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WELL PRODUCTIVITY RELATED TO DRILLING MUDS: UMIAT FIELD, NAVAL PETROLEUM RESERVE NO. 4, ALASKA

By George L. Gates and W. Hodge Caraway

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UNITED STATES DEPARTMENT OF THE INTERIOR
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WELL PRODUCTIVITY RELATED TO DRILLING MUDS: UMIAT FIELD, NAVAL PETROLEUM RESERVE NO. 4, ALASKA[1]

by

George L. Gates[2] and W. Hodge Caraway[2]

INTRODUCTION AND SUMMARY

This report presents an evaluation by the Federal Bureau of Mines of the effect of clay-water, brine, and oil-base drilling fluids on the productivity of test wells drilled on the Umiat anticline in U.S. Naval Petroleum Reserve No. 4 in northern Alaska. Eleven wells were drilled on the Umiat structure as part of the U.S. Navy's extensive exploration of the Reserve during 1944-53 to determine the possibilities for oil production. The Federal Geological Survey cooperated in the exploration program and has published a comprehensive report[3] on the geology of the area and case histories of the wells. The report also includes the results of special studies by the Bureau in connection with the drilling and coring of well 9 with oil-base mud in the hole and was the source of much of the information used in preparing this publication.

Of the eleven wells, four were drilled with rotary tools and water-base mud (one of the water-base muds was an oil-in-water emulsion mud), five were drilled with cable tools with brine in the hole, one was drilled with cable tools with brine in the hole and later reamed with rotary tools and crude oil, and one was drilled with rotary tools and oil-base mud. Although all of the wells penetrated sandstones that contained oil and gas, some were productive and others were not. The latter two wells, one completed with crude oil in the hole (with some added brine) and the other with oil-base mud, had the greatest productive capacities. The wells drilled with cable tools and brine in the hole had lower productive capacities. In contrast, two of three wells completed with rotary methods and fresh-water drilling mud and the well completed with rotary and emulsion mud were unproductive.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to members of the Alaska Branch of the Federal Geological Survey, headed by George O. Gates, who supplied helpful information used in preparing this report.

1/ Work on manuscript completed November 1959.

2/ Petroleum engineer, Bureau of Mines, San Francisco, Calif.

3/ Collins, Florence Rucker, Bergquist, Harlan R., Brewer, Max C., and Gates, George L., Test Wells, Umiat Area, Alaska: Geol. Survey Prof. Paper 305-B, 1958, pp. 71-206.

GENERAL DESCRIPTION OF THE AREA

The Umiat area (fig. 1) is in the southeastern part of the Reserve on the Arctic slope. The arctic slope is bounded on the south by the crest of the Brooks Range and on the north by the Arctic Ocean. The Brooks Range, the Alaskan counterpart of the Rocky Mountains, comprises several groups of rugged, glaciated mountains having a relief of 3,000 to 6,000 feet and maximum altitudes of 3,600 to 9,200 feet. Anaktuvuk Pass (2,200 feet) is the highest elevation on the land route between Fairbanks and the Arctic plain.

The Arctic coastal plain is characterized by abundant lakes, swampy areas, wet tundra, meandering streams and--during the summer--hordes of hungry mosquitoes. Local relief rarely exceeds 100 feet; however, the surface of the Umiat anticline is marked by a maximum relief of about 500 feet.

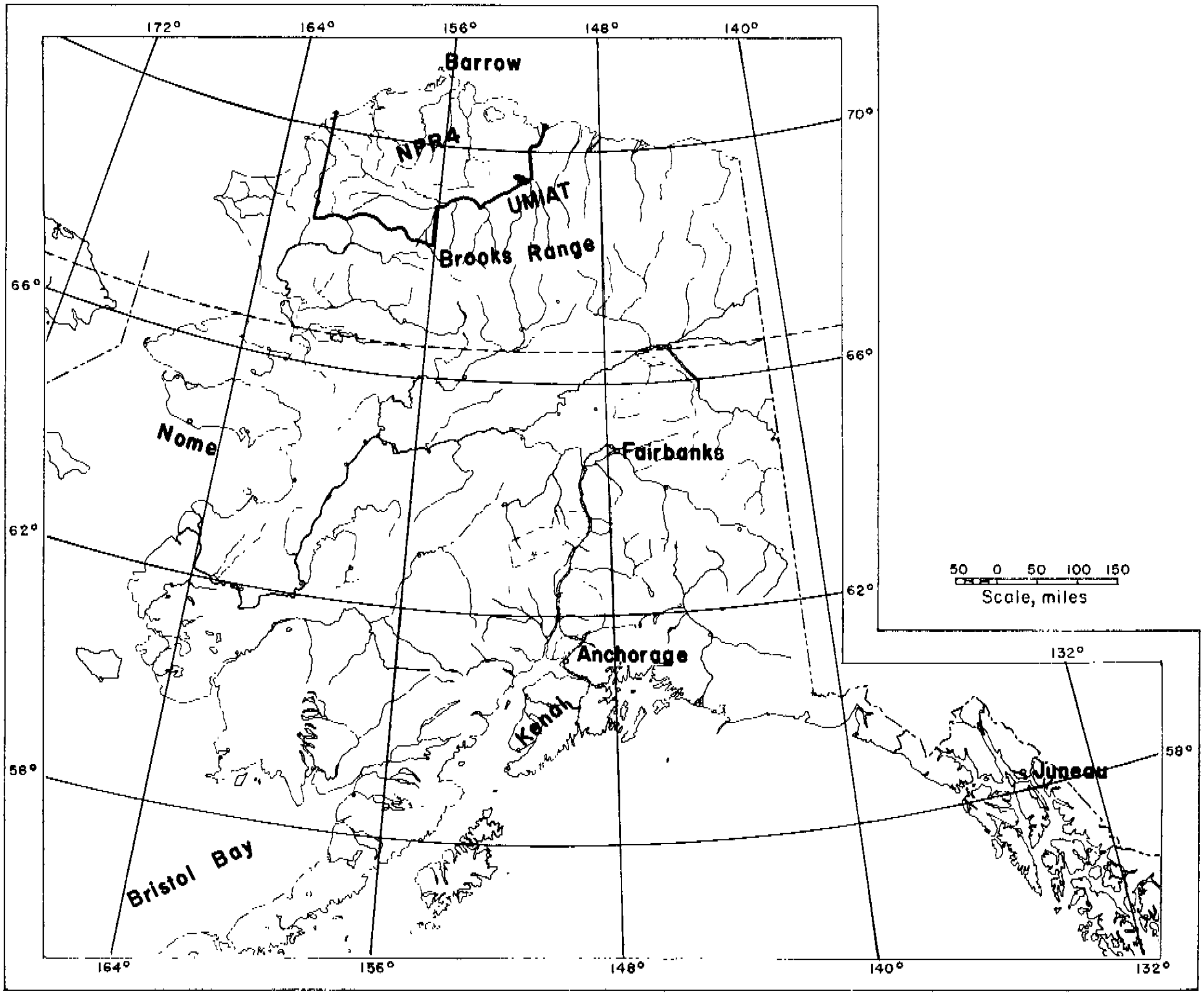

FIGURE 1. - Umiat Field and Naval Petroleum Reserve No. 4 in Northern Alaska.
(Adapted From Federal Geological Survey Outline Map.)

The Umiat anticline is about 150 miles southeast of Point Barrow (fig. 1). The anticline is about 10 miles long, 3 miles wide; the axis trends east and west and the structure has more than 800 feet of closure. It is the highest part in a structural trend extending many miles beyond the limits of the closed anticline and its limits were defined by field and photogeologic mapping. Seismic data on the region are also available.

The oil-productive sand in this area is the Grandstand formation of Cretaceous age. Most of this formation is within the designated zone of continuous permafrost. It is not known that all of the producing formation is colder than the freezing temperature of the interstitial brine. Nearly water-free oil, produced from this sandstone, indicates that the interstitial water is virtually immobile.

Climate

The climate on the Arctic slope is cloudy, cold, and sometimes windy. The annual mean temperature is 10.8° F. at Umiat. The maximum recorded temperature at Umiat is 79° F. and the minimum is -57° F. At Barrow the warmest month, July, has an average of 13 days with freezing temperatures. Mean annual precipitation is 5.4 inches at Umiat. Half of the precipitation is derived from rainfall during July, August, and September. Annual snowfall is about 33 inches at Umiat. Low temperatures, high humidities, and cloudy skies minimize the rate of evaporation and tend to conserve the small total precipitation for surface and ground-water supplies. In contrast to northern Alaska precipitation, the average annual precipitation in southeastern Alaska is about 100 inches.

Length of Day

At the Arctic Circle on the shortest day of the year the sun touches the southern horizon at noon, then drops from sight. Below the Arctic Circle the sun rises a correspondingly longer time, but farther north it stays below the rim of the horizon on this day. For instance, on December 21 at Fairbanks, about 2.5 degrees south of the circle the sun rises at 9:58 a.m. and sets at 1:40 p.m. At Barrow, about 4 degrees north of the circle, the sun is not seen from late November until late January. In summer the length of the days is the reverse of the winter.

Vegetation

The Arctic slope lies beyond the northern limit of the spruce. Small willows and scattered alders grow along the channels of some of the streams in the southern part of the region. Tundra consisting primarily of dwarf shrubs, grasses, sedges, lichens, and herbaceous plants cover a large part of the other areas.

Permafrost

One of the important characteristics of the region to be considered in drilling and producing operations is the permafrost. This area of subground-level ice is discussed in detail by Hopkins, Karlstrom, and others.4/

Permafrost has been defined by Muller5/ as "a thickness of soil or other surficial deposit or even of bedrock, at a variable depth beneath the surface of the earth in which a temperature below freezing has existed continuously for a long time (from two to tens of thousands of years)."

The four permafrost zones in Alaska (fig. 2) are not rigidly defined and their boundaries are arbitrarily drawn. The ground is perennially frozen nearly everywhere in the continuous-permafrost zone; unfrozen ground is found only at a few widely scattered sites. As shown in figure 2, the Umiat area is entirely within the continuous-permafrost zone. Perennially frozen ground is less widely distributed in the discontinuous-permafrost zone, and areas of unfrozen ground predominate in the southern part. In the sporadic-permafrost zone perennially frozen ground is confined to isolated sites where vegetation, topography, soil, and drainage permit its continued existence or its formation. Permafrost also is encountered locally in the no-permafrost zone, but it is so rare that it has little influence on the landscape or human activities.

Permafrost is affected locally by subsurface drainage and surface insulation. In the rigorous climate of northern Alaska local differences in these conditions generally result only in differences in the depth to permafrost. Permafrost is affected by lakes, ponds, and streams which have appreciable heat capacity.

Permafrost is present nearly everywhere beneath the Arctic slope of Alaska. Frozen ground generally extends to a depth of about 1,000 feet in this area. The permafrost lies at considerable depth or may be absent under major rivers, such as the Colville, which flows throughout the winter and has flood plains several thousand feet wide. Permafrost also lies at considerable depth or is absent beneath most lakes deeper than 8 feet and wider than 2,000 feet.

Geothermal Gradients

The geothermal profile or depth-temperature relation in well 6 is shown in figure 3. This survey was made by the Federal Geological Survey by placing thermistor cables in the bore for a period of about one year (10 months) after completion and abandonment of the hole.

4/ Hopkins, David M., Karlstrom, N. V., and others, Permafrost and Ground Water in Alaska: Geol. Survey Prof. Paper 264-F, 1955, pp. 113-146.

5/ Muller, S. W., Permafrost or Permanently Frozen Ground and Related Engineering Problems: J. W. Edwards, Inc., 1947, 231 pp.

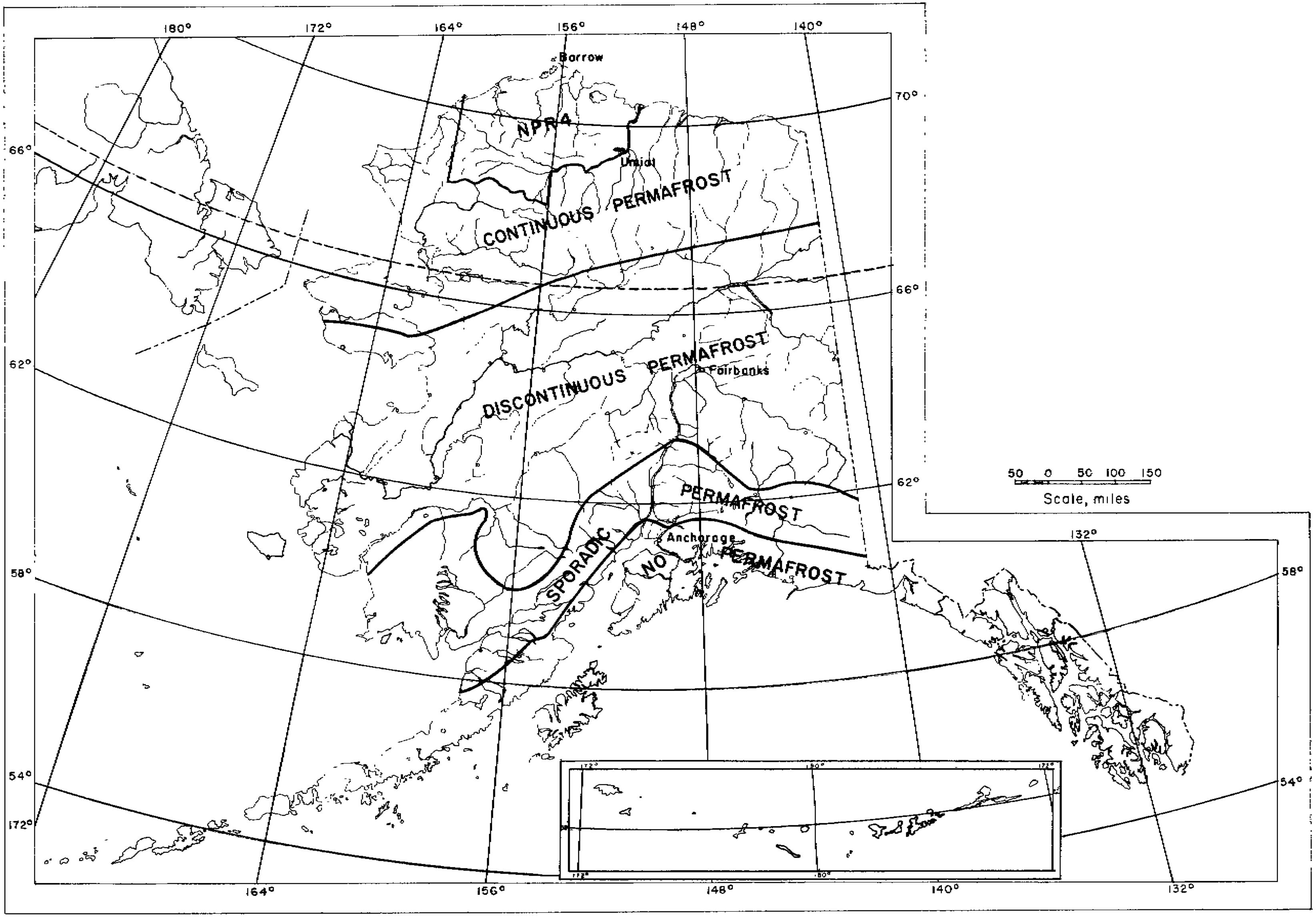

FIGURE 2. - Permafrost Zones in Alaska, Showing Location of Naval Petroleum Reserve No. 4 and Umiat Field.

(Adapted From Federal Geological Survey Prof. Paper 264-F.)

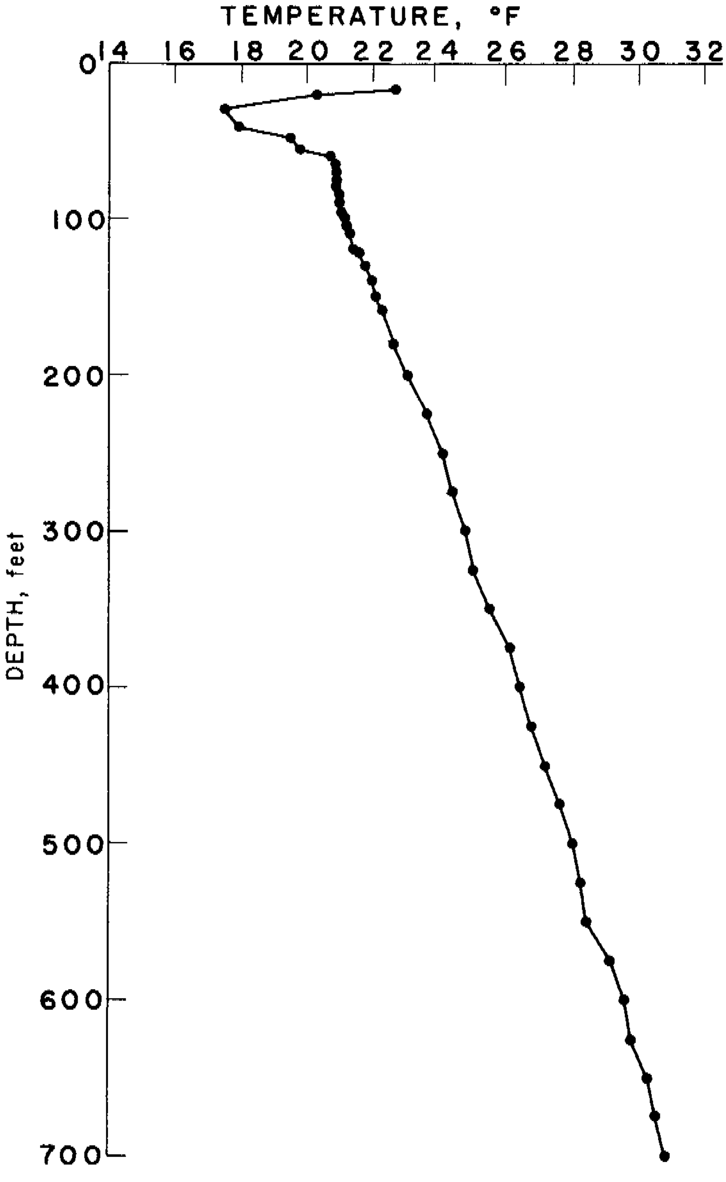

FIGURE 3. - Temperature-Depth Relation in Permafrost Zone of Well 6 (data from Geol. Survey).

The geothermal gradient in well 9 shows an increase of 1° C. per 135 feet (1.33° F. per 100 feet) of depth from approximately 100 to 870 feet. This is the largest gradient found in the Umiat area. The geothermal gradient at wells 4 and 6 is approximately 115 feet per degree Centigrade (1.56° F. per 100 feet) for similar depths.

A short extrapolation of the thermal profile in well 9 on Oct. 13, 1953 indicated a depth of permafrost of 1,055 feet. This thickness of permafrost is approximately 150 feet greater than that found at any of the other Umiat wells where temperature measurements have been made.

A Schlumberger temperature survey was run in well 2 when the final electrical log was run. The lowest recorded temperature was 40.5° F. at 260 feet. Above that depth the temperature was about 42° F. It fluctuated slightly around 43° F. between 310 and 525 feet and increased gradually with depth to 104° F. at 6,198 feet. These well temperatures are higher than the undisturbed temperatures found in a temperature study in a well drilled near Barrow, Alaska.[6] The warming of the formations is the result of friction developed in the drilling operation and the circulation of relatively warm mud during drilling.

The method used to obtain the temperatures has been described by Brewer.[7]

6/ Lachenbruch, Arthur H., Brewer, Max C., Dissipation of the Temperature Effect of Drilling as Well in Arctic Alaska: Federal Geological Survey Bull. 1083-C, 1959, 109 pp.

7/ Brewer, Max C., Some Results of Geothermal Investigations of Permafrost in Northern Alaska: Trans. American Geophysical Union, vol. 39, No. 1, Feb. 1958, pp. 19-26.

The first U.S.S.R. oil deposits in permafrost were found in Nordvik, Siberia, where the permafrost was 540 meters (1,770 feet) deep and the rock temperature was -12.7° C. (+9.2° F.) at a depth of 56-60 meters (184-197 feet).8/

Transportation

Development of this area is greatly dependent on air travel. Point Barrow has a hard-surfaced airstrip and Umiat has a gravel airstrip. Lakes suitable for float planes are not abundant, however, a few such lakes are in the area. Ships can reach Point Barrow about three months of the year.

Tracked vehicles such as weasels are suitable for use in this region. In the winter sleds pulled by tractors on tracks are well suited for hauling equipment in the Arctic Coastal plain and the Arctic foothills when the ground is covered with snow.

DRILLING AND COMPLETION DATA ON TEST WELLS

The eleven wells drilled are considered in groups to point out important differences in drilling and completion practices that could have affected the productivity of the wells. A map of the well locations is shown in figure 4.

Water-Base Mud Completions--Wells 1, 2 and 3

The first and least productive group, comprising wells 1, 2, and 3, were drilled with rotary tools using water-base drilling mud. Well 1 was drilled about 5 miles west of 2 and 3, and oil-bearing formations were logged in each well. Formation tests were made either by bailing or running a packer on 2-1/2-inch tubing and swabbing. Wells 1 and 2 were dry and well 3 produced oil at a rate of about 24 barrels per day.

Evidence of the presence of petroleum in formations penetrated by these three holes was observed during drilling. Additional evidence of oil and gas in well 2 was obtained when the hole was being prepared for a temperature survey after it had been drilled to 6,212 feet. The Grandstand formation was found between 365 and 1,060 feet in this hole. Preparatory to the temperature survey, well 2 was bailed to 950 feet. When the blowout preventers were removed a small gas flow was noted. In preparation for a gas-flow test the hole was found to contain liquid at 730 feet. The hole was bailed to 1,075 feet and the gas flow, as measured by means of a Pitot tube and a water manometer, was estimated at 15,000 cubic feet per day. The gas contained 82 percent methane, 16 percent heavier hydrocarbons, and 1.7 percent carbon dioxide. Natural gas containing such a large quantity (16 percent) of hydrocarbons heavier than methane generally is associated with crude oil in the formation.

8/ Lappo, V. I. (Petroleum Occurrence in Nordvik (ĪURUNG-TUMUS): Neftīanoe mestorozhdenie Nordvik (Īurung-Tumus): Nedra Arktiki, vol. 1, 1946, pp. 74-129.

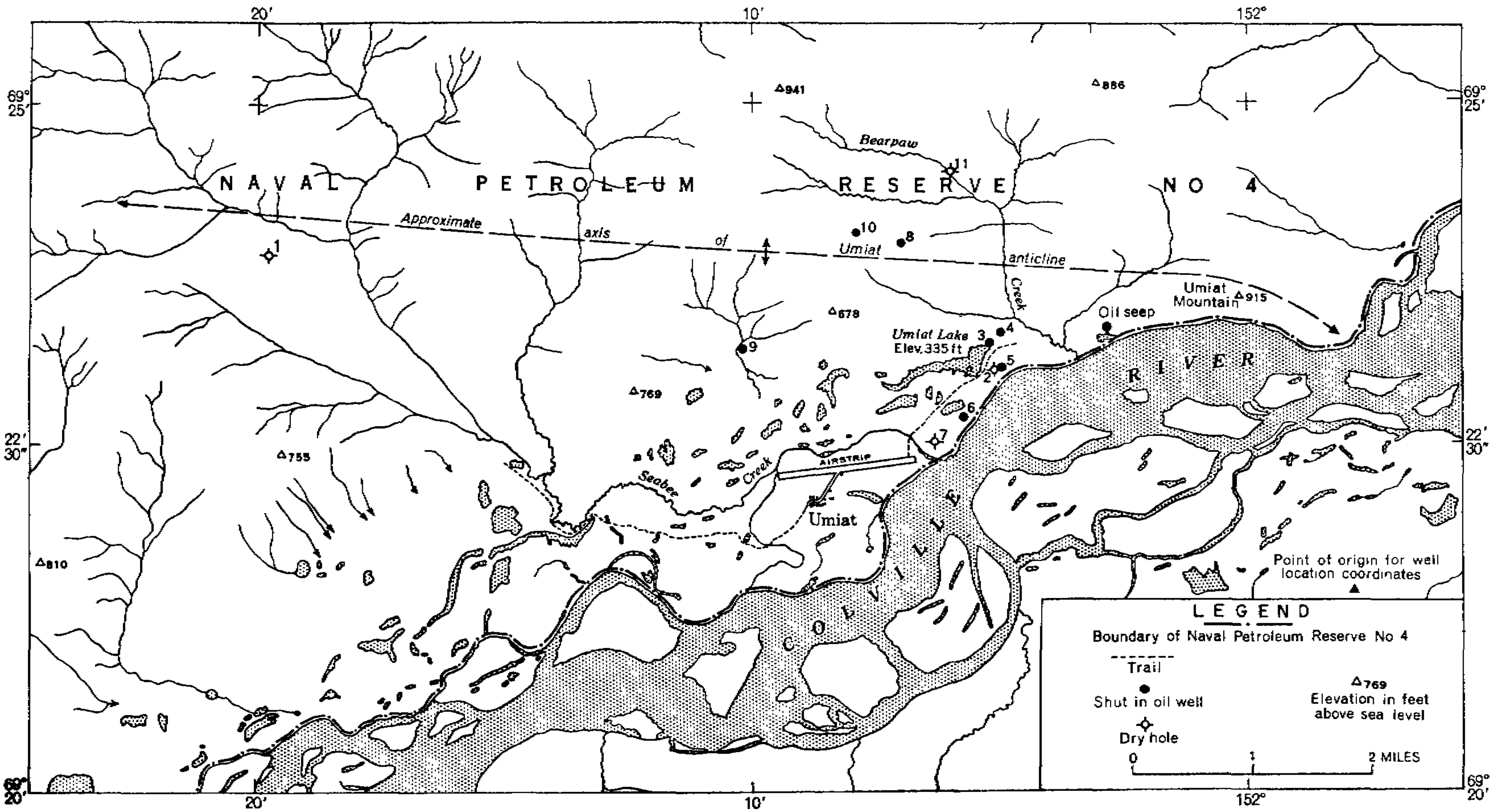

FIGURE 4. - Well Location Map, Umiat Field, Alaska.
(Adapted From Geol. Survey Prof. Paper 305-B, Test Wells, Umiat Area, Alaska.)

Well 2 is of particular interest because of its proximity to well 5 which had good productivity. This relationship is discussed in detail later in this report.

Description of Reservoir Rocks

A study[9/] of thin sections from cores from these wells showed that the fine Graywacke sandstone was not well sorted and that it was composed primarily of angular quartz grains. Authigenic illite was present, surrounding and partly replacing some quartz grains as coatings or elongate masses. An X-ray diffraction pattern of the material through 325-mesh sieve showed that it was composed of quartz and illite with small amounts of montmorillonite, albite, kaolinite, and chlorite. The pore space was lined with a thin coating of clay minerals, mostly illites.

Drilling Mud

The drilling mud used in wells 1, 2, and 3 was a water-base mud containing Wyoming bentonite, to which only a little lost circulation material and chemicals were added to control cement contamination. The density of the mud ranged from about 72 to 85 pounds per cubic foot. The API funnel viscosity ranged from about 33 to 40 seconds. The API filtrate volume ranged from about 17 to 7.0 milliliters.

Cable-Tool Completions--Wells 4, 6, 8, and 10

Several wells were drilled with cable tools after the first three holes drilled with rotary tools and water-base mud were unproductive (although oil and gas shows were observed). A sodium chloride brine was used to minimize the invasion of water into the formation and possible swelling of the clay minerals observed in the oil-bearing sandstones. Sloughing was common in drilling these holes and it retarded drilling. Good showings of oil and gas were observed in this group of wells and the average oil productivity was about 78 barrels per well per day. Most of the production testing was done by bailing which would result in lower than normal productivity when compared with testing by pumping.

Drilling Mud

The brine drilling muds were prepared by adding about 35 pounds of sodium chloride to each barrel of water. This lowered the freezing temperature of the solution below that of the minimum permafrost. The objective was to prevent freezing of the brine filtrate in the cold petroleum reservoir rocks and to minimize the swelling of clay minerals.

Well 7

Well 7 was drilled with cable tools and brine drilling mud. Sandstones containing oil and gas were penetrated and considerable water was produced in

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9/ Work cited in footnote 3, p. 1.

the bailing tests. Small quantities of oil and gas were recovered by bailing. Based on the meager information available, some investigators believed this well to be below the edgewater in this reservoir.

Emulsion Mud Completion--Well 11

Well 11 was drilled to test the production possibilities of the sandstones of the Grandstand formation on the northern downthrow side of a fault that parallels the axis of the structure. The hole was drilled with rotary tools using an oil-in-water emulsion mud which had a water filtrate. Oil and gas shows were noted in the permeable sandstones penetrated, but no commercial production was indicated in eleven formation tests.

Drilling Mud

The drilling mud had an API filgrate volume of about 2.0 milliliter (ml), an API funnel viscosity of about 100 seconds, a weight density of about 85 pounds per cubic foot, and about 30 percent (by volume) of Umiat crude oil which had the fractions boiling below 325° F. removed.

Cable-Tool Completion Followed by Wall Scraping Using Crude Oil--Well 5

Well 5, 175 feet east and 97 feet north of well 2, was drilled with cable tools using 5-7/8-inch bits and brine drilling water. Bailing tests showed the presence of oil and gas. When the depth reached 615 feet a pump was installed to test the productive capacity of the well. In a test that lasted 15 days production averaged about 70 barrels of clean oil per day. Drilling with cable tools was continued to 1,075 feet, using a brine containing 40 to 50 pounds of sodium chloride per barrel of water.

Tubing was run for a swabbing test. A packer set at 630 feet was used to shut off liquids from sands that had been tested at a depth of 615 feet. After the drilling water was swabbed from the hole, oil flowed at the rate of 10 to 16 barrels per hour for short periods. Flow stopped several times; apparently resulting from restricted flow into the well bore or from the formation of ice in the tubing at shallow depths. The tubing was pulled, the rig removed in September 1950, and the well was shut in for the winter.

In April 1951 a rotary rig was moved in place. The hole was cleaned out and reamed in an effort to stimulate production. Circulation was lost and some brine was added to the crude-oil drilling fluid to restore circulation. The hole was reamed to 9-1/2 and 10-1/4 inches in the sandstone sections penetrated by the bit.

During alternate reaming and swabbing tests from May 21 to June 17 the first liquids recovered were brine and crude oil used for circulation while reaming. In the last part of the reaming operation, fresh crude oil was swabbed from the hole at an estimated rate of 400 barrels per day. One of the first samples of oil recovered contained 4.7 percent water and 0.1 percent sediment.

A pump with an electrical heater attached to the bottom of the tubing was set at 1,055 feet. In a 93-day pumping test the maximum production rate was about 400 barrels per day. However, the pump was too small to test the full productive capacity of the well. The water content of the 35.5° API gravity oil decreased from 1.35 to 0.4 percent. The temperature of the oil in the flow line ranged from 27° to 28° F.

Oil-Base Mud Completion--Well 9

Well 9, about two miles west of well 2, was drilled with a rotary rig. Core analyses indicated that this well penetrated a sandstone with appreciable porosity, permeability, and oil content.

Drilling Mud

Water-base mud was used to 209 feet. Below 209 feet to 1,257 feet, an oil-base mud was used to prevent the infiltration of water from a water-base mud into the formations penetrated and to provide cores uncontaminated by water from the mud. The mud contained a chemical tracer that was soluble in oil, insoluble in water, and unaffected by bacteria, to determine the volume of oil filtrate that entered the cores. The tracer was an organic chloride compound containing about 54 percent chlorine by weight. The method for following the volume of tracer-bearing filtrate has been described in detail.[10]

The oil-base mud was composed of diesel oil, a low-gravity crude oil from Fish Creek test well 1, Ken-Oil concentrate, and some unslaked lime. Addition of the concentrate and/or the heavy crude oil increased the viscosity of the mud, whereas, addition of diesel oil decreased viscosity. Gel strength was increased by adding the concentrate and lime, which also decreased the filter rate. The mud weight was kept low to minimize the flow of drilling mud filtrate into the formations. To keep the weight low, it was necessary to reduce the viscosity to less than 50 seconds API funnel viscosity at about 45° F. Cuttings would not drop from suspension otherwise, as no vibrating screen was available during drilling.

The properties of the drilling mud are listed in table 1.

Swabbing and Pumping Tests

Three formation tests in both the upper and lower sandstone sections in the Grandstand formation were made by swabbing through 2-1/2-inch tubing for about 4 hours. A cone packer set above different sections of the formation was used but no oil was produced. The Grandstand formation was found in this hole between 425 and 1,090 feet. The first swabbing test was made with the hole open from 476 to 533 feet. The second swabbing test was made with the hole open from 866 to 901 feet. The third test was made with the hole open from 959 to 1,017 feet.

10/ Gates, George L., Morris, Frank C., and Caraway, W. Hodge, Effect of Oil-Base Drilling Fluid Filtrate on Analysis of Cores From South Coles Levee, Calif., and Rangely, Colo., Fields: Bureau of Mines Rept. of Investigations 4716, 1950, 25 pp.

TABLE 1. - Properties of oil-base drilling mud used in Umiat well 9

Core No.	Core interval, feet	Drilling fluid: Filtrate volume, mg./30 min. 45° F.	Drilling fluid: Filtrate volume, mg./30 min. 75° F.	Drilling fluid: Weight density lb./gal.	Drilling fluid: Weight density lb./ft.^{3}	Drilling fluid: Water content Weight-percent	Drilling fluid: Water content Volume-percent	Drilling fluid: API funnel viscosity, (1 quart out) Time, seconds	Drilling fluid: API funnel viscosity, (1 quart out) Temperature, °F.	Drilling fluid filtrate: Water content, weight-percent	Drilling fluid filtrate: Tracer concentration, mg./ml.
	374-384	0	-	8.6	64.5	10.95	11.34	95	61	-	-
4	413-423	0	9	8.8	66.0	8.85	9.38	79	50	-	14.2
9	464-474	1.3	12	9.0	67.0	9.08	9.77	83	48	1.05	14.7
10	474-484	1.1	10	9.1	68.0	9.07	9.90	85	45	1.07	14.3
11	484-494	1.1	10	9.2	69.0	8.76	9.70	95	46	0.33	14.3
15	502-512	1.1	12	9.4	70.0	8.59	9.65	90	44	0.82	14.1
23	573-583	5.2	16	9.8	73.0	6.92	8.11	72	45	0.16	10.4
38	858-868	20.0	29	10.2	76.0	3.65	4.45	76	48	0	4.5
39	868-878	20.0	30	10.3	77.0	3.57	4.41	69	47	1/	18.5
40	878-888	20.0	27	10.3	77.0	3.64	4.50	69	47	do.	17.7
41	888-898	20.0	34	10.4	78.0	3.71	4.64	69	46	do.	21.7
42	898-901	20.0	33	10.4	78.0	3.72	4.65	69	46	do.	17.5
43	901-911	21.0	36	10.3	77.0	4.03	4.98	59	45	do.	15.6
48	949-959	21.0	38	10.4	77.5	4.02	5.00	60	46	do.	15.3
49	959-969	21.0	42	10.4	77.5	4.29	5.37	60	46	do.	14.6
50	969-979	6.4	12	10.4	78.0	4.33	5.42	59.5	46	do.	13.8
52	989.5-1,000	7.9	14	10.5	78.5	4.54	5.72	57.0	46	do.	13.4
53	1,000-1,010	7.9	10	10.5	78.5	4.67	5.88	57.0	46	do.	12.8
54	1,010-1,017	-	13	10.4	78.0	4.41	5.52	57.0	46	0	13.2
57	1,037-1,047	3.4	7	10.2	76.5	5.01	6.15	53.0	41	-	10.6
58	1,047-1,057	2.2	-	-	72.0	-	-	52.0	42	-	-
59	1,057-1,067	3.0	-	-	72.0	-	-	46.0	42	-	-
61	1,077-1,086	1.9	-	-	59.5	-	-	42.0	45	-	-
62	1,086-1,096	4.1	-	-	59.5	-	-	44.0	42	-	-
67	1,137-1,147	2.0	-	-	60.5	-	-	48.0	40	-	-

1/ The drilling-fluid filtrates from drilling fluid samples 39, 40, 42, 43, 48, and 49 were combined, and the water content of the combined samples was negligible.

After the third formation test, the hole was reamed with 7-7/8-inch bits to total depth of 1,257 feet. Two-inch tubing was run to 1,247 feet and the oil-base mud was swabbed from the hole and pumped into storage tanks. Shortly before all of the mud was swabbed from the hole, crude oil flowed into the hole. After twelve hours of swabbing no trace of oil-base mud was detected in the produced oil. Two hundred barrels of crude oil were swabbed in 15 hours. When swabbing was stopped, for lack of storage space, the liquid level rose to 50 feet from the surface. A subsequent pumping test of 6-1/2 weeks indicated a maximum productivity of approximately 300 barrels per day of clean oil.

Following the pumping test the well was plugged back, in stages, to 400 feet from the surface in an effort to determine the source of the oil. This procedure was partly successful in disclosing the productive sands. The cement plug was then drilled out to 1,077 feet using reverse circulation with oil as the drilling liquid. From that depth to bottom, 1,257 feet, brine containing 40 pounds of salt per barrel of water was used in drilling out the cement. Circulation was lost several times and cleaning the hole was difficult.

A string of 5-1/2-inch casing was cemented at 1,257 feet, total depth. The pipe was perforated repeatedly opposite the permeable sandstones but no oil entered the hole, even after swabbing, for periods longer than a week. The pore space around the well bore was blocked to the flow of crude oil and apparently the blocked area could not be penetrated by gun perforating.

Effect of Water on Permeability of Core Samples From Well 9

A series of tests was made to study the effect of water on the permeability of cores from the Grandstand formation. The effect of invasion of the sandstone by water from a fresh-water drilling mud was simulated. In this series of tests at room temperature one sample from each of four cores was selected. The cores had been sealed in cans at the well. The four selected samples containing the interstitial water and oil, present in the cores when they came from the core barrel, were mounted in low-temperature-setting plastic inert to both water and kerosine. The permeability of these four samples to kerosine was measured without cleaning the samples. The initial water and oil contents were not changed except that the crude oil was displaced by kerosine. The same unextracted core samples were then used in determining the permeability to fresh water. Note in table 2 that only one of the samples had measurable permeability to water. However, a small volume of water entered the three samples that were impermeable to the water. The samples were left in water overnight. Entrance of water into the core samples is analogous to exposure of the wall of the bore hole to fresh water from drilling mud during completion of the well. Following the contact of the cores with water, the permeability to kerosine was determined again and oil was flowed through the samples for several hours, apparently flushing part of the invasion water from the core sample. The results are shown graphically in figure 5 and are listed in table 2.

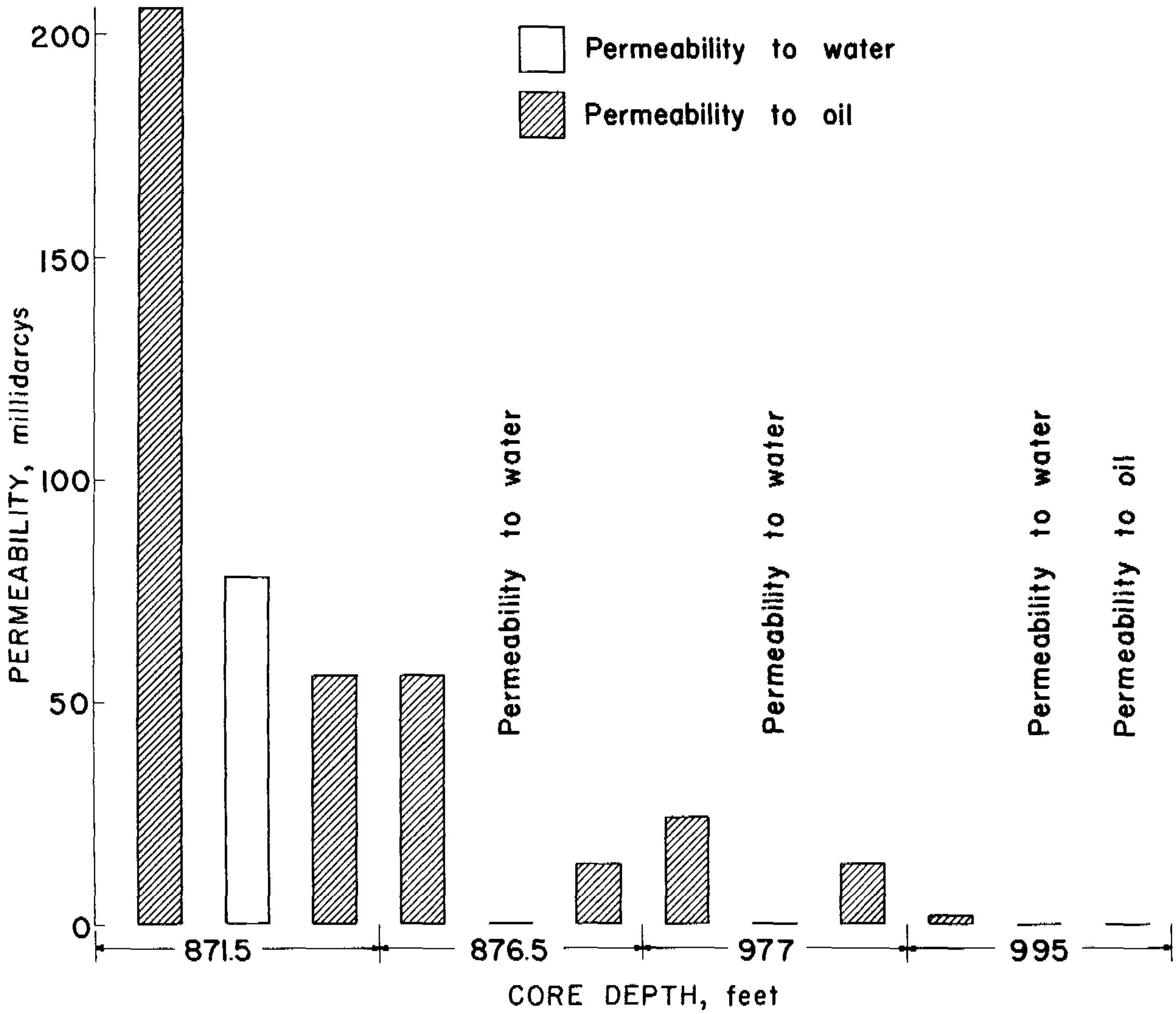

FIGURE 5. - Permeability of Core Samples to Oil and Water.

The observed reduction in permeability to oil after water invaded the core sample is believed to be, primarily, the result of the relative permeability changes.

When water entered the pore space the permeability to oil was reduced. Apparently when oil was flowed through the core some of the invasion water remained in the pore space. The core samples were left in water overnight so that the clays in the sandstone would have ample time to become fully hydrated. Overnight may not have been long enough for complete hydration because some clays required several days to reach equilibrium. In evaluation of drilling-mud clays the American Petroleum Institute Recommended Practice 29, May 1957, the minimum time for hydration of bentonite is 72 hours.

TABLE 2. - Permeability of well 9 core samples to oil and water

	Sample from--feet,			
	871.5	876.5	977	995
Permeability before soaking, md.				
Oil (water phase remained immobile)...........	206.0	56.5	24.0	2.1
Water (oil phase remained immobile)...........	78.1	.0	.0	.0
Oil permeability after soaking overnight in water, md.				
Immediately after removal.....................	31.4	-	-	-
30 minutes after beginning test...............	37.9	-	10.8	-
1 hour after beginning test...................	-	8.9	-	-
2 hours after beginning test..................	-	-	-	0.3
2-1/4 hours after beginning test..............	-	13.4	-	-
3 hours after beginning test..................	-	-	13.4	-
4-1/2 hours after beginning test..............	56.6	-	-	-
6 hours after beginning test..................	-	-	-	.6

Six samples having a range of permeabilities were selected to determine the relative effects of air, oil, salt water, and fresh water on the permeability of extracted cores. The samples were cleaned by extraction with toluene to remove the water and oil simultaneously. The permeability to dry air was measured, cores were saturated with oil, and the oil permeability was determined. As shown in table 3 the two values were nearly the same. The core samples were cleaned of oil by toluene extraction again and then saturated with 0.5 N sodium chloride solution. The permeability to this solution was found to be less than the previously determined values. Finally the permeability to distilled water was measured and found to be less than any of the previous permeabilities. This change in permeability indicates that the fresh water entered the cores to lower the permeability as shown in figure 5. Similar reduction in permeability of Umiat cores was found by Yuster[11/] and Baptist.[12/] This permeability reduction is independent of reduction that may have been caused by freezing of fresh-water filtrate in the pore channels.

When the formation tests in well 9 indicated no producible crude oil although the cores contained crude oil and gas, a study was made to determine the effect of the low formation temperature on the filtrate from the oil-base mud. A sample of filtrate from the mud was blended with crude oil and placed in the camp refrigerator for several days. The refrigerator was maintained at 8° F., which is 10° F. below the lowest permafrost temperature measured in this hole. Neither the filtrate nor the blends of filtrate with crude oil gelled at this temperature, indicating that filtrate from the oil-base mud was not blocking the pore channels of the formation by the formation of a gel.

11/ Yuster, S. T., Oil and Gas Investigations Map OM 126 (in 3 sheets) sheet 2: Geol. Survey, 1951.

12/ Baptist, O. C., Oil Production From Frozen Reservoir Rocks, Umiat, Alaska: Jour. Petrol. Technol., vol. 11, No. 11, Nov. 1959, pp. 85-88.

TABLE 3. - Permeability of selected Umiat 9 cores to air, salt water, and fresh water

Depth (feet)	Permeability in millidarcys to--			
	Dry air	Oil	0.5 normal sodium chloride solution[1/]	Distilled water
866-867	22	18	15	13
867-868	31	34	32	30
873-874	270	260	250	200
875-876	150	160	140	120
880-881	140	150	130	100
907-908	54	54	35	26

1/ Samples were extracted and dried before permeability to salt water was determined.

Volume of Drilling Mud Filtrate in Cores From Well 9

A tracer was added to the drilling mud to obtain a quantitative measure of the volume of filtrate from the oil-base drilling mud that entered the pore space of the cores. This tracer was soluble in oil, insoluble in water, and not affected by bacteria. Analysis of the oil extracted from the cores was made by a chemical method that has been described previously.[13/] The results indicated that about 3 percent of the pore space in the permeable sections contained filtrate from the oil-base mud.

DISCUSSION OF RESULTS

Drilling and production data for the eleven test wells in the Umiat field are summarized in table 4 and shown in figure 6. The results indicate that the use of clay-water and clay-brine completion fluids damaged the productivity of some of the wells. This damage was a result of reduction in permeability of the sand at the well bore by the invasion of filtrates from the drilling fluids.

The two best wells in the field were completed with oil-base mud. These wells were approximately two miles apart. Four wells completed with brine mud (using cable tools) had a productivity of about 78 barrels of oil per day. In contrast, three wells drilled with water-base mud also penetrated oil-bearing (not necessarily oil-productive) sandstones, but none was completed as producers.

Information on the wells drilled indicates that all of the wells penetrated oil-bearing sandstones and the correlation between the type of drilling fluid used and the well productivity has been shown. However, any study of well completion practices is difficult because generally a well can be completed only once and the productivity attainable by any other method is a

13/ Gates, George L., Morris, Frank C., and Caraway, W. Hodge, Effect of Oil-Base Drilling Fluid Filtrate on Analysis of Cores From South Coles Levee, Calif., and Rangely, Colo., Fields: Bureau of Mines Rept. of Investigations 4716, 1950, 25 pp.

conjecture. It should be noted that wells 1 and 11 are located an appreciable distance from the producing wells. The lack of production from these holes may be due to lack of sufficient permeability of the reservoir rock. Also, lack of production from the other holes may be complicated by the lack of permeability. However, observed damage to wells 5 and 9 could not be the result of these factors.

TABLE 4. - Drilling and production data, Umiat field, Alaska, 1944-53

Well No.	Drilling method	Drilling mud	Production rate, barrels per day	Production test method	Length of test, days	Total depth, feet
1	Rotary..	Clay-water..	0	Formation..	<1	6,005
2	..do....	....do......	Trace	....do.....	<1	6,212
3	..do....	....do......	24	Pumping....	14 approx.	572
4	Cable...	Brine.......	100	....do.....	18	840
6	..do....	....do......	80 (wet)	....do.....	1 approx.	825
7	..do....	....do......	<1	Bailing....	1 approx.	1,384
8	..do....	....do......	60	Pumping....	14	1,327
10	..do....	....do......	70	Bailing....	1	1,573
5	..do....	Brine....... Reamed, oil.	400+	Pumping....	93	1,077
9	Rotary..	Oil-base....	300+	....do.....	45	1,257
11	..do....	Oil-in-water emulsion	0	Formation..	1	3,303

Comparison of Wells 2 and 5

Comparison of the productivity of wells 2 and 5 indicates that damage results from completion practice in which water from the drilling fluid invades the reservoir formation. Well 2, completed with clay-water mud, was a dry hole and well 5, which was about 200 feet from well 2, was completed first with brine. Both holes penetrated oil-bearing sandstone with appreciable permeability. Well 5 then was reamed with oil as the drilling mud and a sustained production test indicated productivity to 400 barrels per day.

The brine drilling mud used in these holes had a freezing point below the formation temperature, therefore, the filtrate from these drilling muds reasonably would not be expected to be in the state of ice.

Study of the electrical log[14] of well 2 indicated that the Grandstand formation might have been expected to be productive. The spontaneous potential and resistivity curves indicated that this formation might be expected to contain oil. However, very little oil was produced from this hole which was completed with water-base mud. Well 5, about 200 feet from well 2, was completed in this formation with oil-base mud and the productive rate was about 400 barrels per day.

14/ Collins, Florence Rucker, With Bergquist, Harlan R., Brewer, Max C., and Gates, George L., Test Wells Umiat Area, Alaska: Geol. Survey Prof. Paper 305-B, 1958, Pl. 11.

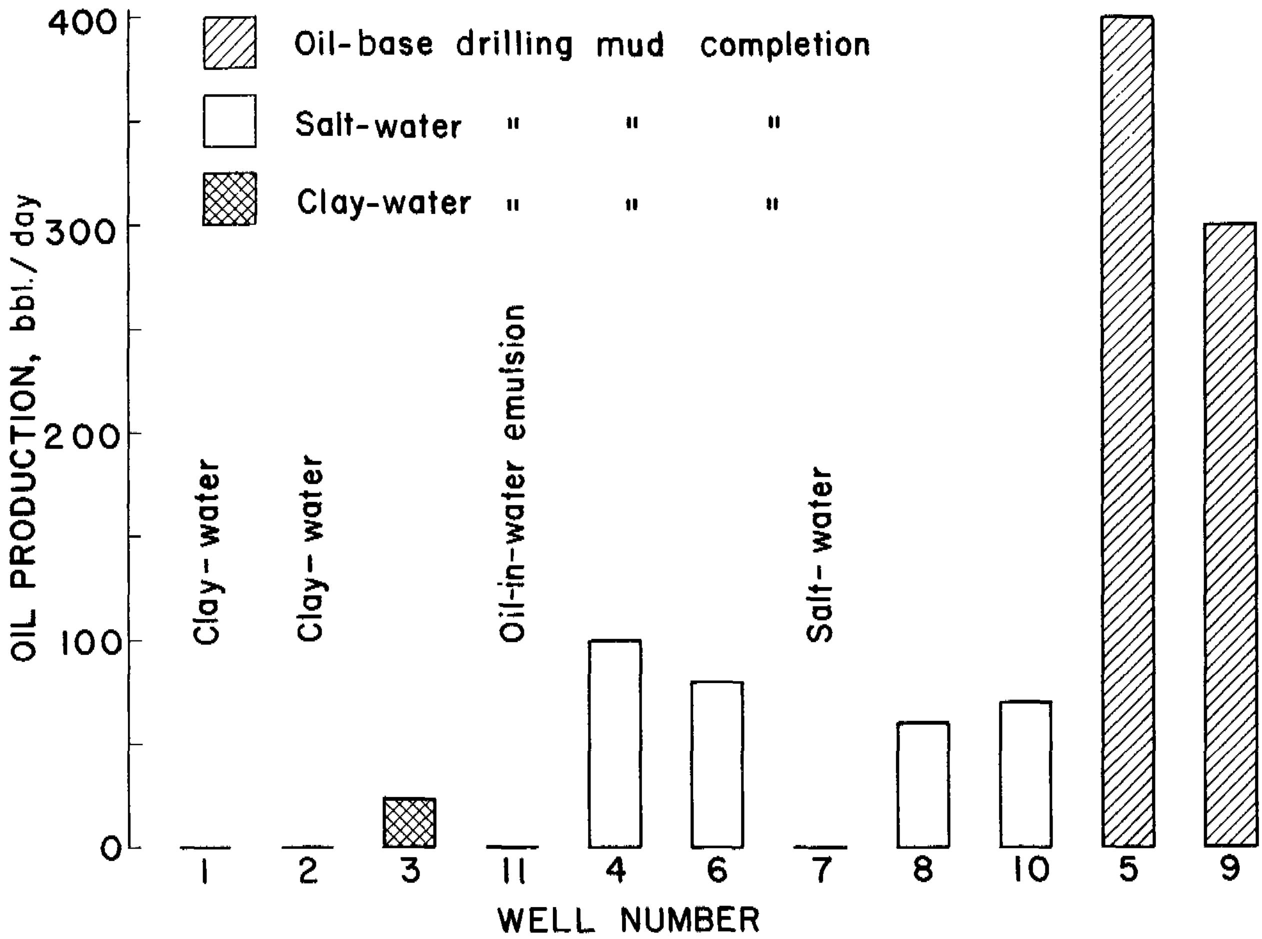

FIGURE 6. - Production Capacity of Umiat Wells Related to Drilling Mud.

Unusual Features of Well 9

Because of the time required to pump the oil-base mud from the mud pit into tanks the formation was exposed to a low pressure from the liquid column for about 6 hours. Why the crude oil came into the hole after this time interval and did not flow into the hole during the 4-hour formation tests is not understood. There is nothing in Darcy's law to indicate that time (several hours) is required for crude oil to flow from the formation into the bore hole.

Effect of Water on Relative Permeability to Oil

Where water from the drilling mud or any other source enters the pore space (especially if the water freezes) the channels available to the flow of oil are greatly reduced. A large decrease in permeability to oil with a small increase in water content has been established from relative permeability studies. Dunlap[15/] showed this relation in a laboratory study of the oil

15/ Dunlap, Eldon N., Influence of Connate Water on Permeability of Sands for Oil: AIME Petrol. Trans., vol. 127, 1938, pp. 215-225.

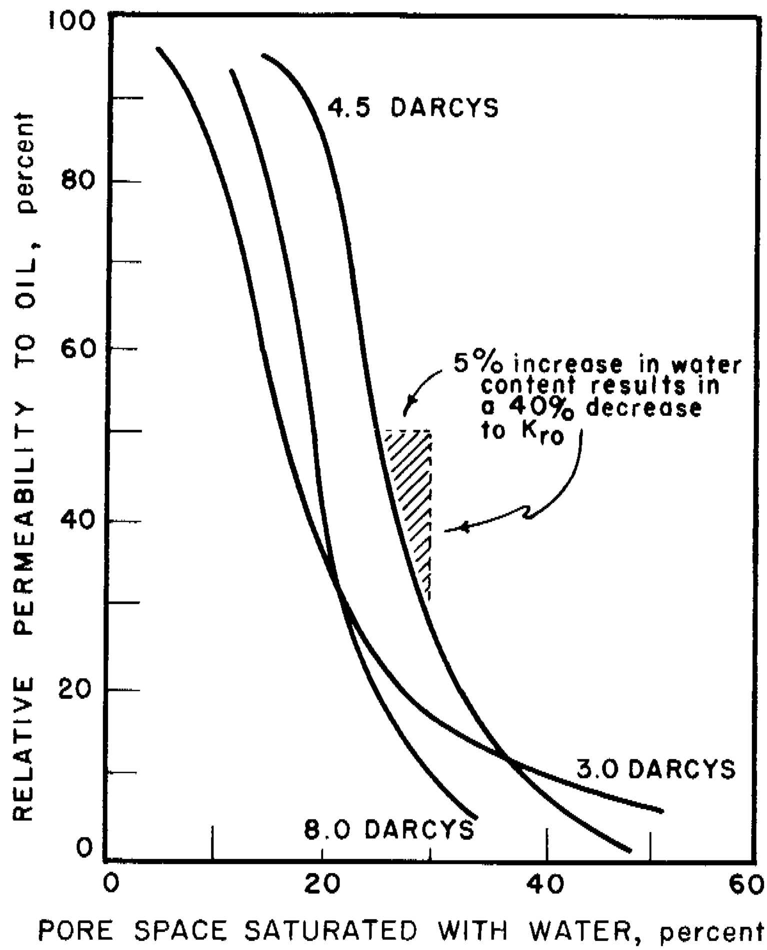

FIGURE 7. - Effect of Water Content of Sands on Permeability to Oil. *(Adapted From Dunlap, AIME Petrol. Trans. 1938).*

permeability of sands containing increasing volumes of water (fig. 7). The tests showed that a 5 percent increase in the water content of the sand resulted in a 40 percent decrease in permeability to oil. The permeabilities of the sands used in the laboratory tests were much higher than normal oil-reservoir sands. However, data are considered indicative of relative permeability trends.

Formation Pressure

Although few data are available regarding the formation pressure in the Grandstand sandstone in the Umiat field, some indication of the pressure may be obtained indirectly. Shut-in gas pressure at the surface of well 8 reached a maximum observed value of 270 pounds per square inch. The depth from which the gas was flowing and the liquid level in the well were unknown.

Wells 5 and 9 had liquid levels that reached nearly to the surface. Based on a crude oil specific gravity of 0.84 the pressure in well 9 at a depth of 900 feet was 900 x 0.84 x 0.43 lb./ft. of water = 325 pounds per square inch. The calculated pressure in the upper Grandstand sandstone at a depth of 470 feet was 170 pounds per square inch.

These pressures available to push water (brine) or ice from the pore channels are not large. The affinity of the clays in the reservoir rock also tends to hold water solutions in the pore channels thereby restricting the rate of flow of crude oil through the rock into the well bore.

Low Formation Temperatures

Wells in this field penetrated rocks at temperatures below the freezing temperature of water and some of the oil produced from these holes was shown to be flowing through rocks below 32° F. The measured oil flow temperature was about 26° F. indicating approximately the temperature of the oil-reservoir rock. Although this temperature is below the freezing temperature of fresh water in large containers, tests have shown that water solutions in small pores may have a freezing point at temperatures below 32° F.16/ The relative amounts of water in the liquid and solid states in ground at temperature below 32° F. depend on the physiochemical composition of the ground, on the presence of water-soluble particles, and on the temperature and pressure.

PROPERTIES OF THE CRUDE OIL

The produced crude oil has the following characteristics: API gravity, about 36°; pour point, -5° F.; sulfur, 0.1 percent, no hydrogen sulfide; Saybolt Universal viscosity at 100° F., 37 seconds; color, National Petroleum Association No. 4; and carbon residue, Conradson, weight percent, 0.1 to 0.2. The crude oil was relatively high in naphthene hydrocarbons. Analyses of some crude oils from Alaska have recently been published by the Bureau of Mines.17/

BASIC WELL DATA

Well 1 had a ground elevation of 801 feet and the elevation of the kelly bushing was 810 feet. The total depth from the surface was 6,005 feet. Sixteen feet of 24-inch conductor pipe was set 19 feet below the kelly bushing in a 30-inch hole. Sixteen-inch casing was cemented at 97 feet. A string of 11-3/4-inch casing was cemented at 685 feet.

Well 2 had a ground elevation of 333 feet and the kelly bushing was located at an elevation of 342 feet. Sixteen-inch conductor pipe was cemented at 103 feet. A string of 11-3/4-inch casing was cemented at a depth of 1,005 feet. The well was drilled to a total depth of 6,212 feet.

Ground elevation at well 3 was 351 feet and elevation of the kelly bushing was 360 feet. Seven-inch casing was cemented at a depth 72 feet below the kelly bushing. The well was drilled to a total depth of 572 feet.

The ground elevation of well 4 was 482 feet. Surface pipe was set at a depth of 33 feet. This hole was drilled to a total depth of 840 feet.

The ground level of well 5 was 334 feet and the rig floor was 335 feet above sea level. At a depth of 23.5 feet, 8-5/8-inch casing was cemented. The well was drilled to a total depth of 1,077 feet. After the 93-day pumping test, 5-1/2-inch casing was cemented at a depth of 1,068 feet with the top of the plug at 1,065 feet. The pipe was filled with Umiat crude oil and shut in.

16/ Nersesova, Z. A., (The Relative Amounts of Water the Solid and Liquid States Present in the Ground During Freezing or Thawing.) Fazovyy sostav vody v gruntakh pri zamerzanii i ottaivanii, Materialy po Laboratornym Issledovaniiam Merzlykh Gruntov, vol. 1, 1953, pp. 37-51.

17/ McKinney, C. M., Garton, E. L., and Schwartz, F. G., Analyses of Some Crude Oils From Alaska: Bureau of Mines Rept. of Investigations 5447, 1959, 29 pp.

Well 6 was at a ground level of 334 feet and the rig floor was at 337 feet. Surface casing was driven to a depth of 35 feet. The hole was drilled to a total depth of 825 feet.

Well 7 was spudded from a ground level of 326 feet and a derrick floor level of 330 feet. Surface pipe was driven to 52 feet. The hole was drilled to a total depth of 1,384 feet.

Well 8 was at a ground level of 735 feet and the derrick floor was 5 feet higher. Two joints of 11-3/4-inch casing were set at 50 feet. After testing promising sandstones, excessive caving of the walls of the hole resulted in setting 8-5/8-inch casing at a depth of 1,231 feet. The hole was drilled to a total depth of 1,327 feet.

Well 9 was at a ground level of 418 feet and the kelly bushing was 6 feet higher. A string of 8-5/8-inch surface pipe was cemented at a depth of 61 feet. After a sustained pumping test, 5-1/2-inch casing was run to bottom, cemented, and gun perforated. The total depth of this hole was 1,257 feet.

Well 10 was at a ground level of 741 feet and the derrick floor was 5 feet higher. A string of 11-3/4-inch casing was cemented at a depth of 70 feet. After caving and several fishing jobs, casing was cemented at a depth of 1,339 feet. The hole was drilled to a total depth of 1,573 feet.

Well 11 was at a ground level of 464 feet and the kelly bushing was 7 feet higher. The 13-3/8-inch casing was cemented at a depth of 89 feet, with 57.7 feet jacketed with 16-5/8-inch casing. The hole was drilled to a total depth of 3,303 feet.