fine- to fine-grained; sandstone is moderately calcareous at 1,350–1,355 ft, trace of coal at 1,345–50 ft.
----	1, 355–1, 400	Sandstone, light-gray, fine-grained, probably rather soft; subangular grains; 75 percent white and clear quartz; coal particles, rock fragments; noncalcareous to moderately calcareous; as much as 20 percent medium-dark-gray clay shale. *Inoceramus* prisms at 1,395–1,400 ft.
----	1, 400–1, 415	Clay shale, medium- to medium-dark-gray, silty; as much as 40 percent medium-gray siltstone.
----	1, 415–1, 420	Siltstone, medium- to medium-light-gray, sandy; 10 percent black shiny coal.

Lithologic discription—Continued

Core	Depth (feet)	Remarks
----	1, 420–1, 425	Clay shale, medium-dark-gray, 80 perpercent and light-gray very fine-grained sandstone; 5 percent coal. *Inoceramus* prisms.
----	1, 425–1, 445	Sandstone, light-gray, fine-grained; 85 percent white and clear quartz; moderately to very calcareous at 1,430–1,440 ft; 20–50 percent medium- to medium-dark-gray clay shale.
----	1, 445–1, 460	Clay shale, medium-dark-gray; 5 percent coal at 1,445–1,455 ft.
----	1, 460–1, 465	Siltstone, medium-light-gray, argillaceous, 60 percent; and medium-dark-gray clay shale.
----	1, 465–1, 479	Clay shale, medium-dark-gray, 70–90 percent; some medium-light-gray siltstone and very fine-grained sandstone; moderately calcareous at 1,465–1,470 ft, trace of coal at 1,470–1,475 ft. *Inoceramus* prisms at 1,475 and 1,485 ft.
17	1, 479–1, 481	Recovered 9 in.: Microfossils absent. Clay shale, medium-dark-gray, noncalcareous, hard; fair cleavage; rare micaceous partings; very rare slightly silty lighter colored laminae; dip undetermined, possibly 25°?
----	1, 481–1, 495	Clay shale, medium- and medium-dark-gray, very silty.
----	1, 495–1, 505	Sandstone (samples mostly loose sand), light-gray, fine-grained, noncalcareous; 15 percent medium-dark-gray clay shale.
----	1, 505–1, 507	Clay shale, medium-dark-gray, 60 percent; also light-gray slightly calcareous fine-grained sandstone.
18	1, 507–1, 510	Recovered 1 ft: Microfossils absent. Sandstone, medium-light-gray, fine-grained, massive, hard; subrounded to subangular grains; 90 percent white and clear quartz; remainder is dark chert, rock particles, mica, and other minerals rare; argillaceous cement; brownish cast to some of the quartz grains; essentially noncalcareous; dip undetermined. At 1,508 ft fleeting odor on fresh fracture; straw-colored cut; olive-yellow residue. At 1,508 ft effective porosity 11.45 percent, and sample is impermeable.
----	1, 510–1, 517	No sample.
19	1, 517–1, 521	Recovered 2 ft 10 in.: Microfossils absent. Sandstone, as above, noncalcareous; 85 percent white and clear quartz; dip undetermined. At 1,521 ft effective porosity normal to bedding 9.7 percent, and sample is impermeable.

Lithologic discription—Continued

Core	Depth (feet)	Remarks
----	1, 521–1, 557	Sandstone (samples mostly loose sand), light-gray, very fine- to fine-grained; grains subangular to subrounded; 85 percent white and clear quartz; also dark chert, coal particles, rock fragments, rare mica; slightly calcareous; 30 percent medium- to medium-dark-gray clay shale at 1,545–1,550 ft, trace to 8 percent clay shale elsewhere; some siltstone in lowest part.
20	1, 557–1, 560	Recovered 2 ft: Microfossils absent. Sandstone, medium-light-gray, silty to very fine-grained, hard; grains subrounded to subangular; 90 percent white and clear quartz; remainder is dark chert and coaly particles; argillaceous cement; noncalcareous; dip undetermined, suggestion of 5°–15°; fleeting odor; no cut; very pale-yellow residue from 1,557 ft. At 1,557 ft effective porosity 11.56 percent, and the air permeability <1 millidarcy.
----	1, 560–1, 580	Sandstone, as in the core above.
21	1, 580–1, 584	Recovered 3 ft 6 in.: Microfossils absent. Siltstone, argillaceous, and some clay shale, medium-gray, hard; fair to poor cleavage; rare streaks of fine-grained sandstone; coarser-grained material occurs toward bottom of core; noncalcareous; dip 18°–23°; no shows.
----	1, 584–1, 590	Siltstone, medium-light-gray; some loose sand; 5 percent clay shale.
----	1, 590–1, 607	Sandstone (mostly loose sand), light-gray, very fine- to medium-grained; grains subangular; 75 percent white and clear quartz; some dark-gray and black chert, rock fragments, coal particles; noncalcareous; trace of clay shale.
22	1, 607–1, 610	Recovered 2 ft 10 in.: Microfossils absent. Siltstone, clay shale, and some very fine-grained sandstone, medium-light- to medium-dark-gray. Sand is 75 percent white and clear quartz; many of the grains are stained brown; remainder of grains are dark carbonaceous material and some dark chert. Sandstone is slightly to moderately calcareous or possibly dolomitic, as rock reacts slowly with acid; dip undetermined; faint oily odor, dull-yellow cut and brown residue from 1,608 ft.
----	1, 610–1, 620	Loose sand, fine- to medium-grained.
23	1, 620–1, 622	Recovered 1 ft 4 in.: Microfossils absent. Sandstone, light-gray, fine-grained with very rare medium grains, hard; fair cleavage parallel the bedding; subrounded to subangular; 85 percent white and clear quartz; remainder is

Lithologic description—Continued

Core	Depth (feet)	Remarks
		mostly dark chert, some carbonaceous particles and mica, other minerals rare; rare argillaceous partings; noncalcareous; dip 8°–19°; some crossbedding; no shows.
----	1, 622–1, 661	Loose sand, 85 percent fine-grained, rarely very fine- or medium-grained; white and clear quartz.
24	1, 661–1, 664	Recovered 1 ft 9 in.: Microfossils absent. Sandstone, light-gray, fine-grained, hard; 90 percent white and clear quartz; remainder is dark chert, coal, and rock particles; argillaceous cement; one black carbonized-coaly plant fragment 2½ in. long and one quarter inch wide; noncalcareous; dip 8°–12°; no shows. At 1,661 ft effective porosity 6.13 percent, and sample is impermeable to air.
----	1, 664–1, 690	Loose sand, very fine- to fine-grained; 85 percent white and clear quartz; one clay chip at 1,680–1,685 ft.
----	1, 690–1, 725	Sandstone chips, light-gray, very fine-grained; trace to 8 percent siltstone and trace of clay shale; much very fine loose sand.
----	1, 725–1, 730	Siltstone, medium-light-gray, sandy; much loose sand.
----	1, 730–1, 755	Sandstone, light-gray, fine-grained; mostly loose sand; trace to 20 percent clay shale at 1,730–1,740 ft.
----	1, 755–1, 765	Clay shale, medium-dark-gray, silty.
----	1, 765–1, 770	Loose sand, light-olive-gray, very fine-grained to silty; grains subangular; mostly white and clear quartz.
----	1, 770–1, 775	Siltstone, medium-light-gray, sandy, noncalcareous.
----	1, 775–1, 780	Loose sand, very fine-grained; some siltstone.
----	1, 780–1, 785	Siltstone, medium-light-gray; loose sand; some clay shale.
----	1, 785–1, 790	Clay shale, medium-gray, silty; rare medium-dark-gray chips.
----	1, 790–1, 802	No sample.
25	1, 802–1, 805	Recovered 2 ft 9 in.: Microfossils very rare. Claystone, closely interbedded, with siltstone, with all gradations of each, medium- to medium-dark-gray, noncalcareous, hard; irregular fracture; dip 21°.

CORE ANALYSES

Effective porosity, air permeability, and carbonate content analyses were made in the Fairbanks laboratory of the Geological Survey on core samples shipped from the test well sites. Porosity and permeability were determined on the type of equipment mentioned on page 392. In coring with the cable tool rig there was a tendency for the softer sandstones to disintegrate, leaving only hard impermeable fragments for analysis.

The results given in the following table were obtained on samples from Knifeblade test well 1. All plugs were cut normal to the bedding.

Core analyses, Knifeblade test well 1

Core	Depth (feet)	Effective porosity (percent)	Air permeability (millidarcys)
2	267	4. 42	0
3	314	5. 29	0
7	828	10. 58	0
13	1, 162	11. 50	<1
14 [1]	1, 269	13. 06	<1
15	1, 297	8. 16	0
16	1, 377	4. 58	2. 72
17	1, 394	6. 08	2. 66
18	1, 486	11. 10	<1

[1] Carbonate-mineral content 19.64 percent by weight.

No analyses were made of Knifeblade test well 2.

The following table gives the porosity and permeability determinations made on Knifeblade test well 2A.

Core analyses, Knifeblade test well 2A

Core	Depth (feet)	Effective porosity (percent)	Air permeability (millidarcys)
1	[1] 172P	16. 00	41.
3	465P	10. 07	0.
5	758P	10. 25	Sample too small to drill plug.
7	792P	14. 20	1.3.
9	807P	20. 90	325.
11	893P	8. 93	0.
14	1, 066P	9. 45	0.
18	1, 508N	11. 45	0.
19	1, 521N	9. 74	0.
20	1, 557N	11. 56	<1.
24	1, 661N	6. 13	0.

[1] P is parallel to the bedding. N is normal to the bedding.

HEAVY-MINERAL ANALYSIS

Robert H. Morris examined (see p. 392) 5 heavy-mineral samples from Knifeblade test well 1 and 8 from Knifeblade test well 2A. (See fig. 31.) No samples were prepared from Knifeblade test well 2. He determined that in Knifeblade test well 1 the zoned zircon zone ranges from 1,290 to 1,490 feet. A sample at 1,160 feet is nondiagnostic. In Knifeblade test well 2A the zoned zircon zone ranges from 460 to 1,540 feet. One sample at 160 feet is nondiagnostic.

OIL AND GAS

OIL AND GAS SHOWS

No good oil or gas shows were found in the Knifeblade test wells although many of the sandstone and silt-

stone beds contain small amounts of interstitial bitumen or asphaltic residue. A slight show of gas at 681 feet in Knifeblade test well 2A was completely exhausted in 1 hour. Salt water entered both the Knifeblade test well 1 and test well 2A holes while drilling. No free oil appeared on any of the water bailed from the tests.

Only two tests for oil in carbon tetrachloride were made in the Fairbanks laboratory on samples from Knifeblade test well 1: one at a depth of 1,377 feet, had no cut; the other, at 1,394 feet, had a brownish-yellow cut and a blackish-yellow-brown residue. Bitumen was noted in the sediments at 1,037, 1,065, 1,220, 1,245, 1,255, 1,265, 1,290, 1,375, 1,390, 1,555, 1,625, and 1,730 feet.

No shows were found in Knifeblade test well 2 nor did any water enter the hole. Bitumen was noted in the sandstone in the interval 315–320 feet. In addition, bitumen was noted in Knifeblade test well 2A at 171–174, 455–464, 464–467, 570–645, 750–755, 1,180–1,185, and 1,200–1,210 feet.

The following shows were noted in Knifeblade test well 1 by Arctic Contractors' well geologist at the time the well was drilled.

Oil and gas shows reported by Arctic Contractors, Knifeblade test well 1

Depth (feet)	Show
640	Slight amount of gas encountered while drilling.
1,265–1,270	Reddish-brown cut.
1,273–1,274	A little gas while drilling.
1,300	Odor of oil.
1,300–1,305	Reddish-brown cut.
1,370–1,375	Pale cut.
1,390–1,395	Good reddish-brown cut.
1,400–1,405	Straw cut.
1,480–1,490	Good straw cut.
1,505–1,510	Do.
1,550–1,555	Do.
1,695–1,700	Do.
1,705–1,710	Do.
1,755–1,760	Do.
1,760–1,765	Do.
1,780–1,785	Do.
1,795	Slight blow of gas while drilling.

The Arctic Contractors' well geologist reported the following shows from Knifeblade test well 2A.

Oil and gas shows reported by Arctic Contractors, Knifeblade test well 2A

Depth (feet)	Show
575–585	Slight asphaltic oil stain, no cut.
585–655	Slight asphaltic oil stain.
681	Slight show of gas in ditch.
708–726	Slight asphaltic stain.
1,035–1,086	Cores bled gas, strong odor, no stain.
1,479–1,481	Very light oil staining and odor.
1,507–1,510	Very light oil staining and odor.

The following table gives the results obtained by the Fairbanks tests.

Test for oil stain in carbon tetrachloride, Knifeblade test well 2A

Core	Depth (feet)	Cut	Residue
3	465	Brown	Blackish brown.
11	893	None	Slight greasy stain.
14	1,067	Exceedingly pale	Very pale yellow.
18	1,508	Straw colored	Olive yellow.
19	1,521	Brownish yellow	Brown.
20	1,557	None	Very pale yellow.
22	1,608	Dull yellow	Brown.

BAILING TESTS

Many bailing tests were made on Knifeblade test well 1. No fluid entered Knifeblade test well 2; however, Knifeblade test well 2A gave more water than test well 1. The results of these tests are given below.

Bailing tests on Knifeblade test well 1

Depth (feet)	Remarks
650	Bailed 1 hr. Found hole dry.
882	Hole began giving water. Bailed hole dry, recovered 3½ bbl of water. Hole stood 1 hr. Found 3 bbl of water had entered.
910	Fluid level came up to 860 ft. Bailed hole dry obtaining 38 bbl of water. Hole stood 1 hr. Bailed 7.5 bbl of water. Salinity of water was 5,000 ppm. No more salt added to hole because of influx of salt water. Fluid level rose to 375 ft from surface.
1,250	Made bailing test. Lowered fluid level from 451 to 606 ft. Recovered 25.9 bbl in 1 hr. Hole stood 1 hr. and fluid level rose from 606 to 586 ft. Made 2d bailing test—lowered fluid level from 586 to 820 ft. Recovered 33.4 bbl of water in 2 hrs. Hole stood 1 hr and fluid level rose to 770 ft. Hole stood 2½ hr more and fluid level rose to 649 ft. Salinity of the water was 4,000 ppm. Made 3d bailing test—lowered fluid level from 649 to 1,000 ft in 3 hrs. Recovered 19.75 bbl of water the 1st hr, 18.4 bbl the 2d hr, and 16.35 bbl the 3d hr. Could not bail below 1,000 ft. Hole stood 1 hr at end of bailing test and fluid level rose 850 ft. Rate of entry 17.7 bbl per hr. Salinity was 4,000 ppm. Cased off to 1,211 ft. Found hole dry after 1 hr test.
1,373	Encountered water. Level rose to 1,040 ft. Bailed hole dry in 1¼ hr. Recovered 17.7 bbl. Hole gave 1.02 bbl of water per hr. Salinity was 6,380 ppm.
1,640	Bailed hole dry. Recovered 15 bbl of water.
1,805	Hole was giving about 10 gal of water per hr when abandoned.

Bailing tests on Knifeblade test well 2A

Depth (feet)	Remarks
750	Bailed ½ hr and found hole dry.
758	Water began entering hole. Fluid level rose to 170 ft in 2 hr. Could not be lowered by bailing. Salinity was 4,500 ppm.
825–1,000	In drilling from 825 to 1,000 ft, fluid level dropped from 170 to 250 ft. Level could not be lowered by bailing.
1,020–1,693	In drilling from 1,020 to 1,693 ft, the fluid level dropped from 250 to 300 ft.
1,805	At the total depth the fluid level stood at 235 ft. Continuous bailing did not lower the level. Salinity was 4,000–5,000 ppm.

It is interesting to note that salt water was first encountered in Knifeblade test well 1 while drilling at 882 feet (117 feet above sea level), and that water was first encountered in Knifeblade test well 2A at 758 feet (116 feet above sea level). These depths may represent the base of the permafrost, or there may be a common water level between the two tests.

LOGISTICS

Transportation.—The rig used to drill the Knifeblade test wells was moved from the Wolf Creek area after the completion of Wolf Creek test well 2. This move was made late in the season and was, for that reason, quite costly. It took six tractors from July 7th to 12th to accomplish the work. The lead tractor, which could not pull a load, was taxed to its capacity by bulldozing a furrow down to the permafrost zone so the following tractors could secure sufficient footing. As much as 18 inches of thaw was encountered in some places, although 12 inches was an average depth. By comparison, the same load could be transported in winter in 1½ days with 2 tractors.

An airstrip suitable for C–47 type aircraft was constructed on top of a nearby ridge, and 100 tons of supplies were flown in. Under favorable wind conditions it was possible to land a C–46.

Personnel and housing.—The same personnel and housing was used in drilling all three wells. A drilling foreman and a geologist were the supervisors. During the drilling of Knifeblade test well 2A, the geologist divided his time between Knifeblade and Umiat. Two drillers, 2 tool dressers, 1 heavy-duty mechanic, 1 fireman, and 1 welder made up the drilling crew. In addition there was 1 oilfield warehouseman-timekeeper-storekeeper, 2 cooks, 1 tractor operator, and 1 bull cook. Electricians, carpenters, etc., were brought in from Barrow and Umiat as needed.

The camp was made up of 15 wanigans and was located close to the drilling rig. Two of the wanigans were used for sleeping quarters, 1 for a galley, 1 for a mess hall, 1 for the radio and store, 1 for a food warehouse, 1 for a power and boiler room, 1 for a geological and engineering office, 1 for a machine shop, 1 for storage of cement, 1 for cement pumps, 1 for the electric logging equipment, 1 utility, and 2 for water. During the drilling of Knifeblade test well 1 the electric logging wanigan was moved to Umiat.

Vehicles and drilling equipment.—Three weasels, 4 D8 Caterpillar tractors, and 1 small crane (TD–9 cherrypicker) were used at the rig sites. Two additional D8's were borrowed from Titaluk test well 1 and were used originally in hauling the drilling equipment from the Wolf Creek to the Knifeblade area.

One of each of the following major items of drilling equipment was used by Arctic Contractors:

Bucyrus Armstrong spudder, model 29W, water well drill with 45-ft all-steel mast.
Caterpillar D311, 4-cylinder engine.
15 kilowatt generator powered by D-3400 engine with a 4-kilowatt Kohler standby generator.
Heat Pak boiler.

Plate 27*C* shows the cable tool rig used for drilling the Knifeblade holes.

Fuel, water, and lubricant consumption.—The drilling of Knifeblade test well 1 required 187,000 gallons of water, 13,420 gallons of diesel fuel, 3,282 gallons of 72-octane gasoline, 159 gallons of 80-octane gasoline, 32¼ pounds of 9170 lubricating oil, 14½ pounds of 9500 lubricating oil, 13 pounds of grease, 53 gallons of kerosene, and 10 gallons of Prestone. Knifeblade test well 2 and 2A required 12,764 gallons of diesel fuel, 1,526 gallons of 72-octane gasoline, 87½ gallons of lubricating oil and 124 pounds of grease for drilling. At this latter site the transportation of water was particularly difficult. It was necessary to haul the water up a steep hill for a distance of 3 miles during the period of maximum thaw.

DRILLING OPERATIONS

RIG FOUNDATION

The mast, engine, and other parts were assembled as a complete unit and were mounted on a welded steel-pipe sled, which in turn was blocked up on 12- by 12-inch timbers. The rig and the camp was skidded from one location to the other.

DRILLING NOTES

Notes from drilling records, Knifeblade test well 1

Depth (feet)	Remarks
0	Test spudded on October 13, 1951.
58	Ran 52 ft of 11 ¾-in. 47-lb casing. Cemented with 27 sacks of Cal-Seal.
160	Stranded drill line 20 ft above tools. Cut off same.
290	Line stranded 6 ft above socket. Cut off same.
340	Broke pin on bit, leaving bit in hole. Went in with horn socket and recovered fish after 2 hr.
680	Tools hung up when coming out of hole. Freed tools.
1,000	Replaced ⅞-in. drilling cable with ¾-in. cable.
1,090	Lost bailer in hole when sand line parted 50 ft above bailer. Recovered bailer after 1 hr fishing.
1,250	Ran 19 joints, (8⅝ in., 28-lb, H–40, A. O. Smith Electroweld, range 2, 8–V thread,) seamless casing to 420 ft. Drilling engine broke down. Shoe of casing 30 ft above water level in hole. Waited 3 days for engine parts. Continued to run casing after engine was repaired, and landed it at 1,211 ft. Cemented with 180 sacks construction Type C cement treated with 5 percent $CaCl_2$.
1,375	Mechanical failure of drilling engine. Shut down 24 hr for repairs.
1,440	Broke dart in bailer, leaving dart in hole. Drilled up.
1,555	Broke pin on sub, leaving bit and sub in hole. Went in with 6¼-in. friction socket to get over 6½-in. sub. Split the socket but recovered fish. Waited 3 days for new sub.
1,610	Drilling engine broke down. Received orders to repair engine and attempt to complete hole. Shut down 6 days for parts and repairs.
1,640	Line stranded, cut off 250 ft.
1,805	Completed December 22, 1951. Final condition of well head: master gate removed and blank steel plate bolted on top of flange. Top of plate 2 ft 8 in. above ground level. Barrel inverted over casing.

Notes from drilling records, Knifeblade test well 2

Depth (feet)	Remarks
0	Spudded in July 26, 1951.
45	Ran in two joints of casing (11 ¾-in., 45-lb seamless range 1, 8 thread round). Cemented with 11 sacks of Cal-Seal.
373	Broke box on drill stem leaving 10¾-in. bit and part of box in hole. Ran in with 10-in. horn socket but found fish driven into side of hole. Could not get over fish. Hole junked and abandoned August 5, 1951. Condition of well at surface: stub of 11¾-in. casing sticking up above ground about 1 ft. Open. Two thermistor cables 205 ft long were installed.

Notes from drilling records, Knifeblade test well 2A

Depth (feet)	Remarks
0	Spudded in August 6, 1951.
38	Ran 3 joints of casing (11¾-in. 45-lb range 1 seamless) and cemented at 38 ft with 16 sacks Cal-Seal.
846	Shut down 10 hr to repair clutch on power unit.
910	Line pulled out of rope socket leaving tools in hole. Recovered fish in 5 hr with 8-in. combination socket.
980	Shut down 12 hr to repair sand reel clutch.
1,190	Drilling line parted leaving tools and 125 ft of line in hole. Recovered fish after 6 hr.
1,285	Drilling line parted leaving tools and 800 ft of line in hole. Recovered fish with 6-in. rope spear in 4 hr.
1,465	Shut down 18 hr to repair crown sheaves and shock absorbers.
1,605	Jumped pin in sub leaving 8-in. bit and sub in hole. Recovered fish with friction socket after 6 hr.
1,805	Completed Oct. 7, 1951, after an electric log and temperature survey. Condition of hole at surface: stub of 11¾-in. casing projecting above the ground about 1 ft.

DRILLING FLUID

The tests were drilled with a sufficient quantity of fluid in the holes to lubricate the cable tool bit and keep cuttings in suspension. While penetrating the permafrost, a sodium chloride brine was used instead of fresh water to keep the hole free of ice. After penetrating the water sands, no salt was used in the drilling fluid. The salinity of the fluid in the holes averaged between 4,000 and 6,000 ppm. Eight thousand, one hundred pounds of salt were used in drilling Knifeblade test well 1 and 1,800 pounds and 5,400 pounds in drilling Knifeblade test wells 2 and 2A, respectively.

HOLE-DEVIATION RECORD

No hole-deviation surveys were made in Knifeblade test wells 1 or 2. In test well 2A, however, a check was made at 235 ft by attaching a light to the bailer and lowering it into the hole. The hole was found to be straight.

ELECTRIC LOGGING AND TEMPERATURE SURVEY

No electric logs were run in Knifeblade test wells 1 and 2. However, a Schlumberger electric log was run in 2A from 268 to 1,798 feet. (See pl. 26.) Since the hole was drilled with cable tools and carried a column of brackish water, a normal electric log could not be expected. Lower resistivities were found at shale

horizons and high resistivities opposite the sandstones. An increase in resistivity is noted near 1,170 and near 1,600 feet where the hole diameter changes.

In Knifeblade 2A bailer samples of water taken at the top and bottom of the fluid column showed temperatures of 31° and 38°F, respectively. An attempt was made using Schlumberger equipment to determine the existence of and the possible permeability of sandstones below 771 feet on the basis of change in the temperature gradient before and after bailing. The results were inconclusive. Both temperature surveys recorded 28°F at the top and 29.7°F at the bottom with a uniform gradient. In other wells of the Reserve, records indicate a gradient of from ¾° to 1° per 100 feet. It is not known if the results obtained in Knifeblade test well 2A were the result of temperature equalizing convection currents or faulty tests.

TEMPERATURE-MEASUREMENT STUDIES—KNIFEBLADE TEST WELL 2

By Max C. Brewer

Knifeblade test well 2 was abandoned and left open on August 5, 1951, 10 days after drilling began. Two cables, containing thermally sensitive electrical resistance elements of the thermohm type, were installed on November 2, 1951. Temperature readings were obtained the following day after the thermally sensitive elements had time to reach equilibrium with the surrounding materials. Equilibrium temperatures should vary little, if any, from these temperatures as the hole had been abandoned for 3 months, was a cable-tool hole, and was very shallow and little disturbed by a long period of drilling. The minimum temperature, below the depth of seasonal change, occurs at a depth between 105 and 155 feet beneath the surface of the ground.

This well is near the bottom of a small valley, and hence the temperatures in the well may be affected by topography. However, if it is assumed that the thermal profile in this well is similar to those in wells in the Umiat area (in the same physiographic province), the recorded temperatures indicate the permafrost to be thinner here than it has been found in any other area of Naval Petroleum Reserve No. 4. No attempt has been made to extrapolate the profile to the depth of the 0° C isotherm, bottom of permafrost, because data are not sufficient. However, water was found at depths of 845–850 feet in Knifeblade 1 and 857 feet in Knifeblade 2A.

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MICROPALEONTOLOGIC STUDY OF TEST WELLS IN THE TITALUK AND KNIFEBLADE AREAS, NORTHERN ALASKA

By HARLAN R. BERGQUIST

Approximately 430 samples were studied from Titaluk test well 1 and Knifeblade test wells 1, 2, and 2A, all of which penetrated Cretaceous strata. In the Titaluk test well these strata include nearly 600 feet of the Ninuluk formation; a thick sequence of 1,260 feet of nonmarine beds of the Killik tongue of the Chandler formation, and 2,170 feet of older marginal marine beds. Within these beds are two faunal zones, the *Gaudryina canadensis-Trochammina rutherfordi* zone of Cenomanian age and the *Verneuilinoides borealis* zone of Albian age. These faunal zones are more distinctive in the Titaluk well section than in the Knifeblade wells. In the Knifeblade area, test wells 1 and 2A each penetrated 1,805 feet of beds older than the Ninuluk formation. Much of the section in each well carried the *Verneuilinoides borealis* fauna.

Most of the Foraminifera found in these test wells are species that have been recently described by Mrs. Loeblich (Tappan, 1951 and 1957). Four or five species were first found in beds of Cenomanian and Albian age in western Canada (Cushman, 1946; Nauss, 1947; Stelck and Wall, 1955; Wickenden, 1932).

TITALUK TEST WELL 1

Gaudryina canadensis - Trochammina rutherfordi *zone (surface (?) to 590 feet).*—*Gaudryina canadensis* Cushman and *Trochammina rutherfordi* Stelck and Wall were found in most of the samples from the upper 500 feet, beginning with the first recovered sample (40–50 feet) in the Ninuluk formation. Both species were abundant in a sample from a core from 300–310 feet and were abundant or common in some of the ditch samples. The same relative abundance and frequency of occurrence of these two species, with the near exclusion of other Foraminifera, is found in most of the subsurface occurrences of the Ninuluk formation. Thus, I have designated these fossiliferous beds as the *Gaudryina canadensis-Trochammina rutherfordi* faunal zone. In the Titaluk well, however, the middle part of this faunal zone includes a few pyritic casts of a radiolarian (*Zonodiscus* sp. C).

Nonmarine beds (590–1,850 feet).—Between the fossiliferous beds of the Ninuluk formation and a lower fossiliferous section of the Nanushuk group, an interval of approximately 1,260 feet of sedimentary beds has been placed in the Killik tongue. Most of the cores from this section were barren, but specimens of a simple long-ranging species (*Saccammina* sp.) occurred sparingly in a core sample from 850–860 feet and were abundant in a core sample from 1,136–1,151 feet. Specimens of *Gaudryina canadensis* and *Trochammina rutherfordi*, found in several ditch samples in the upper 500 feet of the nonfossiliferous section, were probably introduced from the overlying fossiliferous beds of the Ninuluk formation. A solitary charophyte oogonium was found in a ditch sample from 1,350–1,360 feet, and scattered *Inoceramus* prisms occurred in a few samples, even in the lower 450 feet of this unit in which no Foraminifera were found.

Verneuilinoides borealis *zone (1,850 feet to total depth).*—In Northern Alaska an assemblage of Foraminifera of Albian age occurs in beds of the upper part (2,000 feet or more) of the Torok formation and in the Tuktu and Grandstand formations, including the subsurface beds defined as the Topagoruk formation. This is the *Verneuilinoides borealis* microfaunal zone, which is widespread regionally and has in its entirety a large number of species of Foraminifera; but in the Titaluk well only 24 species were found. Of these species 9 occurred in several samples, and 6 of that number were only in beds below the Ninuluk formation. About 15 species occurred once or twice in the samples, and only 1 or 2 specimens of each were found. Nevertheless, a sufficient number of diagnostic species was found in the well to establish the presence of the zone and to allow a correlation with surface formations.

In the Titaluk well the top of the *Verneuilinoides borealis* zone at 1,850 feet is marked by the abrupt appearance in a ditch sample of abundant specimens of *Verneuilinoides borealis* Tappan, common specimens of *Haplophragmoides topagorukensis?* Tappan and *Miliammina awunensis* Tappan, and a few specimens of two other arenaceous species of Foraminifera. In the ditch samples from the succeeding 1,100 feet, *Haplophragmoides topagorukensis* was very rare, and none were found in the core samples. In a core from 2,378–2,393 feet, *Psamminopelta subcircularis* Tappan was common and *Verneuilinoides borealis* and *Miliammina*

awunensis Tappan were abundant, whereas cores from 2,670–2,676 feet had abundant specimens of *Verneuilinoides borealis*, common specimens of *Gaudryinella irregularis* Tappan and *Trochammina rutherfordi* Stelck and Wall, and a few specimens of *Miliammina awunensis*. A few specimens of these species were found in ditch samples down to 3,100 feet, but cores from 2,983–3,027 feet were barren.

Numerous specimens of *Verneuilinoides borealis*, *Miliammina awunensis*, and *Gaudryinella irregularis*, and a few specimens of *Ammobaculites wenonahae* Tappan and *Haplophragmoides topagorukensis* occurred in cores from 3,102–3,137 feet. *Verneuilinoides borealis* was the only abundant fossil in a core from 3,289–3,307 feet, and lower cores through 3,450 feet were barren. A core from 3,550–3,560 feet, however, carried very abundant tests of *Haplophragmoides topagorukensis*, abundant specimens of *Verneuilinoides borealis*, and a few specimens of *Ammobaculites wenonahae* Tappan, and *Ditrupa* sp. A core from 3,679–3,698 feet yielded specimens of *Ditrupa* sp. and a fragment of *Balanocrinus* sp. (identified by Arthur L. Bowsher). In the cores and ditch samples below that depth the fauna was sparse, but more than a dozen species were in the bottom-hole core from 4,001–4,020 feet. However, *Haplophragmoides topagorukensis* was the only abundant species in the last sample, and only single specimens of some of the species were found.

Although calcareous Foraminifera are relatively common and distinctive in the *Verneuilinoides borealis* faunal zone of some areas, very few specimens were found in the Titaluk well. A few specimens of *Gavelinella stictata* (Tappan) and *Eurycheilostoma grandstandensis* Tappan came from a core from 3,550–3,560 feet, and a few specimens of 6 calcareous species were found in the bottom-hole core. *Lenticulina macrodisca* (Reuss) occurred in a core from 3,679–3,689 feet.

KNIFEBLADE TEST WELL 1

Four or five species of the *Verneuilinoides borealis* faunal zone occurred erratically in the upper few hundred feet of Knifeblade test well 1 in a sequence of interbedded fossiliferous and unfossiliferous strata. *Verneuilinoides borealis* Tappan was abundant in 2 samples and common in 1, and a few specimens were found in 7 other samples. The species occurred alone or in association with a few specimens of *Miliammina awunensis* Tappan, *Trochammina rutherfordi* Stelck and Wall, and *Gaudryinella irregularis* Tappan.

Microfossils were found in 55 percent of the samples, but most occurred in the rocks in two intervals in the lower half of the well. One of these intervals extends from 860 to 1,245 feet and the other from 1,625 to 1,805 feet, the total depth of the well. Only 2 cores (1,149–1,152 feet and 1,801–1,805 feet) were fossiliferous, and another core (1,710–1,712 feet) yielded only 1 foraminifer.

Fossils concentrated in rocks in the 2 more fossiliferous intervals include 12 species of Foraminifera, but only *Verneuilinoides borealis*, *Miliammina awunensis*, and *Haplophragmoides topagorukensis* Tappan were relatively abundant.

The entire well is within the *Verneuilinoides borealis* zone.

The first few cores taken from the upper part of the section below 860 feet were unfossiliferous, but specimens of *Verneuilinoides borealis* were common in two ditch samples, and *Haplophragmoides topagorukensis* Tappan was common in a sample from 920–930 feet; a few specimens of *Miliammina awunensis* were associated with both species. *Verneuilinoides borealis* was found in abundance in every sample from 970–1,152 feet. Five other species of the *Verneuilinoides borealis* faunal zone were found in this part of the section, but these were relatively few except for common specimens of *Miliammina awunensis* in 3 samples. Foraminifera were few in samples from 1,152–1,245 feet, but samples from 1,255–1,625 feet were unfossiliferous except for a few *Inoceramus* prisms and a few fragments of worm tubes. The latter, *Ditrupa* sp., first occurred in a sample from 1,335–1,345 feet.

In the lower part of the well from 1,625 feet through the bottom-hole core (1,801–1,805 feet), Foraminifera occurred sparingly, but *Haplophragmoides topagorukensis* was common at 1,625–1,660 feet and *Verneuilinoides borealis* at 1,740–1,750 feet. A few specimens of *Eurycheilostoma grandstandensis* Tappan, *Gavelinella stictata* (Tappan), and *Pallaimorphina ruckerae* Tappan were found in some ditch samples below 1,625 feet and in the bottom-hole core. Tubes of *Ditrupa* sp. occurred in 4 samples.

KNIFEBLADE TEST WELL 2

The section in Knifeblade test well 2 was barren down to 125 feet, but from 125 feet to the bottom of the hole at 370 feet a few species of Foraminifera from the *Verneuilinoides borealis* faunal zone occurred in all samples except one. The most common species was *Verneuilinoides borealis* Tappan, found in nearly all samples and especially abundant in the core from 300–303 feet and in the last two ditch samples (350–370 feet). *Milliammina awunensis* Tappan was common in the aforementioned core and in a ditch sample from 215–220 feet and was very abundant in a ditch sample from 350–355 feet. Specimens of *Gaudryinella irregularis* Tappan were common in the same ditch sample.

KNIFEBLADE TEST WELL 2A

No fossils were found in the upper 118 feet of the section in Knifeblade test well 2A, but a limited fauna of the *Verneuilinoides borealis* faunal zone occurred in samples from three intervals, from 118–160 feet, 335–460 feet, and 815–1,260 feet. Almost all of the cores were unfossiliferous. In the two highest fossiliferous intervals *Verneuilinoides borealis*, *Miliammina awunensis*, and *Trochammina rutherfordi* occurred in more samples than any others. *Verneuilinoides borealis* was very abundant in samples from 155–160 feet and 335–340 feet, abundant at 435–440 feet, and common at 395–400 feet. *Miliammina awunensis* was common from 155–160 feet and 435–440 feet; and in the latter sample, specimens of *Trochammina rutherfordi?* were also common.

No samples were taken in the interval from 180 to 335 feet; the section from 464 to 675 feet was barren. A few specimens of Foraminifera and fragments of worm tubes (*Ditrupa* sp.) occurred from 695–700 feet, whereas the interval from 715–810 feet was barren. The greatest occurrence of Foraminifera in the formation was in the interval from 903–1,020 feet, although the fossiliferous section extends from 815–1,260 feet. *Verneuilinoides borealis* was common to very abundant from 903–980 feet and *Haplophragmoides topagorukensis* was common from 975 to 1,020 feet.

Inoceramus prisms and a fragment of *Ditrupa* sp. occurred in several samples from the formation, but were concentrated in the samples from 935–1,000 feet. A few specimens of calcareous Foraminifera representing seven species were scattered through samples below 900 feet; most frequent of these was *Gavelinella stictata* (Tappan). In samples below 1,260 feet only rare specimens of Foraminifera were found, as most of the interval was barren. Common specimens of *Haplophragmoides topagorukensis?* and a few specimens of *Verneuilinoides borealis* occurred in the bottom-hole core (1,803–1,805 feet).

I consider that the entire section penetrated in this well is part of the *Verneuilinoides borealis* faunal zone, representing beds correlative with the Grandstand and Tuktu formations. The absence of fossils in the uppermost 118 feet in no way indicates that the upper beds are a separate unit.

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