Subsurface Stratigraphic, Structural and Economic Geology, Northern Alaska

By FLORENCE R. COLLINS and FLORENCE M. ROBINSON

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

SUBSURFACE GEOLOGY AND ENGINEERING DATA

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ABSTRACT

This paper presents conclusions drawn from the data obtained by nine years of drilling in Naval Petroleum Reserve No. 4 in northern Alaska.

No metamorphic or igneous rocks were found in any of the 81 holes, but sedimentary rocks ranging in age from Devonian to Recent were examined. Paleozoic, Triassic and Jurassic beds were reached only in the northern part of the Reserve (except for some Jurassic(?) beds in Oumalik test well 1), and most of the holes were drilled in beds of Cretaceous age. Probably the oldest rocks are the steeply dipping black argillite with interbedded siliceous dolomite at Barrow, or the red and green argillite at Simpson; they contain no identifiable fossils. Four hundred feet of interbedded Devonian conglomerate and shale, 270 feet of red beds, and 390 feet of siliceous Permian siltstone, sandstone and claystone penetrated by Topagoruk test well 1 complete the known Paleozoic section in the subsurface. At Topagoruk, Triassic beds are predominantly black clay shale; at Simpson and Barrow they are very calcareous siltstone and silty limestone; the

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Barrow section contains beds of oolites composed of limonite, as well. Jurassic beds composed of dark gray clay shale and olive gray siltstone and silty sandstone are found in most of the northern test wells; gas is produced from the Jurassic beds at Barrow. The distinctive lithologic unit known as the "pebble shale" (a black clay shale with very well rounded grains and granules of clear quartz and black chert, scattered at random singly or in small groups through the rock) ranges from Late Jurassic(?) to Early Cretaceous (Early Albian) in age. It is overlain by dark shales of the Lower Albian Oumalik Formation, which is very thick in the central part of the Reserve but thins greatly in the Barrow area. Clay shale and siltstone, sandstone with interbedded clay shale, and interbedded clay shale, coal, and a little sandstone make up the Topagoruk, Grandstand and Chandler Formations, respectively. They are off-shore, near-shore, and nonmarine beds that were deposited, in part simultaneously, in the Cretaceous geosyncline that occupied most of northern Alaska during Middle and Upper Albian time. Sandstone beds in the Grandstand Formation contain oil at Umiat, and gas was noted in several test wells, but the deposits have little present commercial value. The Ninuluk Formation, of Cenomanian age, records the advance of the Upper Cretaceous sea which later, in Turonian time, laid down the Seabee Formation, a fossiliferous sequence of clay shale with some sandstone beds, particularly near the base, and some bentonite. The Tuluvak Tongue of the Prince Creek Formation, overlying the Seabee Formation, is the result of nonmarine deposition which succeeded the retreat of the Turonian

sea. It contains a large amount of coal and bentonite, and its sandstone beds are reservoirs of gas at Gubik. The Rogers Creek, Barrow Trail, and Sentinel Hill Members of the Schrader Bluff Formation, the youngest marine Cretaceous strata in the Reserve, consist of medium to light gray sandstone and clay shale which is bentonitic in part and which contains abundant volcanic shards, in the upper part, particularly in the Sentinel Hill Member. The Kogosukruk Tongue of the nonmarine Prince Creek Formation interbeds with and overlies the Sentinel Hill Member, and is the last identified record of Mesozoic sedimentation within the subsurface of the Reserve.

The present structure was probably delineated concurrently with the Late Cretaceous and Tertiary uplift of the Brooks Range. Along the southern margin of the Reserve, long, narrow anticlinal folds, trending west-northwest, were formed paralleling the Brooks Range; many are asymmetrical or overthrust from the south. Farther north, gentler folds are superimposed on the geosyncline. The Barrow area marks the northern edge of the geosyncline; Cretaceous rocks there are as little as 1,600 feet thick compared to more than 10,000 feet in the central part of the Reserve. A low arch in the vicinity of the Meade River separates the Cretaceous basin into a western part dominated in Albian time by nonmarine sediments, and an eastern one containing beds which are primarily marine in origin.

Jurassic sandstone contains a small reservoir of gas in a structurally complex area near Point Barrow. Two of the six closely-spaced wells to penetrate the field are flowing and furnish enough gas to heat the nearby government installations and Barrow village. Fish Creek test well 1, drilled close to an oil seep near the mouth of the Colville River, penetrated 130 feet of interbedded Cretaceous clay shale and siltstone containing dark, heavy oil. A pumping test produced 9 to 12 barrels a day for 3 weeks, before the hole was abandoned. A large gas field was discovered at the Gubik anticline, located a few miles northeast of Umiat. The anticline is estimated to be 14 miles long and 3.2 miles wide, with a closure of more than 500 feet. Two wells, one located near the crest and the other on the south flank, both produced gas from sandstone beds of Late Cretaceous age, and reserves were estimated by Arctic Contractors as more than 200 billion cubic feet. Three large oil seeps are located near Cape Simpson, 50 miles southeast of Point Barrow, and several shallow test holes were drilled near them to determine the source of the oil. Shows of oil were found in most of the tests, and oil and gas flowed or was bailed from a few wells. Impermeable shale deposited unconformably above sandstone has trapped the oil against the irregular upper surface of the permeable sandstone. The extent of the field, and the amount of oil present were not determined but they are believed to be small. The largest oil field found in the Reserve is at Umiat. It is in a faulted, asymmetrical anticline of Cretaceous sandstone and shale which has at least 1,200 feet of closure in an area about 10 miles long and 3 miles wide. An average estimate of reserves is about 60 million barrels of 36° gravity oil.

INTRODUCTION

Naval Petroleum Reserve No. 4 is a tract of approximately 37,000 square miles in northern Alaska, see figure 1, which was set

Figure 1. Map of Naval Petroleum Reserve No. 4 and adjacent areas, showing locations of test holes and of regional cross sections.

aside by President Harding in 1923; about 20 years later, during World War II, the Navy began a program of exploration for oil there. The objective of this program was to evaluate the petroleum potentialities of the Reserve and adjacent areas, based primarily on the results of test wells which were to be drilled and tested to yield a maximum amount of geological, engineering, and production data. A great amount of effort was devoted to the drilling of test wells and core tests and it is with the results of this phase of the work that Professional Paper 305 is primarily concerned.

In 1944 and 1945, Navy Construction Battalion Detachment No. 1058 drilled three shallow holes near a base camp at Barrow, several core tests near Cape Simpson, and began a deep test at Umiat. In 1946 the work was taken over by Arctic Contractors, who completed the first Umiat hole and also drilled a shallow test in the same area. Under contract to the Navy, the Contractors carried on a drilling program for the next six years, of which 1949, 1950, and 1951 were the most active. By 1953, when work on the project was suspended, 78 test holes had been drilled in various parts of the Reserve, plus three which were located outside of the boundary. Of these, 36 were test wells and the rest core tests; all are listed on figure 2, which also includes two additional wells drilled in the Barrow gas field in 1955 and 1964. A detailed history of the exploration of the Reserve has been prepared by John C. Reed (1958).

Figure 2. Chart giving locations, formation tops, and other pertinent data on the test wells and core tests in northern Alaska.

The core tests, most of which are near Cape Simpson, are almost all less than 1,500 feet deep. A few test wells are also shallower than 1,500 feet, but most of them are more than 2,500 feet deep: eleven are between 2,500 and 5,000 feet deep, seven are 6,000 to 7,020 feet in depth, and the two deepest holes, Topagoruk test well 1 and Oumalik test well 1, are 10,503 and 11,872 feet deep, respectively. The total footage drilled was 174,360 feet, of which 30,949 feet, or about 18 percent, was cored.

Most of the holes were located on the Coastal Plain of northern Alaska, a nearly flat, tundra-covered area dotted with lakes and crossed by meandering streams; outcrops are very rare. South of the Coastal Plain, ridges and valleys of the northern section of the Arctic Foothills province have a relief of more than 500 feet, with numerous outcrops of bedrock. About a fifth of the tests, including eleven in or near the Umiat oil field, were located in this province (see fig. 1).

A magnetometer survey by the U.S. Navy and the U.S. Geological Survey in 1945 and 1946, and gravity and seismic surveys by the United Geophysical Co., Inc. (Woolson and others, 1962), made simultaneously with the drilling program, located most of the anticlines which were tested by drilling in the northern part of the Reserve. The long, narrow anticlines which cross the southern section of the Arctic Foothills province approximately from east to west were mapped by geologists of the U.S. Geological Survey, who studied the southern part of the Reserve and the Brooks Range in the field and on aerial photographs.

Both cores and cuttings from the tests were sent to the Fairbanks laboratory of the U.S. Geological Survey, established in 1945 to process samples from the Reserve. The laboratory personnel included several geologists, a paleontologist, and a varying number of laboratory technicians. The lithology was studied and described in detail and washed samples were examined for microfossils. Samples from sandstone beds were tested for porosity, permeability, and content of carbonate minerals, and heavy-mineral separations were made. Some core segments, wrapped and sealed at the well, were crushed and heated in a Ruska still, to determine the fluid content. The cores and cuttings have been filed as a reference collection in Fairbanks, Alaska.

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The empirical information obtained has been included in U.S. Geological Survey Professional Papers 305-A through 305-L, which present geologic and engineering data of the individual tests. This report discusses the subsurface stratigraphy, structure, and geological history of the area delimited by Grandstand test well 1 on the south, Gubik test well 2 on the east, Kaolak test well 1 on the west, and the Arctic Ocean on the north. Knowledge of this region, which underlies more than half of the Reserve, is based primarily on subsurface data.

In compiling the material for this paper, as well as for the professional papers, the authors have drawn on many sources for information. In addition to the work that was done at the Fairbanks office of the Geological Survey, the records of Arctic Contractors, United Geophysical Co., Inc., and the Schlumberger Well Surveying Corp., prepared for the U.S. Navy were consulted. The authors are indebted to paleontologists of the U.S. Geological Survey and of the U.S. National Museum--particularly to H. R. Bergquist for his studies of the microfaunas which were the bases for establishing many of the stratigraphic units, and to Helen Tappan Loeblich who has done the Foraminiferal taxonomic work. Most of the division of the Jurassic and early Cretaceous units into equivalents of the various European stages is dependent on studies of mollusks by Ralph W. Imlay. His and Mrs. Loeblich's conclusions concerning the environments in which animals lived has proven especially important in interpreting the geologic history. Identifications by J. M. Schopf of Devonian

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plants, D. Dunkle of Permian and Upper Cretaceous fish, B. Kummel of Triassic megafossils, R. W. Brown of Cretaceous plants, G. Gryc of Upper Cretaceous megafossils, and F. M. Swain of Pleistocene ostracods have also been of great value.

Stratigraphy

Introduction

The following pages attempt to synthesize and summarize the details of the rock units and to present characteristics which set each stratigraphic unit off from those above and below it, as well as to describe variations within a unit. Age determinations are also given, and the reasons for them discussed. The stratigraphic information is presented graphically in figure 3.

Figure 3. Stratigraphic chart giving a brief description of all formations found in the subsurface of Naval Petroleum Reserve No. 4, and their European equivalents.

Rocks recovered from the test wells are all sedimentary, except for the probably slightly metamorphosed argillite at Barrow and Simpson. They range in age from Devonian to Upper Cretaceous (again excluding the argillite, which is of unknown, but pre-Triassic, age). In many localities, especially in the northern part of the Reserve, they are covered by a thin deposit of silt, sand, and gravel of Recent or Pleistocene age. Conglomerate, sandstone, siltstone, and shale are all represented; "red beds", limestone, coal, and bentonite are present in lesser quantities. Megafossils of Devonian, Permian, Triassic, Jurassic, Lower and Upper Cretaceous ages were recovered; most are pelecypods, with rare fish, brachiopods, and plants. Foraminifera and a few other types of microfossils, particularly pollen, were found in the Mesozoic formations. With the support of the U.S. Navy, R. A. Scott is currently studying pollen samples from many of the well cores.

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Pre-Mesozoic rocks

Lower Paleozoic(?) argillites

Five test wells in the vicinity of Point Barrow, and Simpson test well 1, about 40 miles to the southeast, penetrated steeply-dipping argillites (see definition in Pettijohn, 1949, p. 269) beneath nearly flat-lying beds of Upper Triassic age.

At Barrow, the argillite is light bluish gray to black, siliceous and hard, with splintery to conchoidal fracture (Collins, 1961, p. 573). Minute spines of pyrite, which are almost certainly of organic origin and which have some resemblance to sponge spicules or brachiopod spines, are found as well as spheroidal quartz aggregates suggestive of Radiolaria. Quartz and calcite veinlets are rare to common. Much of the rock is too fragmentary to permit dip determination, but in a few cases slight changes in color or texture suggest that the beds dip 60-70°. Because of the steep dip, the four South Barrow test wells sampled sections only 100 feet or less thick, but Avak test well 1, a few miles to the east, went through a much longer sequence. A little more than 1,700 feet of the hole was drilled in these beds, but the stratigraphic thickness penetrated is uncertain. Cores are so fragmentary that only one dip measurement was possible; the 20-30° dip recorded may not be typical of the whole section, and the sequence may also be affected by faulting. The electric log shows no sign of duplication of beds, however, and probably well over 1,000 feet of beds were penetrated. In this sequence, beds of black argillite as much as 300 feet thick make up about half of the rock. Alternating with them are

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strata composed of thin interbedded layers of gray siliceous authigenic dolomite, dolomitic chert and more argillite. Dolomite rhombs, some later replaced by silica, are visible in thin sections. Pyrite and quartz or calcite veinlets are present in the dolomite and chert, as well as in the argillite; no evidence of organic remains was found. The uppermost 20 feet of the sequence is black, earthy, and friable; it may be a regolith weathered from the harder rock below.

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At Simpson test well 1 (Robinson, 1959b, p. 548) the argillite differs from that at Barrow in color and in containing no beds of chert or dolomite. It is grayish green with some grayish red shale which has been slightly silicified and is hard, dense, and massive; a few thin beds contain grains of silt size. Some slickensided fracture planes are coated with pyrite and calcite. Although 459 feet of the argillite was drilled, the stratigraphic thickness represented is only about 100 feet because the beds dip between 75 and 80° (see fig. 4). No fossils were seen.

Figure 4. Steeply dipping argillites in Simpson test well 1. The core was moistened with water to bring out color differences.

There was no evidence of a weathered zone at the top of the argillite as there was at Barrow but the contact was not cored and such evidence may have been lost in the cutting samples.

With the information now available, it is doubtful that any definite age can be assigned to the pre-Upper Triassic rocks discussed above; indeed, there is no certainty that the rock in the Barrow area is the same age as that at Simpson. Both show the same degree of induration, but at Barrow both induration and angular unconformity could be local phenomena associated with the Barrow "cryptovolcanic" structure (p.142).

T. G. Payne postulated that the tests are on the southern flank of an early Paleozoic stable area encompassing most of the Arctic Ocean that had not been subjected to orogeny since Precambrian time and hence, that the argillite was of probable Precambrian age (personal communication, 1952). However, drilling of Topagoruk test well 1 subsequent to Payne's studies indicates pre-Permian, post-Devonian structural movement close to Barrow: Middle Devonian beds in Topagoruk test well 1 dip 35° to 60°, whereas the Permian beds that directly overlie them dip 8° or less, and appear to be conformable with the overlying Mesozoic rocks. In the eastern Brooks Range there is also evidence for pre-Permian, post-Devonian orogenic movement (Brosgé, Dutro, Mangus, and Reiser, 1962, p. 2,194). The Neruokpuk Formation, which crops out there, contains some red and green phyllite in the upper part which is strikingly similar to the Simpson argillites. Brosgé, Dutro, Mangus, and Reiser (1962, p. 2,184) have tentatively referred the upper third of the Neruokpuk Formation, the portion that most closely resembles the Simpson argillite, to the Upper Devonian.

There is also some similarity between the Simpson argillite, the mottled red and gray beds of Permian age found in Topagoruk test well 1, and the Permian Siksikpuk Formation which crops out in the Brooks Range (Patton, 1957, p. 41-42). Correlation with the Permian beds seems unlikely, however, for two reasons: the Permian beds in Topagoruk test well 1 are approximately conformable with the Mesozoic strata, whereas in Simpson test well 1 the argillite is markedly unconformable; and the degree of induration of the Simpson beds is much greater than that of most of the nearby Permian rocks. Even a few beds of Triassic age cropping out in the Brooks Range resemble the argillite at Simpson (Gryc, personal communication, 1956) but the same arguments that apply to correlation with the Permian strata also apply to correlation with the Triassic beds.

Hard black shales or argillites like those from the South Barrow test wells are present, in small quantities, in rocks of almost every Paleozoic period in northern Alaska, as well as in some rocks of probable Precambrian age. Grayish black pyritic hard clay shale in the Middle Devonian beds in Topagoruk test well 1, a small amount of black phyllite in the Neruokpuk Formation, and some Devonian strata in the central Brooks Range are all similar, lithologically, to the argillite penetrated by the South Barrow test wells. The much thicker section drilled by Avak test well 1, however, is more distinctive because of the interbedded dolomite and chert. No identical beds have been reported elsewhere in the region for although many of the black shale sequences contain interbedded chert, the presence of intermingled carbonate beds is not recorded. Conversely, the limestone-phyllite member of the Neruokpuk Formation lacks chert, and contains graywacke, grit, and sandstone (Brosgé, Dutro, Mangus, and Reiser, 1962, p. 2,184).

The alternating chert-dolomite and black argillite of the Avak test well and the black argillite of the South Barrow tests may be a quiet-water equivalent of the conglomerate-black shale sequence of Middle Devonian beds drilled at Topagoruk test well 1; both sequences are marked by a high silica content and a lack of graywacke-type sediments. Widespread Middle and Upper Devonian sediments to the south and east, however, suggest that the area north of the shoreline facies at Topagoruk was part of a land mass in Devonian time, and that the Barrow strata are pre-Middle Devonian in age. The lack of fossils and the great distance between Barrow and Simpson and localities having comparable strata make dependable correlation impossible at the present time.

Devonian conglomerate

Devonian rocks have been identified in the subsurface only in Topagoruk test well 1, where beds between 10,040 and 10,503 feet consist of approximately equal amounts of interbedded medium-gray chert conglomerate and dark gray carbonaceous shale and claystone. The beds dip 35° to 60° (in contrast to the overlying strata which are nearly horizontal), and the stratigraphic thickness is only about 300 feet. The conglomerate is made of subangular to rounded white, gray and black chert pebbles 1/8 to 1/4 inch in diameter in the upper part, increasing to a maximum of 2 1/2 inches near the bottom of the hole (see fig. 5). The pebbles are set in a matrix of coarse to fine-grained chert sand, with some silty and argillaceous material, and the whole

Figure 5. Devonian conglomerate from 10,479-81 feet in Topagoruk test well 1, northern Alaska. The core was moistened before being photographed, to bring out color differences.

is cemented with additional silica. The beds of clay shale and claystone are grayish black, slightly silty and siliceous, and have discontinuous carbonaceous partings; irregular patches and minute cubes of pyrite are also present. None of the rock is metamorphosed; its hardness results from the siliceous cement. At 10,441 feet, carbonaceous partings contained a few specimens of land plants, identified by James M. Schopf of the U.S. Geological Survey as Psilophyton sp. nov., Zosterophyllum(?) sp. nov., Aphyllopteris sp., and Hostimella(?) sp., of Middle(Early?) Devonian age (Collins, 1958b, p. 288).

The nearest Devonian outcrops are in the Brooks Range, in the vicinity of Shainin Lake, about 200 miles southeast of Topagoruk. An "incomplete section of shale and sandstone more than 1,600 feet thick" (Bowsher and Dutro, 1957, p. 4) is exposed there, but it contains Upper Devonian marine fossils in the lower 400 feet. Somewhat farther away, however, in the vicinity of the John River and south of the crest of the Brooks Range, thick black slate and phyllite are present beneath Upper Devonian beds, and are underlain conformably by the Middle(?) Devonian Skajit limestone and unconformably by Middle Devonian and older schist, phyllite, black siltstone, and limestone (Brosgé, 1960, p. B351). The metamorphism increases from north to south across the range, and some of these clastic rocks might be a finer-grained, somewhat metamorphosed equivalent of the beds in Topagoruk test well 1. The Eastern Brooks Range also has metamorphosed clastics (Brosgé, Dutro, Mangus, and Reiser, 1962, p. 2,184), the quartzite- and phyllite-chert members of the Neruokpuk Formation, which may be of Middle Devonian age. The DeLong Mountains, west of the Brooks Range, contain Upper Devonian rocks, mostly limestone and dolomite (Sable and Dutro, 1961). Many areas in Alaska south of the Brooks Range are also underlain by rocks of Middle Devonian age. Clastic beds, commonly metamorphosed, are found in the upper Yukon valley, in southeastern Alaska, and along the eastern boundary of the state. No Lower Devonian strata have yet been identified in Alaska, and the younger beds rest on rocks of Silurian or older age. This regional break in sedimentation suggests that the beds in Topagoruk

test well 1 are also Middle Devonian and not Lower Devonian, a possibility which was suggested by the plant fossils.

Permian(?) red beds

Above the Devonian beds in Topagoruk test well 1 is a 270-foot interval of red beds which are nearly flat lying. The rock consists of interbedded brick red to grayish red claystone, siltstone, and sandstone with a few thin layers of conglomerate and rare interlaminated red and green shale; fossils are lacking. No similar beds were penetrated by any other holes and the absence of fossils leaves the age of the beds in doubt, although they presumably are closer in age to the overlying Permian beds, with which they are structurally conformable, than to the underlying Devonian beds from which they are separated by an angular unconformity.

The nearest outcrops of post-Devonian Paleozoic strata are in the Brooks Range, more than 150 miles to the south. Mississippian and Permian rocks are widespread through the mountains and in the foothills north of the Range, and Pennsylvanian beds have been tentatively identified in the eastern Brooks Range (Brosgé, Dutro, Mangus, and Reiser, 1962, p. 2,192). The Mississippian strata are dominantly dolomite and limestone, with some chert, and contain no distinctively red sediments; neither does the Wahoo limestone of probable Pennsylvanian age. Permian rocks, on the other hand, include red and green shales, particularly in the Siksikpuk Formation. This formation is found in the central Brooks Range, and its type section there is described as variegated green, gray, and dark red shale and siltstone (Patton, 1957, p. 41, Patton and Tailleur, 1964, p. 428, and Brosgé, Dutro, Mangus, and Reiser, 1962, p. 2,194); the red beds of the test may well be the equivalent of this formation.

Permian sandstone

Overlying the red beds in Topagoruk test well 1 are the only strata in the subsurface which have been identified as Permian. The sequence (from about 9,380 feet to 9,770 feet), approximately 390 feet thick, is predominantly light gray siliceous and dolomitic sandstone, with some interbedded medium gray siliceous siltstone and silty claystone, particularly toward the base, and about 15 feet of conglomerate near the middle. The sandstone is composed of subangular white and clear quartz grains, commonly frosted, that are deposited in beds a few feet to 65 feet thick. The cement is siliceous throughout, and dolomitic as well, in the upper part. Most of the siltstone and claystone is medium gray to medium dark gray, except for a few feet of rock overlying the conglomerate, which is mottled grayish red and gray. The conglomerate, 140 feet below the top of the unit, is composed of rounded 1/4- to 3/4-inch pebbles of white chert, with a few of gray or black chert, in a matrix of coarse to fine quartz sand and siliceous cement.

Brachiopods (Lingula sp., a long-ranging form) are present in the sandstone, and coelocanth fish teeth found about 60 feet below the top of the sequence were described by David H. Dunkle of the U.S. National Museum as being similar to some reported from Permian formations in Wyoming and Texas.

The Nuka Formation which crops out in the central and western Brooks Range, is composed of more than 6,500 feet of "fine clastic, felspathic coarse clastic, and cherty strata" and coarse clastic rocks (Tailleur and Sable, 1963, p. 632). The lower part contains Late Mississippian fossils; the upper part is Late Permian. The uppermost unit ("member p", p. 633) contains silicified Late Permian brachiopods in a sequence of sandstone, dolomite and clastic limestone which is light to medium gray; "member m", composed of coarse clastics of Permian(?) age (p. 637) also resembles the Permian beds in Topagoruk test well 1. The Permian beds in the test well may therefore be the equivalent of the upper part of the Nuka Formation 160 miles to the south. The great distance between outcrop and test well, however, makes correlation hazardous and, consequently, the beds in the hole are described as of Permian age.

Mesozoic rocks

Upper Triassic shale

Beds of Late Triassic (Norian) age, penetrated in three test wells, are dated by the presence of the diagnostic pecten Monotis subcircularis (Gabb), or by a distinctive microfauna (Tappan, 1951, p. 5). The three holes, Topagoruk test well 1, South Barrow test well 1, and Simpson test well 1, are all located on the Arctic coastal plain within 60 miles of Point Barrow (see fig. 1).

The section in Simpson test well 1 is 280 feet thick. The lower 115 feet is made up of very calcareous siltstone, sandstone, and some limestone. The siltstone is medium light gray and is mottled with dark patches of argillaceous material. The matrix is very calcareous and the rock grades into a silty dark colored limestone in several places. Pelecypod impressions and shell fragments are common. The basal 25 feet of this section is mostly light gray to medium light gray fine-grained sandstone with clear, subangular quartz grains, a few rock particles and pyrite grains, a trace of glauconite and carbonaceous material, and calcite cement.

The upper 165 feet of Triassic beds in Simpson test well 1 are more argillaceous, with some beds of medium gray shale as much as 25 feet thick. The rest of the rock is calcareous siltstone, with some silty limestone beds concentrated about 50 feet below the top of the section. Glauconite is found throughout the Triassic strata but is most abundant in the bottom half of this 165-foot sequence, where it colors some siltstone beds grayish green. An abundant, dominantly calcareous Triassic foraminiferal assemblage has been described from these beds (Tappan, 1951, p. 5,8-16); the same microfauna has been found, although in lesser quantities, in the other two holes.

In South Barrow test well 3, where Triassic strata are 189 feet thick, the sequence of beds (limestone beds near the top and bottom, separated by shale and calcareous siltstone) is almost the same as it is in Simpson test well 1, although the Barrow hole penetrates proportionately more limestone and less shale. The limestone in South Barrow test well 3 is lighter and slightly yellower or more olive in color than at Simpson, and it has two thin beds of pelecypod-shell coquina near the base. Interbedded with it are beds of oolites composed of limonite with hematite coatings, and with ferruginous or calcareous cement. These layers, which are 4 inches to 10 feet thick and total more than 15 feet, are concentrated in the upper limestone beds, although a few thin layers are present in the lower limestone. No beds of oolitic limonite have been reported elsewhere in northern Alaska as yet. Foraminifera common in Triassic beds at Simpson are very rare at Barrow.

The Triassic sequence at Topagoruk test well 1 is thicker than that in the two northern tests; it is at least 550 and possibly as much as 740 feet thick. Ditch samples from this hole are of very poor quality, being badly contaminated by caving from above; the following description may therefore be incomplete. The basal 180 feet of the 550-foot sequence (from 8,830 to 9,380 feet) is composed of silty, dark gray clay shale which is hard, micaceous, and slightly pyritic and contains thin beds of medium gray very calcareous siltstone. A few fragments of light brown limestone and glauconite pellets were noted in the ditch samples. This is overlain by a little more than 100 feet of medium dark gray to medium light gray, very sandy, very calcareous siltstone, with a bed of dark brownish gray limestone near the middle. Above the siltstone an interval of about 200 feet is occupied by dark gray silty clay shale with interbedded slightly glauconitic siltstone containing shell fragments of the pelecypods *Monotis* and *Halobia*, and a poorly developed foraminiferal assemblage, which are diagnostic of Triassic beds. Between 8,830 feet and 8,890 feet the ditch samples were similar to the clay shale and siltstone described above, but the electric log shows a large and abrupt increase in both long and short normals of the resistivity curve that suggests a change in lithology. Just above this, at 8,830 feet, the resistivity curve returns to its more common low value, but the spontaneous potential curve shows a definite increase. The contact between Triassic and Jurassic beds is placed, tentatively, at this change in the electric log. Sandy beds between 8,640 and 8,830 feet were originally thought (Collins, 1958b, p. 270, and Bergquist, in Collins, 1958b, p. 313) to be part of the Triassic strata. The fossils within these beds give no conclusive evidence of age (Bergquist, personal communication, 1956), and as the strata have the same relative stratigraphic position as Lower Jurassic sandstone beds at Barrow and Simpson, they are considered in this paper to be of Jurassic age, and are described with the other Jurassic strata.

The Triassic strata in all the holes are flat-lying. In the two northern tests they rest unconformably on steeply-dipping pre-Mesozoic argillite; in Topagoruk test well 1 they are apparently conformable on the underlying Permian sandstone and siltstone.

Upper Triassic beds crop out in the Brooks Range southwest, south, and southeast of the wells. The Triassic Shublik Formation, described by Leffingwell in the eastern Brooks Range (about 250 miles east of Simpson test well 1) consists of a 500-foot sequence of dark limestone and shale, with a 30-foot sandstone member near the base (Leffingwell, 1919, p. 115-118) which is very similar to the strata in Simpson test well 1. Correlative rocks in the Sadlerochit River drainage, not far from the type section, contain the same microfaunal assemblage as is found in the test wells (Tappan, 1951, p. 5). Upper Triassic megafossils are common to both test wells and outcrops.

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Because the beds in Simpson test well 1 are similar lithologically and faunally to those at the type section, they are considered to be part of the Shublik Formation. Upper Triassic rocks in South Barrow test well 3 and Topagoruk test well 1 differ in the proportion of siltstone, limestone, and shale, and in South Barrow test well 1 are unique in containing a large amount of limonite, but because the order of deposition is similar and the faunal content the same (although less well represented), as at Simpson, these strata are also, although more tentatively, considered as part of the Shublik Formation.

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Lower and Middle Jurassic sandstone and shale

The same three test wells that penetrated Triassic rocks also tested Jurassic beds which contain Foraminifera and ammonites ranging from Hettangian (Basal Jurassic) to Bajocian (Middle Jurassic) in age (Imlay, 1955, p. 82, and Tappan, 1955, p. 27), as shown in figure 6. In addition to these three holes, Lower Jurassic beds are present in Avak test well 1 and South Barrow test wells 2 through 6.

Figure 6. Comparison and possible correlation of Lower and Middle Jurassic beds in test wells in northern Alaska.

These rocks vary from hole to hole in the proportions of sandstone, siltstone, and shale, in the total thickness of the deposits, and in the amount of Jurassic time they represent in any one test well. Nevertheless, they have some lithologic characteristics in common that distinguish them from the overlying and underlying beds. They are generally noncalcareous, and lack the limestone common in Triassic strata; the shales are lighter in color than in the older beds. Pyrite and glauconite in many of the Jurassic deposits impart an olive tinge to the sandstone, distinguishing it from the overlying formations. Vermicular pyrite streaks in the clay shale are also distinctive.

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Lower Jurassic sandstone and shale.--In South Barrow test well 3, the basal 65 feet of Jurassic deposits rest on Triassic beds, and consist of gray to reddish brown clay shale with thin beds of brownish or olive gray bentonite. This lithologic sequence, which contains Foraminifera of probable Hettangian age (Tappan, 1955, p. 27) is not known to occur elsewhere in Naval Petroleum Reserve No. 4, and no bentonite has yet been described from basal Jurassic beds elsewhere in northern Alaska.

At Avak test well 1, between 1,892 feet and 2,307 feet, is an interval containing light to dark gray clay shale with streaks of sandstone in the upper part, and a conglomerate of clay shale pebbles as much as 3 inches in diameter at the base, which rests on pre-Mesozoic argillite. The rock has been much disturbed, and dips ranging from 20° to 90° were recorded, with slickensides and much fracturing. The true stratigraphic thickness is therefore unknown, but may approximate 150 feet.

Above the shale in South Barrow test well 3 and Avak test well 1, and overlying pre-Jurassic rocks at Simpson and the other two Barrow holes, is a section composed primarily of sandstone, with some siltstone and clay shale. This sandy unit is composed dominantly of subangular very fine- to silt-size grains of clear quartz with some white quartz and a few dark rock particles. Pyrite and carbonaceous particles are also present, and glauconite pellets and particles are common to abundant in the lower part. The rock varies slightly in color from light olive gray to olive gray in South Barrow test well 3, to medium light gray in the other holes. In the Barrow area it is mottled by intercalations of medium dark gray clay shale, and is very argillaceous; at Simpson it is harder and more massive; at Avak it is slightly calcareous in the upper part, and contains a minor amount of clay shale. It varies in thickness from less than 100 feet at Simpson to an estimated 200 feet at Avak. In South Barrow test well 3 it contains Sinemurian or Pliensbachian Foraminifera; at Avak it contains a Sinemurian ammonite, and at Simpson two Lower Jurassic pelecypods (Tappan, 1955, p. 27, and Imlay, 1955, p. 82). It therefore seems to be roughly correlative throughout this northern area, and most of it is probably Sinemurian in age. It is structurally conformable with the beds below and above it except at Avak test well 1, where all the beds have been much disturbed.

Above the Sinemurian sandstone is a section of medium gray to medium dark gray slightly silty claystone that is micaceous and slightly carbonaceous in part. An outstanding characteristic is the abundance of pyrite, present as grains, small nodules, and vermicular streaks. The thickness of this unit is about 500 feet at Simpson and South Barrow test well 3; at Avak test well 1, where post-Middle Jurassic erosion may have removed the upper part, it is about 200 feet thick, and in the other Barrow holes it is missing entirely. In South Barrow test well 3 these beds contain a large number of ammonites of Late Pliensbachian and Early Toarcian age. One specimen of <u>Amaltheus</u> sp., an upper Pliensbachian ammonite, came from Simpson test well 1, (Imlay, 1955, p. 82), where Lower Jurassic Foraminifera were also found (Tappan, 1955, p. 26). In South Barrow test well 3, Lower Toarcian fossils continue above the shale into the lower part of a 100-foot bed of siltstone.

In the Canning River region 4,000 feet of black shales overlying the Triassic beds have been described by Leffingwell (1919, p. 119). These rocks are called the Kingak shale, and are assigned to the Lower Jurassic. They are the only Lower Jurassic beds which have been given a name in northern Alaska. It is possible that the Pliensbachian and Toarcian claystone in the subsurface are the partial equivalents of the Kingak shale.

In Topagoruk test well 1 between 8,640 feet and 8,830 feet, is a sequence of sandstone and shale resting on strata of Triassic age. The lower part is represented in the samples by olive gray very fine grained siliceous sandstone apparently interbedded with dark clay shale near the base. No lithologic characteristics were noted which would link it with beds of either Triassic or Jurassic age; the sandstone is apparently siliceous, instead of calcareous like the Triassic sandstone, but mottling characteristic of the Jurassic sandstone was not noticeable. The olive gray color, though more common in Jurassic beds may be found in rocks of both ages. The thickness of the sandstone is uncertain; the resistivity curve of the electric log suggests that there is about 150 feet of it, overlain by about 40 feet of clay shale, with another 50 feet of sandstone or siltstone above that. The ditch samples, which were not dependable through this interval, contained a large proportion of sandstone only below 8,720 feet. A few ostracods, echinoid spines, and minute pyritic pelecypod casts in the clay shale and sandstone, although similar to some found in Triassic beds, are nondiagnostic; no megafossils were found. This section was tentatively placed with the underlying Triassic strata (Collins, 1958a, p. 270) because of the slight resemblance of the rare microfaunal specimens to those of the older beds (Bergquist, in Collins, 1958a, p. 314). In this paper, however, the sequence is considered Lower Jurassic because of its similarity to Lower Jurassic beds in the more northerly test wells. Further information must be obtained before either age can be verified.

Above 8,640 feet is a 370-foot sequence of dark gray micaceous claystone of uncertain age. No cores were taken of it, and no diagnostic fossils were recovered. It is similar to the Middle Jurassic shale above it, from which it is separated by about 50 feet of very argillaceous siltstone; it is equally similar to the Lower Jurassic shale in Simpson test well 1 and South Barrow test well 3. It is here considered Lower Jurassic, because it occupies the same relative stratigraphic position as the 500-foot section of shale in South Barrow test well 3 which contains Lower Jurassic fossils.

In South Barrow test wells 2, 4, 5, and 6 Jurassic deposits consist of 115 feet of light greenish gray, silty, very fine grained sandstone mottled with patches of dark gray clay, very similar to the Sinemurian sandstone in South Barrow test well 3 described above. This rock, present between 2,328 and 2,443 feet in South Barrow test well 2, is apparently the reservoir of a supply of gas which furnishes sufficient fuel to heat the base camp at Barrow, and the village nearby. The age of this sandstone is discussed by Harlan R. Bergquist as follows (Bergquist, written communication, 1964):

"The upper part of this section yielded a few Foraminifera of which the most common species is Haplophragmoides kingakensis Tappan, ... This species and 9 others from a core at 2,341-2,356 feet have been identified by Helen Loeblich (Tappan, 1955, p. 27) as being some of the species found in cores considered to be Toarcian age in South Barrow test well 3 ... . Arenaceous Foraminifera from the section have milky white quartz grains on the surface of the tests in the same manner as are on specimens found in a core from ... South Barrow test well 3.

"Ammonites of Toarcian age have been identified by Ralph Imlay (1955, p. 73) from South Barrow test well 3 from beds as high as 1,772 feet (that is, 838 feet above the base of the Jurassic beds in that hole), but small fragments of ammonites from a core at 2,391 feet in South Barrow test well 2 have been identified by him as Tmetoceras, and regarded as similar to specimens from the lower part of the Kialagvik Formation (lowermost Bajocian) of

southwestern Alaska (Imlay, 1955, p. 82, 89). However, this ammonite occurrence at 2,391 feet is below the core containing Foraminifera identified as the same as those of Toarcian age found in South Barrow test well 3. It therefore seems somewhat questionable to consider the thin Jurassic beds in South Barrow test well 2 to be Bajocian age when no Middle Jurassic rocks were recognized in test well 3 where only a thick sequence of fossiliferous Lower Jurassic rocks were identified."

The similarity of the sandstone in South Barrow test well 2 to the Lower Jurassic sandstone in test well 3 also suggests an Early Jurassic age for both sequences. South Barrow test wells 4, 5, and 6 are all offsets to South Barrow test well 2, and penetrated the same section. It is present from 2,352 to 2,471 feet in test well 4, and although the section was cored, very few microfossils and only a few pelecypod(?) shell fragments were recovered. The sandstone, which was oil-stained, dipped about 10-15°. In South Barrow test well 5, a similar sandstone was determined from ditch samples to be present from 2,374 to 2,453 feet; a core at 2,300 to 2,310 feet also contained a little sandstone; no electric log is available for the hole, and the true thickness of sandstone there is unknown. South Barrow test well 6 was drilled in July 1964. Stratigraphic data on it was not available at the time of this writing.

Middle Jurassic siltstone and shale.--Fossils of Middle Jurassic (Early Bajocian) age have been definitely identified only from beds in Topagoruk test well 1. The Lower Bajocian beds are made up of 450 feet (7,820 to 8,270 feet) of medium light gray argillaceous siltstone and medium dark gray pyritic micaceous clay shale. The siltstone is present at the top and bottom of the section, and it is the clay shale between that contains two genera of Bajocian ammonites (Imlay, 1955, p. 82). It resembles the underlying clay shale, however, in containing no diagnostic microfossils; it is also similar lithologically.

In the central Foothills of the Brooks Range, a few isolated outcrops of "tuffaceous graywacke interbedded with chert and mafic volcanics" are reported by Patton (1956a, p. 215, 218) to contain fragmentary ammonites suggesting a Middle Jurassic age. These beds he classes with the dominantly Upper Jurassic Tiglukpuk Formation, as "present information is not sufficient to warrant a separate stratigraphic unit for these beds", and "lithologically and stratigraphically they appear to be more closely allied to the Tiglukpuk Formation than to any other". Recently (Jones and Grantz, 1964) evidence has been submitted which suggests the Tiglukpuk Formation itself is lower Cretaceous rather than Jurassic. No additional stratigraphic data were available on these beds in 1964 (see Patton and Tailleur, 1964, p. 443) The isolated occurrences of Middle Jurassic beds, and the presence, in many places, of Upper Jurassic beds in contact with Triassic strata, suggest that the erosional break postulated in the subsurface beds (see below) extends to the foothills of the Brooks Range.

Upper Jurassic and Lower Cretaceous Pebble Shale

No fossils of late Middle Jurassic or basal Late Jurassic age have been reported from test wells in northern Alaska, the European Bathonian and Callovian stages (see fig. 3) apparently being represented in this area by an erosional disconformity. The oldest post-Bajocian fossils in the subsurface occur in a distinctive lithologic unit called the "pebble shale", which varies considerably in thickness from south (1,200 feet in Topagoruk test well 1) to north (350 feet in South Barrow test well 3), and which contains fossils of ages ranging from Oxfordian(?) in the southern tests to Albian in the north (see fig. 7). Only tests in the northern part of the Reserve drilled deep enough to reach these strata. In every case, it is the only unit present, in the subsurface, between the overlying Oumalik

Figure 7. Possible stratigraphic relations of beds having the distinctive lithologic characteristics of the "pebble shale".

Formation and the underlying Middle Jurassic or older rocks.

The "pebble shale" consists of claystone or clay shale, distinguished from the over- and underlying beds by its grayish black color, the rarity of siltstone and sandstone laminae, the abundance of granular and euhedral pyrite, and particularly by the quartz and chert grains it contains. Most of the grains are fine-grained to granule size, very well rounded, pitted or polished clear quartz and they are scattered singly or in small groups through the clay shale. Smooth, very well rounded gray and black chert grains of medium sand size to 1/4 inch in diameter are also distributed at random. They are usually rare, but in the Barrow area they increase in number and size toward the base of the section, forming a basal conglomerate with pebbles as much as 1 1/2 inches in diameter. Round, polished clear quartz grains are not recorded in other Mesozoic beds in the subsurface; subangular, white or clear, frosted quartz is the usual constituent of the Mesozoic sandstones, and single quartz grains are lacking in other clay shale units. The very thin, rare sandstone beds in the pebble shale, found in a few test wells, are of angular or subangular clear quartz grains; the rounded grains are not present in the sandstone. In Topagoruk test well 1, the rock is further distinguished by rare to common grains of bluish-green glauconite, and a glauconite sandstone composed of about 75 percent grayish-green glauconite in a matrix of black clay is present there at the bottom of the unit.

Irregular or subconchoidal fracture or poor shaly cleavage make dip determinations difficult. Although no sharp angular unconformities separate the pebble shale from older or younger Mesozoic beds, there may be slight angular unconformities between them.

In the lower 910 feet (6,910 to 7,820 feet) of pebble shale in Topagoruk test well 1, there is a foraminiferal assemblage which may be of Late Jurassic age (Oxfordian or Early Kimmeridgian?) (Tappan, 1955, p. 27); a pelecypod from the same beds, tentatively identified by R. W. Imlay as Buchia cf. rugosa (Fischer) (Imlay, 1955, p. 74, and Collins, 1958b, p. 281), a Late Jurassic species, is of very poor quality, and may be B. "sublaevis," of Early Cretaceous age (Tailleur, written communication, 1964).

The same microfaunal assemblage has been found in shale in the lower part of the Tiglukpuk Formation, an Upper Jurassic and Lower Cretaceous unit found in the central part of the Brooks Range (Patton, 1956a, p. 218, and Bergquist, H. R., personal communication, 1952). A few samples of this shale also contain the distinctive round clear quartz grains. On the Shaviovik River in the eastern part of the Brooks Range is a dark shale sequence with the same scattering of quartz and chert grains and the same foraminiferal assemblage as the one in the lower part of the pebble shale in Topagoruk test well 1. These beds, however, also contain Buchias (Aucella) of very Early Cretaceous (Berriasian) age (Imlay, 1961, p. 29 and 49), and the rock is mapped by A. S. Keller (Keller, Morris, and Detterman, 1961, p. 197) as the Okpikruak Formation. This Early Cretaceous formation is also found in other parts of the Brooks Range and in the foothills to the north (Gryc, Patton, and Payne, 1951, p. 159), but nowhere else does it contain the distinctive quartz and chert grains, or the distinctive microfaunal assemblage; in these other localities microfossils are almost lacking, the fossil content being essentially limited to mollusks.

Near the top of the pebble shale in Oumalik test well 1, Buchia (Aucella) "sublaevis" Keyserling, was identified by R. W. Imlay, (1961, p. 37), establishing the age of the enclosing rock as Early Cretaceous (Valanginian), slightly younger than the beds described in the preceding paragraph.

A much younger age is indicated for the upper part of the pebble shale in Topagoruk test well 1 and in the northernmost test wells. A few microfossils from the upper 300 feet (6,600 to 6,910 feet) of pebble shale at Topagoruk and from the whole section in the South Barrow and Simpson holes, as well as an abundant microfauna from Avak test well 1, show considerable similarity to faunal assemblages of Early Albian age. Astarte ignekensis Imlay, a pelecypod from South Barrow test well 1 identified by R. W. Imlay (1961, p. 37) helps to verify the Albian age of these beds (1961, p. 7).

Thus rocks with the distinctive lithologic characteristics of the pebble shale have been found to contain fossils of possible Oxfordian, Kimmeridgian, and Portlandian stages of the Jurassic period, and of Berriasian, Valanginian, and Albian stages of the Lower Cretaceous. Pebble shale makes up part of the Tiglukpuk and Okpikruak Formations, and part of it seems to be a time equivalent of the Oumalik Formation, as well. A large gap is apparent in the fossil record of this lithologic unit: no fossils of Hauterivian, Barremian or Aptian stages, which separate Valanginian from Albian time, have yet been found in it. The ages of the pebble shale at various localities is shown in figure 7.

Lower Cretaceous

Oumalik Formation.--The marine Oumalik Formation of Early Albian (Early Cretaceous) age is penetrated by several of the test wells in the Reserve. The section is most complete in Oumalik test well 1, located about 100 miles south of Barrow; this was designated the type section, and was first described as such in 1956 (Robinson, Rucker, and Bergquist, p. 225-229):

"The Oumalik formation in the type section is approximately 6,000 feet thick...and can be divided into two units: an upper shale unit, 4,410 feet thick, and a lower sandy shale, 1,610 feet thick. The upper shale unit...is a monotonous section of clay shale, medium dark gray to dark gray, slightly micaceous, carbonaceous, and pyritic. Poor to good shaly parting is parallel with the bedding; where parting is poor the rock can be considered a claystone. Siltstone and sandy siltstone occur very sparingly in the section. The siltstone...occurs in thin medium light gray to medium gray laminae, which are a little harder than the clay shale. The siltstone has very rare ripple marks and small-scale crossbedding. The upper shale unit is noncalcareous.

"The lower sandy shale unit of the Oumalik formation...is made up of 40 percent siltstone and sandstone, in addition to clay shale of the type described in the unit above. The contact between the upper and the lower unit is gradational but is placed at the top of the first sandstone of appreciable thickness; none of the sandstone beds is more than 30 feet thick. The sandstone and siltstone are medium light gray to medium gray, hard, massive, silty and very fine- to fine-grained. The grains are subangular to angular; they consist of approximately 50 percent white and clear quartz; 15 percent shiny black carbonaceous material or bitumen; and mica, altered feldspar(?), and other minerals cemented by argillaceous material or perhaps by a small amount of calcite or dolomite. Excellent small-scale cross-bedding and some ripple marks are also present in this lower unit.

"The carbonate content of the sandstone and siltstone measured quantitatively at selected intervals ranges from 12.2 to 17.4 percent. The sandstones are impermeable to air, and the porosity ranges from 2.8 to 11.4 percent.

"A few chips of bluish gray clay shale (bentonitic?) occur very rarely in cuttings from...500 to 180 feet above the base. Cuttings from the basal section of the lower unit contain rare chips with lithologic characteristics suggestive of the underlying...(pebble shale). These chips of shale contain rounded, medium to coarse quartz grains and a small amount of olive-gray, quartzitic-appearing siltstone.

"Partings of bitumen and carbonaceous plant fragments or impressions are very rare throughout the Oumalik formation in Oumalik test well 1."

Topagoruk test well 1, Simpson test well 1, and the South Barrow test wells are the only other test holes which drilled through the Oumalik Formation to the pebble shale below. In Topagoruk test well 1 the formation has a thickness of 2,700 feet, the lower 1,600 feet of which contains thin beds of sandstone and siltstone, and is probably the equivalent of the lower unit in the type section. A few tests made on the sandstones in this well showed them to be impermeable to air, with effective porosity ranging from 4.72 to 11.8 percent and a content of carbonate minerals (probably in the matrix) ranging from 2.2 to 16.5 percent by weight. The upper 1,100 feet of section in Topagoruk test well 1 consists of dark clay shale similar to the upper unit in Oumalik test well 1. In Simpson test well 1 the Oumalik Formation is 1,710 feet thick and the two units are not so well defined. The whole section is slightly siltier than the overlying Topagoruk Formation. Particularly silty and a few slightly sandy beds are found within the lowest 600 feet.

Of the remaining holes, East Oumalik test well 1 penetrated 385 feet, North Simpson test well penetrated 184 feet, Umiat test well 1 penetrated 355 feet and Umiat test well 2 penetrated 1,512 feet; three of these four holes were still drilling in the Oumalik Formation at the total depth, and Umiat test well 2 had crossed a fault and reentered the Topagoruk Formation. In these test wells, the formation consists almost entirely of clay shale.

From Oumalik test well 1, the formation thins rapidly northward, in large part at the expense of the upper unit. Southward its thickness and extent is uncertain, although similar and probably correlative beds crop out in the foothills of the Brooks Range.

Very few mega- or microfossils have been found in the Oumalik Formation in the test wells but one Radiolarian, a pyritic _Lithocampe?_ sp. is a good marker, as are a few Foraminifera (Robinson, Rucker, and Bergquist, p. 226). On the basis of these fossils, the absence of the _Verneuilinoides borealis_ microfauna (Bergquist, 1956, p. 65) so abundant in the overlying Topagoruk Formation, and its stratigraphic position, the Oumalik Formation is dated as Early Albian, and correlated with the lower part of the Torok Formation which crops out in the foothills north of the Brooks Range.

The Oumalik Formation rests on pebble shale beds, and is the oldest formation representing the graywacke-type of sedimentation common in the late Lower Cretaceous and Upper Cretaceous beds. It differs from the pebble shale in being slightly lighter colored and having practically no rounded quartz grains, very little pyrite, no glauconite, and no large mica euhedra. The siltstone of the Oumalik Formation is lighter colored because it contains grains of both white and clear quartz and chert, instead of exclusively clear quartz as in the pebble shale. The Oumalik siltstones are also less well indurated, with an argillaceous matrix in contrast to the more siliceous siltstone of the pebble shale.

The Oumalik Formation is much like the overlying Topagoruk Formation but the shales are slightly darker, harder, and less silty (in the upper part) and the microfauna is different. In North Simpson test well 1, although both formations are shale, the electric log shows a distinct change in resistivity at the contact, and there is a change in dip between the two formations, as well. There is other evidence for an unconformity at the top of the Oumalik Formation in the northern part of the Reserve: the upper unit is only 1,100 feet thick in Topagoruk test well 1, compared to 4,410 feet in Oumalik test well 1, and at Topagoruk there is a small change in dips from 3° to 8° in the Oumalik Formation to 5° or less in the Topagoruk Formation. Many of the reflection seismograph sections prepared by United Geophysical Co. show an angular discordance at the top of a zone which coincides with the Oumalik Formation as identified in the test wells. These show clearly at a depth of approximately 4,000 feet on the Simpson Peninsula (Woolson and others, 1962, p. 17). At Umiat, however, the upper contact of the Oumalik Formation is obscured by contaminated cutting samples. No sharp lithologic change was noted, however, and deposition may have been continuous there, as it appears to have been at Oumalik.

Topagoruk Formation.--The Topagoruk Formation, a sequence of Middle Albian beds consisting of medium dark gray clay shale, siltstone, and a small amount of sandstone, underlies most of Naval Petroleum Reserve No. 4 and has been penetrated by many of the deeper test wells. It includes strata which have been variously considered part of the Torok, the Tuktu, or the Umiat Formations, Lower Cretaceous units which crop out in the foothills north of the Brooks Range. The outcropping formations have been described by Gryc, Patton, and Payne (1951) and by Gryc and others (1956). The Topagoruk Formation, however, constitutes a lithologic unit which has been described as a separate formation because 1) the Tuktu Formation is defined as predominantly sandstone, 2) the Torok Formation which is defined as mostly clay shale (particularly in the upper part) contains beds of Early Albian as well as Middle Albian age, and 3) the Umiat Formation has been officially abandoned (Gryc and others, 1956, p. 211). The Topagoruk Formation was defined, and the type section described, from Topagoruk test well 1, which penetrated a typical section of the unit. The description which follows is from the paper defining the two subsurface formations (Robinson, Rucker, and Bergquist, 1956, p. 229-230).

"The Topagoruk formation type section described in this paper includes a major part of the Topagoruk member type section of the Umiat formation as defined by Gryc, Patton, and Payne, (1951, p. 162). The original member extended from 50 feet to 3,100 feet in Topagoruk test well No. 1, whereas the Topagoruk formation as now defined extends from 1,350 feet to 3,900 feet in the same hole.

"Most of the clay shale is silty, micaceous, and noncalcareous, and contains rare scattered carbonaceous partings and carbonized plant particles. Poor to fair parting is commonly parallel with the bedding planes. The medium gray siltstone is present as thin beds, laminae, and small lenses in the shale, and decreases gradually from about 25 percent of the rock to less than 10 percent with increasing depth. It is very argillaceous, noncalcareous to slightly calcareous, and micaceous. Much of the siltstone is crossbedded at a low angle. The sandstone is very fine grained, except for some minor fine-grained beds. The sandstone is concentrated in the upper 800 feet where it occurs in 1 to 20-foot beds and one bed about 60 feet thick. A few sandstone beds, a few inches to 10 feet thick, are present to a depth of 3,300 feet. The sandstone is medium light gray, argillaceous and silty; some beds are slightly to very calcareous, and most are slightly micaceous. The grains are subangular to subrounded, and the composition is similar to that of the sandstones of the overlying Grandstand Formation. Some of the clay, silt and sand were deposited in irregular streaks and lenses. Bands of silt or sand intermingled with clay impart a marbled appearance and probably reflect contemporaneous deformation caused by slumping of unconsolidated sediments.

"A typical shallow-water marine microfauna is well represented in the first 100 feet of the type section...The Verneuilinoides borealis fauna can be recognized in equivalent beds throughout the Reserve, and is a very diagnostic zone. The fauna becomes less abundant in both species and specimens with depth, and at the base of the formation microfossils are very rare or absent...

"Some megafossils have also been found in this formation. A specimen of Cleoniceras (Cleoniceras (Grycia) sablei Imlay), an ammonite characteristic of the correlative Tuktu formation, was taken from a core at 3,249 feet. Prisms and small fragments of the shells of the pelecypod Inoceramus sp. are common to a depth of 2,600 feet; a scaphopod, Laevidentalium sp. (since identified by R. W. Imlay as a tube of the worm Ditrupa cornu Imlay) is present to 2,150 feet. Both Inoceramus and Laevidentalium are present in correlative sections in every well except Kaolak test well No. 1, and Laevidentalium is limited in range to the upper part of the formation.

"The Topagoruk formation consists dominantly of fine marine clastics, in contrast to the overlying sandstone of the Grandstand formation. The base of the Topagoruk formation, at 3,900 feet, is separated in this well from the underlying Oumalik formation by a slight angular unconformity. The shale above 3,900 feet dips 5° or less, whereas the shale of the Oumalik formation dips 3-8°...Lithologically the formations are very similar, but the shale of the Topagoruk is generally slightly softer, lighter in color, and tends to break into more equidimensional, less angular fragments than the older shale. The underlying Oumalik formation contains a different microfaunal assemblage.

"Deposition was continuous from the Topagoruk into the overlying Grandstand formation, and the change from shale to sandstone was gradual. The top of the Topagoruk formation is therefore placed somewhat arbitrarily at 1,350 feet, the base of the lowest thick sandstone bed."

One anomalous feature of regional significance is the phenomenon of discordant dips within the Topagoruk Formation recorded in many seismic profiles. Reflections from formations above and below the Topagoruk Formation dip gently, paralleling the formation boundaries, but within the Topagoruk Formation there are numerous intermittent reflections recording dips which are consistently steeper than those of the formation itself (and may result from deltaic foreset bedding). These dips are inclined south and east from Barrow to Simpson and toward Fish Creek, eastward from Oumalik to Square Lake and northward from Oumalik toward Topagoruk (Woolson and others, 1962, p. 15).

The Topagoruk Formation attains its maximum thickness in a northwest-trending basin covering most of the eastern part of the Reserve (see fig. 8). The northeasternmost test well, Fish Creek test well 1,

Figure 8. Isopach map of the Topagoruk Formation based on subsurface data.

penetrated the thickest section of the formation drilled in any hole--some 4,000 feet of strata composed almost entirely of clay shale. Siltstone and sandstone laminae in the upper few hundred feet may be part of the Ninuluk Formation, but because they are unfossiliferous, and the lithology is not distinctive enough to permit good correlation, the beds are tentatively included in the Topagoruk Formation. These laminae and a few thin beds of siltstone and very fine grained sandstone in the lower part of the formation are the only interruptions in the monotonous sequence. The bottom of the hole is probably very close to the bottom of the formation, and a slight change in the resistivity curve of the electric log suggests that it may actually have drilled into the top of the underlying Oumalik Formation. For lack of control, however, the entire section is here considered part of the Topagoruk Formation.

At Gubik, the wells drilled through a section of shale with a small amount of siltstone and sandstone in the upper few hundred feet. This sequence, which underlies the Chandler-Ninuluk Formations (undifferentiated) was separated into Grandstand and Topagoruk Formations, in the paper on the Gubik test wells (Robinson, 1958a, p. 211), but because of their fine grain size the beds are here classed with the Topagoruk Formation. The upper, sandier part of the strata is equivalent to the sandstone beds at Umiat which contain most of the oil in that field; eastward replacement of Grandstand sandstone by Topagoruk shale is well illustrated by a comparison of the two areas.

To the west, southwest and south, the formation becomes thinner. Beds of sandstone appear in the upper part of the unit and thicken gradually westward, developing to form the Grandstand Formation as coarser deposits take the place of the silty clay shale. At Gubik the sandstone beds are thin and rare; farther west and south, along an arc outlined by Simpson Seeps, Topagoruk, Oumalik, Wolf Creek, Umiat, and Grandstand, the sandstone beds are thicker and more numerous, and, as is particularly well shown from east to west along the Umiat structure (see pl. 11), massive sandstone beds of the Grandstand Formation interfinger with and replace the shale and siltstone of the Topagoruk Formation. Still farther south and southwest, even more of the Topagoruk Formation is replaced by sandstone, which crops out in the foothills of the Brooks Range and is there designated the Tuktu sandstone. The lower part of the Topagoruk Formation persists as shale, however, and is correlative with the upper part of the Torok

Formation, a clay shale sequence underlying the Tuktu Formation where they crop out in the foothills.

To the west, the Topagoruk Formation is displaced gradually, first by the marine sandstone of the Grandstand Formation, and eventually by nonmarine beds which include some coal and clay ironstone. At Kaolak test well 1, the most westerly hole, the Topagoruk Formation is represented by a slightly fossiliferous section of clay shale which contains a little siltstone and sandstone in the lowest 2,400 feet of the hole; it is overlain by nonfossiliferous coaly clay shale which appears to be nonmarine, and is probably equivalent to part of the Corwin Formation, as described by Chapman and Sable (1960, p. 102). Marine sandstone containing microfauna of the Verneuilinoides borealis zone crops out near and west of the western border of the Reserve, and has been described as the Kukpowruk Formation (Sable, 1956, p. 2,637). Underlying and interfingering with it is marine shale which is part of the Torok Formation; it too contains microfauna of the Verneuilinoides borealis zone (Chapman and Sable, 1960, p. 83). The Topagoruk Formation in the lower part of Kaolak test well 1 contains a Verneuilinoides borealis assemblage similar in quantity and preservation to that of the Kukpowruk Formation (Bergquist, in Collins, 1958, p. 374) and is probably equivalent, therefore, to the interfingering Kukpowruk and upper part of the Torok Formations as they occur in this western area. The distance between the test wells and the outcrops (the nearest outcrops of the Kukpowruk Formation are about 35 miles south of Kaolak test well (Chapman and Sable, 1960, plate 9)) makes definite correlation uncertain, and more data will be needed to clarify the exact relations between the Topagoruk Formation in the eastern part of the Reserve and the sequence of beds laid down farther west.

The northern extent of the Topagoruk Formation is unknown (it may continue for some distance north of the present Arctic coastline) but, unlike its western and southern limits, the upper boundary of the formation in the north is marked in most test wells by a disconformity, and much of the unit has been removed by erosion. In North Simpson test well 1, where a period of erosion preceded deposition of Late Cretaceous sediments, all but the lowest 820 feet of the section is missing. A short section of shale in the lower part of Simpson core tests 25, 27, and 28 is here considered to represent the Topagoruk Formation, although it was not differentiated from the Grandstand Formation in the original description of the holes (Robinson, 1964, p. 654). In the vicinity of Point Barrow, erosive action taking place since Early Cretaceous times and before deposition of the Quaternary mantle has also cut deeply into the Topagoruk beds, removing them entirely in the structurally complex area at Avak test well 1, and leaving only the lower 1,000 feet of the formation at South Barrow test well 3. The presence of 1,700 feet of Topagoruk clay shale and about 300 feet of the overlying Grandstand Formation in South Barrow test well 1, the northernmost test, suggests, however, that the original area of deposition extended some distance to the north.

The Topagoruk Formation, in which the Verneuilinoides borealis microfauna has its best development, is the most consistently fossiliferous unit of Early Cretaceous age in the subsurface. Besides the Foraminifera, worm tubes of Ditrupa cornu Imlay, Inoceramus sp., and minute crinoid ossicles (Balanocrinus, sp.), are found near the top of the formation. Fossils are most common in the upper, slightly silty and sandy part of the formation. The fauna also increases in abundance, particularly in calcareous Foraminifera, from south to north. Much of the fauna has been described by Mrs. Leoblich (Tappan, 1958, p. 201-222).

Nanushuk Group (Lower and Upper Cretaceous)

The Nanushuk Group of Early Cretaceous and early Late Cretaceous age was described by Gryc, Patton, and Payne (1951, p. 162), and was redefined by R. L. Detterman in 1956 (1956a, p. 233). Outcrops in the foothills north of the Brooks Range consist of sandstone, conglomerate, siltstone, and shale, with minor amounts of coal, ironstone, bentonite and limestone concretions. It is divided into the marine Tuktu, Grandstand, and Ninuluk Formations, and the nonmarine Chandler Formation which intertongues with the two latter formations. The Chandler Formation has two major tongues, the Killik and Niakogon Tongues. In the subsurface, the Tuktu Formation is absent (it is represented there by the marine shale of the Topagoruk Formation), and the upper (Niakogon) tongue of the Chandler Formation has not been identified. The appearance of the other three units is described below.

Grandstand Formation.--The marine Grandstand Formation, of Albian age, composed primarily of sandstone, interfingers with and overlies the Topagoruk Formation in the subsurface, and is distinguished from it by the comparatively large proportion of sandstone. It is a widespread unit, present in almost every test well, and is the reservoir of much of the oil so far produced in northern Alaska. The sandstone is commonly light gray, medium to very fine grained, poorly to moderately well sorted, and is composed of subangular to subrounded grains of white and clear quartz with some gray chert and dark rock fragments. The grains have low sphericity; their surfaces may be frosted. Argillaceous cement is common, and in a few beds calcium carbonate further consolidates the rock. Mica and pyrite are rare, and glauconite is present only as casts of Radiolaria. Medium dark gray clay shale is interbedded with the sandstone, separating the coarser deposits into massive or thin-bedded layers. Siltstone makes up only a minor part of the rock. The formation varies greatly in thickness, ranging from 100 feet or less at the eastern and westernmost occurrences to nearly 3,000 feet in the area of greatest deposition. The formation grades upward into the nonmarine Chandler Formation and the boundary in some cases is obscure.

The type section, named from exposures on the left bank of the Anaktuvuk River where it crosses the Grandstand anticline, is described by Robert L. Detterman (1956a, p. 236). At that place, "the basal part of the formation is predominantly fine-grained, light olive-gray to dark yellow-red sandstone, with a thin, greenish, "salt and pepper" sandstone bed at the base, and subordinate amounts of siltstone and shale. In the upper part, siltstone and silt shale constitute about 50 percent of the unit; minor amounts of coal occur within this sequence". Concretions, plant fossils, and crossbedding are present in the type section, which also contains the Verneuilinoides borealis microfauna and some long-ranging pelecypods. The formation in the subsurface is correlated with this unit because both are marine and are predominantly sandstone, both contain the distinctive microfaunal assemblage, and both occur between nonmarine beds above and finer-grained marine strata below.

The Grandstand Formation is thickest in the central part of the region, in the vicinity of Meade and Oumalik test wells, thinning gradually to the east and south and, probably, to the west; it thins more rapidly to the north where some of it has been eroded (see fig. 9). The greatest concentration of sandstone does not coincide with the thickest part of the formation, however, and figure 10 shows the concentration to be in a northwest-southeast band extending from East Topagoruk test well 1 to the Wolf Creek area, approximately parallel

Figure 9. Isopach map of the Grandstand Formation based on subsurface data.

Figure 10. Isopach map showing the total thickness of sandstone beds in the Grandstand Formation.

to the strike of isopach lines drawn on the Topagoruk Formation as shown in figure 8.

An east-west cross section, plate 1, shows the major characteristics and changes in the Grandstand Formation in the subsurface of the southern part of the Reserve. The most thoroughly examined strata of the formation are those in the Umiat field, where all holes were drilled into or through it. In this field, the Grandstand Formation consists of an upper and a lower series of sandstone beds separated by clay shale, a sequence that is described in the chapter on the Umiat field (p. 212 ff). Both the upper and lower sandstone beds contain oil at Umiat but the lower sequence has more massive, slightly more permeable and somewhat coarser sandstone than the upper part of the formation (see table 2, p. 225) and consequently is a better reservoir. At Gubik, 20 miles to the east, most of the sandstone beds have graded into siltstone and clay shale and are here considered to be part of the Topagoruk Formation, although they had previously (Robinson, 1958a, p. 211-212) been placed in the Grandstand Formation. A slight show of oil was noted in the coarser beds, but reservoir properties are very poor and almost no fluid was obtained from the strata, which are equivalent to the productive sandstone beds of the Umiat field.

West from Umiat, however, the formation thickens as coarser sediments replace the fine deposits of the underlying Topagoruk Formation. The cross section described above shows the increase in sandstone to the west. In the vicinity of Wolf Creek and Titaluk the upper part of the Grandstand Formation resembles the sequence at Umiat in having some interbedded sandstone and clay shale near the top which are separated by a predominantly clay shale section from more massive and slightly coarser sandstone layers below. At Umiat the more massive group of sandstone beds is underlain by the Topagoruk Formation, made of clay shale with a few thin beds of sandstone and siltstone. At Wolf Creek, however, this group of sandstone beds is underlain by more than 600 feet of strata, also of the Grandstand Formation, consisting of thick sandstone beds separated by clay shale. In Titaluk test well 1, more thick sandstone beds lower the base of the formation, and the sandstone is coarser than it is in the eastern holes. Porosity and permeability decrease from east to west in spite of the increasing grain size, partly because the grains are less well sorted and have much more interstitial material, and partly because of an increase in the amount of calcareous cement, especially at Titaluk.

East Oumalik test well 1 is 40 miles northwest of Titaluk test well 1, and the Grandstand Formation there, consisting of 2,320 feet of interbedded sandstone and clay shale, is about 650 feet thicker than at Titaluk. The sandstone beds are more evenly distributed throughout the unit and the more massive beds are not concentrated in one part of the section. Coarse sand is lacking, and the most common grain size is fine-grained. Porosity is about 10 percent, and permeability is also low but in this case the poor reservoir properties are primarily the result of a large amount of calcareous cement, as the sorting is better and the argillaceous interstitial material less abundant than it is at Titaluk. Oumalik test well 1, only 12 miles northwest, has a section similar to that at East Oumalik but there are some very fine grained sandstone beds lower in the section than any at East Oumalik, and the Grandstand Formation in this hole is almost 2,800 feet thick. The calcareous cement common at East Oumalik is even more conspicuous here, reducing the porosity of most of the beds to about 10 percent and the permeability to less than 5 millidarcys.

In Meade test well 1, 40 miles beyond Oumalik test well 1, the Grandstand Formation reaches its maximum known subsurface thickness of 2,965 feet. In this area, however, the sandstone beds are thinner and less numerous than to the east. The few porosity and permeability figures available suggest poor reservoir qualities. Thus the thickness of the formation in this area indicates not a larger amount of sandstone but a greater interval through which the sandstone beds are distributed. The intervening strata, like those in the holes to the southeast, consist of gray clay shale with a very little siltstone. The beds of coal, present in the upper few 100 feet of the unit, suggest interfingering of nonmarine sediments as the overlying nonmarine Chandler Formation gradually displaces the marine Grandstand beds.

Carbonaceous particles are common in beds above and below the coaly sequence, and in many cases outline laminae and minute lenses in the sandstone or siltstone, as shown in figure 11.

Figure 11. Carbonaceous particles outline laminae and small lenses in siltstone and sandstone of the Grandstand Formation. The core shown here was taken at approximately 2,955 feet in Meade test well 1.

To complete the picture of diminishing sandstone (and of increasing nonmarine deposits) toward the western side of the Reserve, Kaolak test well 1 has also been included in the cross section, plate 1. Nearly 100 feet of sandstone is present in this test between a nonmarine, coaly sequence above and 1,300 feet of probably nonmarine clay shale with a little siltstone below. The sandstone may be marine, although no fossils or lithology diagnostic of either environment were noted within it; if it is, it may represent the westernmost occurrence of the Grandstand Formation. The nearest identifiable sandstones, however, which crop out about 35 miles southwest, are part of the Kukpowruk Formation (Chapman and Sable, 1960, pl. 9), and the sandstone in Kaolak test well 1 may correlate with this western formation instead. A third possibility is that the sandstone in Kaolak test well correlates with both formations, and thus forms the connecting link between them. The relations between the various sandstone beds must wait for additional information before they can be clarified.

In the southeastern part of the Reserve, the Grandstand Formation changes very little from northwest to southeast, in contrast to the rapid facies change from northeast to southwest. About 30 miles south-southeast of Umiat, (nearly at right angles to the line of the cross section in plate 1), Grandstand test well, (Robinson, 1958b, pl. 19) disclosed a sequence which is very similar to that at Umiat, as shown in plate 2. At Grandstand, the sandstone is slightly coarser than it is in comparable beds at Umiat, but it contains a much greater proportion of silt and argillaceous interstitial material, and therefore does not have the good reservoir properties of the beds at Umiat. Except for this difference, a slight increase in thickness is the only change in this distance, in contrast to the marked facies change in the shorter distance from Umiat to Gubik. Comparisons of other tests in which one hole is north of the other, such as Knifeblade and Titaluk or Wolf Creek and Square Lake (see index map, fig. 1), also show comparatively little change in those directions, although the southern tests in each case have a slightly greater amount of coarser sand than the northern ones.

In the northern test wells which drilled through the formation at Topagoruk, Simpson, and Barrow, the thickness of the unit depends primarily on the depth to which erosion has removed the upper beds. East Topagoruk with about 1,660 feet, may have a nearly complete section, whereas it has been removed entirely from some of the holes in the vicinity of Point Barrow. The sandstone in this northern area is fine- to very fine-grained, but is commonly less argillaceous and silty, generally lacks calcareous cement, and has much greater porosity and permeability than the sandstone in the southern tests (fig. 12).

Figure 12. Lines of equal porosity based on averages of all sandstones tested in the Grandstand Formation.

In the Topagoruk test wells, a few thin beds of coal interrupt the dominantly marine sequence, but nonmarine sediments in the other tests are represented only by particles of coaly or carbonaceous material. In keeping with the nearly north strike of sections with similar sequences of beds farther south, the sequence of beds in Topagoruk and Simpson test wells resemble each other, with the thicker sandstone beds in the lower part of the formation and thinner, more widely spaced ones in the upper part. The sections in the Barrow holes include only the lowest few hundred feet of the formation, but these beds have the highest porosity of any rocks in the Reserve.

East of the Topagoruk test wells, the Grandstand Formation thins as the sandstone beds grade into the siltstone and clay shale of the Topagoruk Formation. At Fish Creek test well 1, the northeasternmost hole, the Grandstand Formation is missing and beds of the Colville Group rest directly on the Topagoruk Formation. Thin interbedded layers of siltstone and clay shale in the uppermost 100 feet of the Topagoruk Formation may be the eastern equivalent of the sandstone beds of the Grandstand Formation to the west, or may represent the Ninuluk Formation.

<u>Chandler Formation</u>.--The Chandler Formation, of Albian and Cenomanian (Cretaceous) age, is a nonmarine stratigraphic unit which interfingers with or overlies the marine Grandstand Formation. In some areas it is divided by the marine Ninuluk Formation into two members, the Killik and Niakogon Tongues, the type sections of which are on the Killik River; they have been described by R. L. Detterman (1956a, p. 237-241). The lower part of the Killik Tongue (of Albian age) in these outcrops is nearly 1,100 feet thick, and consists of massive sandstone beds with a little siltstone, common thin layers of pebbles, and some coal and clay ironstone. The upper part of the tongue contains the same rock types but sandstone is much less prominent and siltstone makes up the bulk of the rock, except for massive conglomerate layers. The Killik Tongue is about 2,800 feet thick, at the type section; it has been found in test wells only in the southern part of the Reserve. The overlying Niakogon Tongue (of Cenomanian age) has not been definitely identified in the subsurface. In the eastern holes the nonmarine beds are overlain by the Ninuluk Formation, and hence are part of the Killik Tongue; in the west the thick nonmarine sequence is overlain only by Pleistocene or Recent deposits, and cannot be divided into tongues.

In test wells at Wolf Creek, about 35 miles north of the type section, the Killik Tongue is both thinner (900 feet thick) and finer grained than it is at the type section. The conglomerate and massive sandstone and siltstone beds found in the outcrop are lacking, and the section is made up primarily of medium dark gray clay shale, with thin beds of very fine-grained sandstone, and coal, particularly in the upper part. Clay ironstone and bentonite are rare. A distinctive feature of the lower sandstone and siltstone beds in this and other southern test wells is the abundance of sericite; enough is present to impart a sheen to broken surfaces and to lower porosity and permeability of the beds. The sequence is considered part of the Killik Tongue because the beds appear to be nonmarine, because the underlying sandstone contains the <u>Verneuilinoides</u> <u>borealis</u> microfauna and is typical of the Grandstand Formation, and because the overlying strata of interbedded sandstone and clay shale contain the limited but distinctive microfauna of the Ninuluk Formation.

At Knifeblade, about 35 miles west-northwest of the type section, the Chandler Formation appears at the surface, and only the lower 800 feet of it was penetrated by the drill. The section here is similar to that at Wolf Creek, although clay ironstone concretions and coal are somewhat more common at Knifeblade, and sericite is particularly abundant there.

Titaluk test well 1, about 45 miles northwest of the type section, drilled through 1,260 feet of the Killik Tongue. There is no sharp break between it and the overlying Ninuluk Formation, and the contact is put "at the base of a thick sandstone where there is a diminution of microfossils which may be indicative of nonmarine beds" (Robinson, 1959a, p. 379). The rock is similar to that at Wolf Creek, except that the coal is more common near the middle of the formation instead of in the upper part.

In more easterly tests, the formation is much thinner, as shown in plate 1; it is represented in the Umiat area by approximately 300 feet of clay shale with some sandstone and a little coal and clay ironstone. There are no beds definitely identifiable as nonmarine in the Gubik wells, where a 400-foot section of sandstone and clay shale with a little clay ironstone between the Seabee and Grandstand Formations is equivalent to the Ninuluk and Chandler Formations undifferentiated. A lack of coal beds or other evidence of nonmarine deposition in these beds makes a more specific correlation uncertain. The sandstone in this section is the reservoir of a considerable quantity of gas; its porosity ranges from 1.6 to 15.1 percent and permeability from 0 to 265 millidarcys.

In the western part of the Reserve, the Chandler Formation thickens greatly at the expense of the marine units (fig. 13). Coal also becomes more abundant, with beds several feet thick in the Meade and Kaolak test wells, and in outcrops near the Meade River. In Meade

Figure 13. Isopach map of the Chandler Formation, based on subsurface data.

test well 1, the Chandler Formation is approximately 1,200 feet thick, and the section, although predominantly clay shale, contains many beds of coal and numerous clay ironstone nodules, and many charophytes, typical of this formation, were recovered from the washed microfossil samples. At Kaolak test well 1, 70 miles west of Meade, the nonmarine deposits make up a section (from 113 to about 4,600 feet) which is almost 4,500 feet thick. The lowest part is composed of 1,400 feet of unfossiliferous clay shale with rare sandstone and coal; this is overlain by about 100 feet of sandstone. Above the sandstone is a 1,900-foot sequence which contains numerous coal beds (one of which is 17 feet thick), interbedded with clay shale and a small amount of sandstone. Above the 1,900-foot coaly section coal diminishes and thick sandstone beds make up most of the rock; clay ironstone is particularly abundant in the uppermost 400 feet of this 1,100-foot interval, which completes the essentially nonmarine sequence.

Microfossils indicate that the clay shale underlying these nonmarine beds is largely marine, and the species present are typical of the Topagoruk Formation, with which the fossiliferous beds are correlated. The nonmarine sequence of the Chandler Formation in Kaolak test well 1 may continue and thicken to the southwest, to become the equivalent, at least in part, to the thick, nonmarine Corwin Formation as it is described by E. G. Sable (Sable, 1956, p. 2,641), and Chapman and Sable (1960, p. 101), in the region to the south and west of the test well.

Square Lake test well 1 is the only hole north of the line of cross section of plate 1 to drill into rocks which may represent the Chandler Formation. The section in this test well, which is about 15 miles north of the Wolf Creek holes, consists of 590 feet of beds (from 1,885 to 2,475 feet) which, like those in the Gubik wells, cannot be definitely proven marine or nonmarine. The uppermost few feet contain microfossils typical of the Ninuluk Formation, but carbonaceous plant flakes and a few clay ironstone nodules common in the Chandler Formation are present in the lower part of the section. Most of the rock is clay shale, but there are numerous thin beds of sandstone in the lower part, and a few close to the top. Unlike the comparable sections of the Titaluk and Knifeblade holes, there is no definite correlation of beds between this hole and Wolf Creek, and the boundaries are defined more on the characteristics of the over- and underlying beds than on those of this Ninuluk-Chandler sequence itself.

The northern test wells, at Topagoruk, Simpson and Barrow did not encounter any beds of the Chandler Formation, which was either never deposited or has since been eroded from this area. In Simpson and Topagoruk test wells, however, a few thin coal beds in the upper part of the Grandstand Formation suggest that there was at least a minor amount of nonmarine deposition in the vicinity and probably an increase in quantity and duration of nonmarine sedimentation took place of which no record now remains. At Simpson Seeps and in Fish Creek test well 1, there is no evidence of nonmarine strata: in the Simpson core tests marine sandstones with interbedded clay shale are continuous from the Grandstand through the Ninuluk Formation, and at Fish Creek a marine section is continuous, with the Seabee Formation resting on marine siltstone and shale of the Topagoruk(?) Formation.

<u>Ninuluk Formation</u>.--The type section of the marine Ninuluk Formation, which is Cenomanian (early Late Cretaceous) in age, is at the Ninuluk Bluffs on the Colville River about 20 miles below the mouth of the Killik River. They were described by Detterman (1956a, p. 241). In this area the Ninuluk Formation is 657 feet thick but it is interbedded with two units of the nonmarine Niakogon Tongue of the Chandler Formation which are 261 feet thick. The Ninuluk Formation at the type section is about 60 percent marine clay shale and siltstone. The remainder is mostly coarse sandstone with thin lenses of conglomerate. Marine fossils are present, especially in the basal part.

The subsurface section nearest to the type section is in the Wolf Creek area, about 16 miles north. Here 520 feet of the Ninuluk Formation was penetrated but no part of the Niakogon Tongue of the Chandler Formation is differentiated. In the Wolf Creek holes the formation consists of about 60 percent clay shale and siltstone and 40 percent sandstone, similar to that in the type section, but the average grain size of the sandstone is smaller and the thickness of the nonmarine beds in the section is considerably less. The sandstone at Wolf Creek, similar in composition to that found lower in the Nanushuk Group, is primarily very fine to fine grained with a few strata containing medium grains. A total of 75 feet of carbonaceous clay shale, coaly, and bentonitic beds possibly of nonmarine origin are scattered through the formation, compared to 261 feet of Chandler Formation interbedded at the type section.

Two shallow-water marine or brackish-water Foraminifera, Gaudryina irenensis Stelck and Wall and Trochammina rutherfordi Stelck and Wall, as well as Inoceramus and other pelecypods have been found in the Ninuluk Formation in the subsurface. The microfossils are diagnostic and serve to differentiate the formation from other strata.

Twenty-five miles to the west, the Ninuluk Formation in Titaluk test well 1 is approximately the same thickness as at Wolf Creek, but is somewhat less sandy. Both mega- and microfossils are found throughout the formation, even in the carbonaceous strata which might otherwise be judged nonmarine. Farther west the formation is absent; older Cretaceous beds are at the surface.

East, northeast, and north of the Titaluk and Wolf Creek areas the formation gets thinner. Sandy strata with thin clay shale interbeds containing the Gaudryina-Trochammina fauna are found at Square Lake (about 65 feet) and Umiat (105 feet). At Umiat the fauna is found at the base of a sandstone which has shows of oil. The effective porosity of the sandstone in Umiat test well 11, where numerous determinations were made, averages 12.52 percent; the air permeability ranges from impermeable to 56 millidarcys. At Square Lake the Ninuluk Formation is not differentiated from the Chandler Formation because it is not possible to tell which beds are marine and which are not. The upper sandstone beds immediately underlying the Gaudryina-Trochammina fauna have an effective porosity ranging from 11.1 to 17.5 percent and an air permeability from impermeable to 645 millidarcys. A very thin conglomerate of rounded black chert pebbles is present at the top of the undifferentiated section at Square Lake test well 1. The Ninuluk Formation is also undifferentiated in the Gubik area, where the distinctive microfauna is found only at the top of 300 feet of sandstone and siltstone which produce gas.

In the Simpson area the Chandler Formation is absent and 170 feet of marine beds overlie the Grandstand Formation. These beds contain Radiolaria and a few arenaceous Foraminifera which seem to have affinities to the Colville Group. On the other hand, the rock types---interbedded sandstone, siltstone, clay shale, carbonaceous shale, and a small amount of coal and bentonite---are similar to those of the Ninuluk Formation. These beds are included in the lower part of a sequence which is called the Ninuluk-Seabee Formations undifferentiated.

A sequence of 110 feet of sandy siltstone and shale at Fish Creek test well 1 is described (p. 55) as probably belonging to the upper part of the Topagoruk Formation on the basis of lithology. It contains no fossils, however, and could, from its stratigraphic position, be considered part of the Ninuluk Formation.

The Ninuluk Formation cannot be readily distinguished from the Chandler Formation on the basis of lithology alone, as the contact is gradational. Confirmation by the presence of marine fossils or a correlative sequence of beds is necessary. In some places the Ninuluk Formation is also difficult to distinguish from the Seabee Formation as Nanushuk Group sandstone beds probably have been reworked into the basal Seabee Formation. Both the Ninuluk and Seabee Formations contain bentonite beds which show no visible difference in character, although bentonite is much more common in the Seabee Formation. An unconformity between the Ninuluk and Seabee Formations in the subsurface may be inferred from the rapid thinning of the Ninuluk Formation, particularly between Wolf Creek and Umiat. On the surface near the type section of the Ninuluk Formation, R. L. Detterman reports an angular discordance of 41°, and from 8° to 20° elsewhere (personal communication, 1957, and Detterman, Bickel, and Gryc, 1963, p. 263).

Upper Cretaceous (Colville Group)

The marine Seabee and Schrader Bluff Formations and the nonmarine Prince Creek Formation make up the Colville Group of Late Cretaceous age. The rocks of the Colville Group, which consist of interbedded clay shale, siltstone, and sandstone, are similar to that of the Nanushuk Group, but the Colville Group contains a much larger amount of volcanic material, and a different mega- and microfauna.

Seabee Formation.--The Seabee Formation, of Turonian age, is largely clay shale but contains varying amounts of coarser clastics. At the type section in Umiat test well 11 (Whittington, 1956, p. 246) the formation is about 1,500 feet thick and consists, from bottom to top, of 230 feet of sandstone and siltstone with thin beds of clay shale, 315 feet of medium dark gray clay shale, 190 feet of medium light gray sandstone with a little shale, 195 feet of medium dark gray shale, 320 feet of medium gray clay shale including a small amount of sandstone, 55 feet of medium light gray clay and silty sandstone, and finally 190 feet of medium gray shale. The sandstones and siltstones are made up of subangular grains of clear quartz with a small amount of white quartz and rock fragments. The sandstones are silty, very fine to fine-grained and contain scattered plates of biotite and white mica and some carbonaceous particles. Slight shows of oil were noted in the basal sandstones; the porosity is variable, ranging from 0.55 to 20.64 percent, and permeability from 0 to 48 millidarcys. The clay shale and claystone, differentiated by shaly or conchoidal cleavage, is medium gray to medium dark gray, is commonly silty, micaceous, and usually has laminae or thin beds of siltstone. Bentonite is common throughout the formation and is found in light gray, light bluish gray, or medium light gray beds a fraction of an inch to a few inches thick. In some horizons the thin alternating beds of clay shale and bentonite resemble varves.

The clay shale in the lower 950 feet of the type section is darker in color and is a little harder than the clay shale above. The darker shale beds, which apparently correlate with those that weather to paper-thin fragments on the surface, have been referred to by field geologists in the Umiat area as the "paper" shales (Whittington, 1956, p. 246). These beds are commonly very fossiliferous and contain the ammonite Borissiakoceras sp., numerous specimens of the thin-shelled Inoceramus labiatus Schlotheim, brownish fishbone fragments and scales, a few Radiolaria and a few Foraminifera, both calcareous and arenaceous.

The upper 245 feet of the type section has been tentatively referred to the Ayiyak Member of the Seabee Formation (Detterman, 1956b, p. 253) which crops out south of Umiat. Lithologically, however, this member is not clearly distinguished anywhere in the subsurface although Pseudoclavulina hastata (Cushman) and Arenobulimina torula Tappan, typical foraminifera of the Ayiyak Member, are found in Umiat test well 11, and in other test wells.

The Seabee Formation at Square Lake, 30 miles northwest of Umiat, is 310 feet thinner (700 to 1,885 feet) than at the type section. Most of the loss of section appears to have taken place near the top of the formation which has given way to the nonmarine Tuluvak Tongue of the Prince Creek Formation. The basal sandstone in this test well is a little thicker and coarser grained than at Umiat, and the intermediate sandstone is thinner. Effective porosity of the basal sandstone is moderately good, (10.3 to 20.4 percent), air permeability is poor, (impermeable to 43 millidarcys), and a few thin beds are calcareous.

The only occurrence of the Seabee Formation in the subsurface farther west is at the top of Wolf Creek test well 1, 30 miles west of Umiat, where 85 feet of clay shale, bentonite and siltstone beds containing a sparse Seabee microfauna were drilled.

In the Gubik area, 20 miles east of the type section, the Seabee Formation is a little siltier and sandier in the lower 500 feet; otherwise it is very much the same as the type section, although the distinction between the lighter and darker shale beds is absent, and the shale is mostly medium gray. A few very thin beds of limestone and some prismatic aragonite are found at Gubik. The basal sandstone beds are very "dirty", and porosity and permeability are low; oil shows were negligible.

In the northeastern corner of the Reserve, in Fish Creek test well 1, the Seabee consists of 1,235 feet of light gray micaceous clay shale with very little sandstone or siltstone. Borissiakoceras sp. shells are present and fish bone fragments are common in the lower part of the section.

The Seabee section in the Simpson Seeps area, on the Arctic Coast, apparently is unconformable on, and contains reworked material from, the Nanushuk Group below. The Seabee Formation is only about 200 feet thick over most of that area, although 1,500 feet of Seabee shale fills a canyon there that was eroded in pre-Seabee beds (see p. 183 ff.). Thin beds of the formation which are identical in appearance to the "paper" shale beds at Umiat are found but are only about 50 feet thick. A few argillaceous, silty sandstone beds as much as 25 feet thick are also present, as well as thin limestone beds and aragonite like that at Gubik. Some oil is found in the basal sandy beds of the Seabee Formation at Simpson Seeps Oil Field. These beds, found in the permafrost zone within 400 feet of the surface, are nearly unconsolidated, and the effective porosity (which has never been adequately measured because of the poor induration) must be quite high--25 percent or greater.

The typical megafossils of the type section are common and Radiolaria are abundant. The formation also contains two genera of pelagic Foraminifera, *Hedbergella loetterlei* (Nauss) and *Heterohelix globulosa* (Ehrenberg) (Tappan, 1962, p. 96) which, with *Borissiakoceras* and *Inoceramus labiatus* Schlotheim, are present in North America in the Lower Turonian strata (Stelck and Wall, 1954, p. 14-16, and Jones and Gryc, 1960, p. 160). About 1,250 feet of medium light gray clay shale in North Simpson test well 1 is also considered Seabee in age because of the presence of *Borissiakoceras* sp. and *Inoceramus* prisms. *Leptolepis*, a fish, is present in the same beds.

Sandstone in the Seabee Formation can usually be differentiated from that of the Nanushuk Group by the abundance of the biotite, and rock particles, and by the argillaceous "dirty" matrix. Despite these features determination of the exact contact between the two is difficult. The basal sandy section of the Seabee Formation, which varies locally in thickness, may represent a reworking of the Nanushuk Group sandstone. The nature of the contact itself is obscure and an unconformity is probably present.

The upper contact of the formation is gradational and has been placed wherever the proportion of sandy nonmarine beds of the Tuluvak Tongue of the Prince Creek Formation exceeds that of the marine silty clay shale of the Seabee Formation.

Prince Creek Formation.--The Prince Creek Formation, named for Prince Creek, a tributary of the Colville River southwest of Umiat (Gryc, Patton, and Payne, 1951, p. 166), is divided into two tongues. Both are nonmarine, and interfinger with marine members of the Schrader Bluff Formation. The lower, the Tuluvak Tongue, is partly the time equivalent of the Rogers Creek and Barrow Trail Members of the Schrader Bluff Formation, and of part of the Ayiyak Member of the Seabee Formation. The upper, the Kogosukruk Tongue, is equivalent to and possibly slightly younger than the Sentinel Hill Member of the Schrader Bluff Formation. The Tuluvak Tongue is found in the subsurface in five holes drilled in the northeast part of the Reserve, and the Kogosukruk Tongue in one.

Tuluvak Tongue.--In the type section, at Tuluvak Bluffs on the Chandler River, the Tuluvak Tongue is 1,200 feet thick (Gryc, Patton, and Payne, 1951, p. 166). The thickest section of it in the subsurface, however, is found in the Gubik test wells, where it is 871 feet thick. Six hundred and seventy-five feet and 523 feet are found in Square Lake test well 1 and in Umiat test well 11 respectively, but in both of these, the upper part of the tongue has been eroded. At Fish Creek test well 1, 25 feet of nonmarine beds of the Tuluvak Tongue comprise the northernmost evidence of Cretaceous nonmarine deposition in northern Alaska.

The following description of the Tuluvak Tongue is based on Gubik test well 2, where much of the section was cored. More than half of the rock is sandstone or siltstone which is light gray to medium light gray. It varies from soft to moderately hard and from thinbedded to massive. The sandstones are among the coarsest drilled on the Reserve and the grains range in size from very fine (rarely silt-sized) to very coarse, grading in a few rare thin layers to a conglomerate of well rounded black chert and white quartz granules and pebbles. The grains are subangular to subrounded, and larger sizes are the best rounded. White and clear quartz are the main constituents (50 to 85 percent) of the sandstone but in some beds as much as 40 percent of the total is dark gray and black chert. The latter beds have a typical "salt and pepper" appearance. The remainder of the grains are made up of biotite, coal, ironstone, white feldspar(?), siderite, pyrite, and rock fragments. The matrix is either argillaceous, sideritic, or calcareous. Calcareous cement totalled 54 percent of the rock, in one sample from Gubik test well 2.

The clay shale which makes up 12 percent of the Tuluvak Tongue is medium light gray to medium gray, is soft to hard, and has good shaly cleavage except in the lowest part of the section where claystone is present. A small amount of clay shale, usually associated with coal, is black and carbonaceous. Bentonite is a conspicuous constituent of the section, either finely disseminated in the clay shale or in beds commonly a few inches to 2 feet thick. The rock is soft, and is white or very light yellowish, greenish, or bluish gray. It is also found rarely in the matrix of the sandstones. Coal, shiny to dull black, brittle with conchoidal or blocky fracture, is common in thin beds. Bits of clear yellow amber were seen in the coal. Carbonaceous laminae and partings, and carbonized plant fragments are abundant in both the clay shale and sandstone. Clay ironstone nodules and lenses are common in the Tuluvak Tongue; limestone layers are very rare, thin, hard, and medium gray in color. Calcite and aragonite are present in tiny veinlets in the limestone.

The Tuluvak sandstone is the upper gas-producing horizon in the Gubik field. In this field the porosity of the sandstone ranges from 4.4 to 25.4 percent, averaging about 15 percent, and the air permeability from impermeable to 3,780 millidarcys.

At Umiat, the rock in test well 11 is similar to that at Gubik. Not identified at Gubik, however, are two beds of yellowish white bentonite, 5 and 7 feet thick, which were cored, and coal beds as much as 3 feet thick. The sandstone of the Tuluvak Tongue has been eroded off the crest of the anticline, but low on the north flank of the structure, where it was penetrated by Umiat test well 11, a few oil odors remained in it. The effective porosity ranges from 8 to 18 percent and air permeability from impermeable to 26 millidarcys. A few shale beds containing a sparse microfauna represent intertongues of the marine Schrader Bluff Formation. The Tuluvak Tongue rests on the Seabee Formation in Umiat test well 11.

At Square Lake, the Tuluvak Tongue underlies a thin mantle of alluvium, and, presumably, the upper part has been eroded. The remainder, like the section at Gubik, consists of sandstone with some shale, and much bentonite and coal. Abundant bentonite in the matrix of the sandstone makes most of it impermeable; a variable amount of calcareous cement is also present. The thickest beds of bentonite and coal cored are 2 feet 8 inches and 1 foot 3 inches, respectively, which are much thinner than those at Umiat. The Tuluvak Tongue rests on the Seabee Formation here. A 28-foot shale bed near the base of the tongue contains a sparse microfauna typical of the Colville Group, and may represent a bed of the marine Schrader Bluff Formation.

At Fish Creek test well 1, the Tuluvak Tongue is represented by 25 feet of light gray friable sandstone, with some lignite, yellowish-gray bentonite, and 1/2-inch beds of coal. It contrasts sharply with the marine sediments above and below.

Although the general sequence is the same, correlation of single beds between the test wells (except between the Gubik tests which are within a mile and a half of each other) is uncertain, because of lateral variation in grain size and composition. In the subsurface, interfingering marine beds of the upper part of the Seabee Formation or of the lower part of the Schrader Bluff Formation are found within the tongue but they are infrequent; they are identified only by the rare occurrence of marine fossils. The tongue is conformable with over- and underlying beds.

Kogosukruk Tongue.--The Kogosukruk Tongue of the nonmarine Prince Creek Formation was named for the Kogosukruk River, a north-flowing tributary on the west side of the Colville River (Gryc, Patton, and Payne, 1951, p. 166). The only hole drilled into this unit is Sentinel Hill core test 1, in which the tongue is present from the surface to 469 feet, and between 840 and 949 feet. The intervening beds, as well as those below the Kogosukruk Tongue (i.e. from 949 feet to the total depth of 1,180 feet) are part of the interfingering marine Sentinel Hill Member of the Schrader Bluff Formation.

In the core test, the Kogosukruk Tongue consists primarily of light gray to light olive gray and dark gray claystone and clay shale, with some siltstone and sandstone. The claystone is harder than the bentonitic, commonly carbonaceous clay shale, and some of it is silty or calcareous, or grades to brownish sideritic clay ironstone. Light gray siltstone and fine- to medium-grained sandstone make up about a fourth of the tongue. It is soft, bentonitic, and argillaceous, or hard and calcareous, and is composed of clear and white quartz grains with chert, rock fragments, white mica, carbonaceous particles, and shards of volcanic glass. Porosity ranges from 9 to 32 percent and permeability from 5.2 to 348 millidarcys. A layer of gray and black chert granules with some pebbles as much as 1/2 inch in diameter was found at 882 feet. Bentonite beds as much as 2 feet thick, a small amount of lignite, coal, and black carbonaceous shale, clay ironstone, and a 10-inch bed of yellowish brown limestone add variety to the sequence, and rapid change from one rock type to another is typical of the strata in this hole. No micro- or megafossils were found, except for unidentifiable plant fragments, and there were no shows of oil or gas.

The Kogosukruk Tongue is present in outcrops along the Colville and Kogosukruk Rivers, and studies by Karl Stefansson, Robert Thurrell, and W. P. Brosgé (Brosgé, 1956, personal communication) have demonstrated the thinning and disappearance of the Kogosukruk Tongue to the north, as it gives way, from the bottom upward, to the marine beds of the Sentinel Hill Member.

Schrader Bluff Formation.--The Schrader Bluff Formation, named from a bluff on the Anaktuvuk River near the mouth of the Tuluga River (Whittington, 1956, p. 249) is marine in origin and includes beds of Coniacian? (see p. 133), Santonian, and Campanian age. It crops out in the northeastern part of the Reserve, principally along the Colville River and tributary streams north of Umiat. The formation is marine, and has been divided into three units, the Rogers Creek Member, the Barrow Trail Member, and the Sentinel Hill Member.

In the subsurface the Rogers Creek and Barrow Trail Members are found in the Gubik test wells, and the youngest, the Sentinel Hill Member, is present in Sentinel Hill core test 1 and in Fish Creek test well 1. Farther northwest, characteristics which distinguish the members from each other disappear and the Schrader Bluff Formation is undifferentiated, in North Simpson test well 1.

The Schrader Bluff Formation is 1,460 feet thick in North Simpson test well 1. The rock in this test well is almost entirely clay shale which is light gray to medium light gray. It is fairly soft and parts easily parallel to the bedding. Most of this clay shale is tuffaceous and volcanic glass shards are common throughout the interval. The tuff or altered shards are present in some places as little white specks in the clay shale or in thin light-colored laminae. Sandy, silty, or calcareous beds are very rare. An abundant marine microfauna and *Inoceramus* prisms are present. A few characteristic microfossils usually associated with the Sentinel Hill Member are not present in this test and it is possible that the interval represents the Rogers Creek and Barrow Trail Members.

The lower 952 feet of the Schrader Bluff Formation in Fish Creek test well 1 is composed of light to medium gray clay shale and about 10 percent light gray sandstone and siltstone. Almost all the sandstone is within 100 feet of the base of the formation. Yellowish gray bentonite or bentonitic shale is distributed sparingly throughout the formation. One bed of brown limestone is present 70 feet from the top. Biotite plates are relatively common in the sandy and silty beds. The upper 615 feet of the Schrader Bluff Formation is distinguished from the lower part primarily by the abundance of glassy volcanic shards; it has been referred to the Sentinel Hill Member of the formation (see p. 100) because it appears to correlate with the Sentinel Hill Member in Sentinel Hill core test 1.

Rogers Creek Member.--The Rogers Creek Member of the Schrader Bluff Formation is not well exposed on the surface (Whittington, 1956, p. 250), and is present in the subsurface only at Gubik. It is named from Rogers Creek, located 10 miles southwest of Umiat. At Gubik, the member is about 590 feet thick and consists almost entirely of clay shale with two sandstone or siltstone beds thicker than 15 feet. The clay shale is medium light gray to medium gray, is rather soft, and breaks fairly well parallel to the bedding. The siltstone is light gray and grades to the fine-grained sandstone mentioned above. The grains are subangular and are made up mostly of white and clear quartz with dark-colored chert, biotite, carbonaceous particles and a little pyrite. The matrix is bentonitic and contains a few volcanic glass shards. Volcanic tuff, in beds as much as 20 feet thick, is characteristic of the section. The tuff is rather hard, white, very light gray to light gray, or light greenish gray. It contains flecks of carbonaceous material and brown biotite plates. Soft, white, or light greenish gray bentonite is also present. Calcareous beds, except for a 7-inch medium gray hard limestone layer in a core 90 feet below the top of the member, are lacking.

The Rogers Creek Member contains only a sparse microfauna made up of a few Foraminifera and three species of Radiolaria. A thick-shelled Inoceramus, cf. I. lundbreckensis McLearn (more recently considered synonymous with I. patootensis de Loriol, see Jones and Gryc, 1960, p. 161 and pl. 22), was found in the upper part of the section, and Inoceramus prisms were present lower in the section.

The Rogers Creek Member is distinguished from the Tuluvak Tongue of the Prince Creek Formation below and from the Barrow Trail Member of the Schrader Bluff Formation above by the presence of abundant tuff and by its lack of sandy beds.

Barrow Trail Member.--Sandstone beds of the Barrow Trail Member form prominent bluffs or cuestas, and the member is named for the old tractor trail between Barrow and Umiat which follows one of the cuestas near Umiat. In the subsurface, however, the rock is similar to the Rogers Creek Member, except for a larger proportion of sandstone.

The Barrow Trail Member is identified in the subsurface only at Gubik. Gubik test well 2 penetrated only 395 feet of the member, although it reaches a thickness of at least 700 feet on the surface (Whittington, 1956, p. 251). It consists, in the subsurface, of about equal amounts of sandstone, siltstone and clay shale. The sandstone and siltstone are very light to light gray and are moderately hard. The sandstone is very fine- to medium-grained with 75 to 85 percent angular to subangular grains of white and clear quartz, 15 percent dark chert, coal, and rock fragments, up to 3 percent opaque white volcanic glass shards, and 3 percent mica. The matrix of the sandstone and siltstone is argillaceous or bentonitic. Not many cores were taken in these beds and no tests for porosity or permeability were run. However the bentonitic character of the matrix makes it very unlikely that they are at all porous or permeable.

In one core the siltstone is mottled with small (1/8 x 1/2-inch) rounded masses of darker colored clay that tend to be elongate parallel to the bedding and may be fillings of worm burrows. A three-inch layer of conglomerate contains rounded black chert pebbles up to an inch in diameter but this is the only coarse clastic bed noted. Calcareous beds are absent, as are the thin layers of tuff seen in the Rogers Creek Member. The clay shale is identical to that of the Rogers Creek Member except for the lack of tuffaceous material. A few scattered foraminifers and small fragments of a thick-shelled Inoceramus suggest a shallow marine origin.

Sentinel Hill Member.--The Sentinel Hill Member of the Schrader Bluff Formation and the Kogosukruk Tongue of the Prince Creek Formation, its interfingering nonmarine equivalent, are the youngest Cretaceous rocks found in any of the test wells drilled in northern Alaska to 1964. In the subsurface the strata are apparently limited to the vicinity of the lower Colville valley, where they were penetrated by Fish Creek test well 1 and Sentinel Hill core test 1 (fig. 1). A little more than 600 feet of the Sentinel Hill Member was drilled in Fish Creek test well 1. In Sentinel Hill core test 1, for which the member was named, two parts of it, separated by 109 feet of the nonmarine Kogosukruk Tongue, total 602 feet. The top of the member is eroded in the test well, and neither base nor top was found in the core test.

In Fish Creek test well 1, the Sentinel Hill Member is composed of light gray, noncalcareous clay shale with some interbedded light gray siltstone, and rare light gray, thin beds of fine-grained sandstone. Clear, glassy volcanic shards are abundant, particularly in the siltstone and sandstone. The latter also contain subangular to angular grains of clear and white quartz, some gray chert, and a minor amount of mica. Glauconite pellets and pyrite grains are abundant in some beds. Fossils include rare Foraminifera, and rare to abundant Radiolaria near the base. Minute fish bone fragments and carbonaceous particles are also present, and there are prisms from Inoceramus sp. shells in the lower 75 feet of the member. There were no shows of oil or gas, and no samples were suitable for porosity and permeability tests.

In Sentinel Hill core test 1, sediments are somewhat coarser, with sandstone and siltstone making up almost half of the rock. They are massive, as much as 100 feet thick, and rather friable, except where they have calcareous cement. The sandstone is very fine- to medium-grained, and similar in composition to that in Fish Creek test well 1. Bentonite is abundant both finely disseminated and in beds 1 inch to 5 feet thick; it is white, light gray, or greenish gray, and commonly contains minute biotite plates. Carbonized plant particles are present, some of which were identifiable, according to Roland W. Brown, as dicotyledons (Robinson and Collins, 1959, p. 489). Numerous unidentifiable fragmentary pelecypod shells, and one shell identified by George Gryc as Mytilus sp. (op. cit., p. 489) were found, and maine microfossils were also recovered. No shows of oil or gas were noted; porosity ranges from 15 to 29 percent and permeability from 10 to 290 millidarcys.

Correlation based on the interpretation of reflections from seismic lines close to the two tests indicates that some of the marine beds in Fish Creek test well 1 are the equivalent of the 109-foot section of the nonmarine Kogosukruk tongue in Sentinel Hill core test 1. The upper 400 feet of the Sentinel Hill Member in Fish Creek test well 1 is correlative to the lowest 400 feet of beds, composed of both Sentinel Hill Member and Kogosukruk Tongue, in Sentinel Hill core test 1. This conclusion also has been reached by William P. Brosgé, who has studied data from outcrops of these two stratigraphic units as well as subsurface and seismic information (personal communication, 1956).

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Quaternary deposits

Gubik Formation and Recent alluvium.--The Gubik Formation was first named (the word Gubik comes from Kupik or Kukpuk, meaning "Big River", the Eskimo name for the lower Colville River) by F. C. Schrader and W. J. Peters (1904, p. 93), and was originally described as a "brownish sand or loam about 10 to 15 feet in thickness which unconformably overlies the beds of the Colville series, apparently as a continuous mantle". They did not state whether it was marine or nonmarine, but in general usage this formation has come to include all the relatively unconsolidated sediments of Pleistocene age which overlie the Cretaceous and Tertiary rocks on the Arctic coastal plain of Alaska. It has been described by R. F. Black (1964), who considers it dominantly marine. In practice, particularly in the subsurface, it is difficult to tell the Gubik sediments from those of Recent age and frequently no distinction is made. Subsurface information on the Gubik Formation in the Simpson and Barrow areas is fairly reliable, however, because of the numerous holes drilled and cored in these two areas.

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In the Barrow area, the Gubik Formation ranges from about 25 feet to a maximum thickness of 120 feet. It is made up of complexly interbedded, unconsolidated marine sand and silty clay with a preponderance of the former. The sand grains are distinctive, unusually well rounded, and typically include a large amount of yellow and orange quartz, and yellow and black chert grains. Most of the grain surfaces are exceptionally well polished; some are pitted, and a few frosted. Other sediments present commonly show very poor sorting, with grain size ranging from pebbles larger than 1 centimeter in diameter to clay. Sieve analyses of the poorly sorted material usually have two maxima, and in one case there were three well defined maxima (coarse sand and pebbles, very fine sand, and clay). The cleaner sands are sparsely fossiliferous; the clay contains a moderate number of marine Foraminifera and Ostracoda. The sediments are normally frozen, and are consolidated by the ice which is present in interstices of the sand and commonly as large clear masses in the finer sediments.

In the Simpson area the Gubik Formation has much the same characteristics. The thickness is variable but averages about 75 feet. The lower 50 feet of the formation is made up of the characteristically well rounded sand and some lenses of gravel, and the upper part is silty olive gray clay which contains numerous pelecypods, gastropods, and shallow-water marine Foraminifera. The pebbles in the gravel are mostly black chert or white quartz but fragments of varicolored chert, limestone, quartzite, ironstone, and very rarely of igneous rocks are also found. Iron staining is common; peat, and even coal, the latter probably derived from the underlying Cretaceous beds, is reported, particularly on the west side of the Simpson Peninsula.

At Fish Creek test well 1, near the delta of the Colville River, the Gubik Formation is 40 feet thick and is made up almost entirely of sand. At Topagoruk 40 feet of marine sand is also present. Kaolak test well 1 has 113 feet of unconsolidated silt and clay overlying a sandy gravel with well rounded pebbles. Although no marine microfossils were found at Kaolak---the samples were not good---it is very likely that this represents a marine deposit of the Gubik Formation because of its lithologic characteristics.

The near-surface unconsolidated sediments in all the other test holes appear to be Recent alluvium or possible nonmarine beds of Pleistocene age. Although Sentinel Hill core test 1 is in the area of the type section of the Gubik Formation, it was spudded on the Colville River's edge at the base of high bluffs and went directly from a few feet of river alluvium into Cretaceous beds without penetrating the Gubik Formation. The Gubik test wells drilled through approximately 65 feet of unconsolidated sand, gravel and clay. The sand is coarse grained, subangular yellow, white and clear quartz, and red, dark gray, and black chert which is probably all recent river deposit. In the Umiat area the test holes in the stream valleys and on the floodplain of the Colville River drilled into unconsolidated sand and gravel from a few feet to 80 feet thick. The composition of the sand is the same as that in the Gubik wells but the grains are more rounded. Wells located on the hills at Umiat went directly into the Cretaceous rocks. Fresh-water ostracods of Pleistocene to Recent age and white megafossil shell fragments were found in samples from the upper 30 or 40 feet of the tests in the Oumalik area. The sediments consist mostly of yellowish gray and light olive gray clay and silt with some sand composed of subangular to rounded clear and white quartz and yellow, dark-gray and black chert. A few rounded granules and pebbles of gravel are also present.

Square Lake test well 1, the Wolf Creek test wells, Titaluk test well 1, the Knifeblade test wells, and Meade test well 1 penetrated less than 30 feet of alluvial material. Grandstand test well 1, however, was located on the bank of the Chandler River and penetrated 110 feet of gravel and sand at the top of the hole. The gravel contains broken (possibly by drilling) but otherwise subrounded pebbles of black, brown, yellow, green, and red chert, angular fragments of sandstone, quartz, quartzite, ironstone, and a few other rocks. The sand is very fine- to very coarse-grained and is composed of the same materials as the gravel.

REGIONAL STRUCTURE

The area north of the Brooks Range in northern Alaska is occupied by a structural basin (Woolson and others, 1962, p. 14). Information obtained from drilling alone is inadequate to determine the limits of this basin but geophysical studies (using the seismograph, gravimeter and magnetometer) and studies of the surface geology conducted during the exploration of Naval Petroleum Reserve No. 4 furnish additional data. In general the basin is bounded on the south by the Brooks Range, on the east by the same range as it swings north toward the ocean, and on the north by the Barrow Platform and by the margin of the Arctic Ocean. To the west the basin apparently continues and deepens under the Chukchi Sea (Chapman, R. M. and Sable, E. G., 1960, p. 132). The deepest portion of the basin lies parallel to, and probably just north of, the mountain front, where thickness of sediments on the order of 18,000 to 25,000 feet are postulated. The basin can be divided into subordinate eastern and western parts separated by a structural swell known as the Meade arch, which is oriented in a north-south direction near the Meade River.

The southern third of the basin in the foothills belt is occupied by numerous complex, tight, and in some cases overthrust, folds (Miller, Payne, and Gryc, 1959, p. 104) which are elongate parallel to the mountain front in a west-northwesterly direction. These diminish northward just beyond the latitude of Umiat into broad undulating folds underlying the coastal plain.

Drilling in Naval Petroleum Reserve No. 4 tested some of the folds mapped in the outcrop to the south but most of the drilling took place in the eastern part of the basin on structures located by geophysical methods. Only one test well, Kaolak test well 1, was drilled in the western part, and Meade test well 1 was drilled on the Meade arch. The Barrow and Simpson holes were drilled on the northern margin of the basin, on or near the Barrow arch.

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The north-south structural cross section, (G-G', pl. 3) shows the general configuration of the eastern part of the basin. At the north edge, in the Barrow area, pre-Mesozoic rocks (shown as argillites, on the section) are found within 2,500 feet of the surface. The Barrow area has had a complex structural history and, as can be seen on the section, numerous unconformities of varying magnitudes are present. North of South Barrow test wells 2 through 6 the Cretaceous beds thicken as they dip northward under the Arctic Ocean. The Upper Triassic, Lower and Middle Jurassic, and pebble shale beds are of about the same thickness at both Barrow and Simpson but the Oumalik and Topagoruk Formations show considerable thickening in the direction of Simpson. The unconformity between the Oumalik and Topagoruk Formations is best developed in the Barrow area and seems to disappear basinward. Middle Devonian strata, "red beds", and Permian rocks have been preserved off the flanks of the Barrow high, as shown by their presence at Topagoruk. Seismic work shows deep-seated normal faulting on the south flank of the Barrow arch in the area between Simpson and Topagoruk but there is no evidence of this in the test wells. Seismic work also suggests that early Mesozoic and Paleozoic rocks probably continue to dip southward beneath the greatly increased thickness of Cretaceous beds, (Woolson, J. R. and others, 1962, p. 15). Oumalik test well 1, which found the base of the Oumalik Formation below 10,000 feet, demonstrates the rapidity with which that formation thickens southward into the basin.

Although a comparatively shallow hole, Titaluk test well 1 was included in the cross section to show the presence of Late Lower Cretaceous and Upper Cretaceous beds in the center of the Basin. Knifeblade test wells 1 and 2A give the first indication of rising strata on the south side of the basin. Between the Knifeblade tests and Topagoruk test well 1 the interfingering of the Topagoruk, Grandstand, and Chandler Formations is clearly indicated.

Structure cross section H-H', plate 4, is drawn in a northeasterly direction across the Reserve and shows a slightly different aspect of the basin. Starting on the south with the same Knifeblade and Titaluk holes, this section extends "down dip" nearly at right angles to the regional strike and shows the development of the Late Cretaceous strata in the basin. The Seabee Formation is found on the surface near the Titaluk test. From there it dips rapidly into the eastern part of the basin, resting on an unconformity which has beveled the Ninuluk and part of the Chandler Formations. The basin deepens and Upper Cretaceous rocks thicken in an easterly direction. The Sentinel Hill Member and the Kogosukruk Tongue, uppermost Cretaceous beds identified in the subsurface, are present in Sentinel Hill core test 1 on the Colville River. Limited seismic work indicates that the basin continues to deepen east of the Colville River, and Tertiary rocks crop out in the White Hills (Payne and others, 1951, map, sheet 1).

GEOLOGIC HISTORY

The following discussion of geologic events is concerned with the history of that part of northern Alaska for which subsurface data is now (1964) available. The interpretation is based on information obtained primarily from test holes and geophysical surveys, as there are few bedrock outcrops in most of the area.

Steeply dipping argillite beds which underlie flat Upper Triassic strata in the Barrow and Simpson areas may well be the oldest known record of the geologic history of the region. Unfortunately, the green and red argillite in Simpson test well 1 contains no fossils, and the black argillite and interbedded siliceous dolomite of the Barrow area has yielded only a few minute pyritic spines of uncertain (but probably organic) origin and some spheroidal quartz aggregates that suggest Radiolaria, neither of which furnish evidence of the age of the deposit. On the basis of possible regional correlations, these beds have been compared to stratigraphic units ranging in age from Precambrian to Permian. (The lithologic and structural differences between the argillite and the Late Triassic beds make an earlier Triassic age unlikely.) In this paper, however, they have been described merely as pre-Mesozoic for lack of evidence of a more restricted age designation. A few inferences about the environment of deposition may be made, however, from the texture and composition of the rocks.

The fine texture of the Simpson argillite suggests that deposition probably took place at a distance from the source of the material, or that it took place under very quiet conditions. The coarsest material this pelite contains is silt-size particles present in very rare laminae. No ripple marks, mud cracks, or characteristics of terrestrial deposition were noted, although the red color of a few thin beds might suggest such an environment.

The pyritic black argillite of the Barrow area is almost certainly of marine origin, and probably was deposited under anaerobic conditions, in a quiet basin which received only the finest of clastic material. If the siliceous, dolomitic beds in Avak test well 1 were originally deposited as limestone, they have been too much altered by replacement and recrystallization to have any relict structures indicative of the source of the carbonate. Some of the argillite in South Barrow test wells consists of a few fragments of hard gray rock composed largely of silica. This rock may originally have included much volcanic ash, and it contains the Radiolaria(?) mentioned above. The variable silica content of the argillite (which ranges from friable and sooty to blue-gray and splintery) may result either from variations in secondary enrichment, or from a changing silica content of the original sediment.

The earliest event that can be dated in the geologic history of the subsurface in northern Alaska is the deposition of Middle (Early?) Devonian strata in the vicinity of Topagoruk test well 1. The oligomictic conglomerate of chert sand and pebbles may be a shore line deposit of material derived from a low-lying land mass which, because of being deeply weathered, or being largely underlain by cherty rocks, has furnished little but chert to the deposit. The interbedded silty, hard black shale contains plant remains which are well preserved, although the plants themselves were rather delicate. They grew in fresh-water swamps, and as they could not have been transported far before burial, the black shale was probably a swamp deposit. The alternation of black shale and conglomerate may be a result of slight fluctuations of sea level, with a short retreat of the sea coinciding with the formation of the swamp. The location of the land mass from which the sediments came, however, is uncertain. Lower and Middle Devonian beds are known on the Canadian Arctic Islands (Fortier, McNair, and Thorsteinsson, 1954, p. 2,075) to the east, and Middle Devonian beds have been reported from the central and eastern Brooks Range, to the southeast and south (Bowsher and Dutro, 1957, p. 4, and Brosgé, 1960, p. B351). It is possible, therefore, that the beds in Topagoruk test well 1 record a transgressive sea, encroaching on a land mass to the north---perhaps part of the Ancient Arctica proposed by A. J. Eardley in 1951 (1951, p. 538).

Later seismological studies cast doubt on the existence of this land (Eardley, 1960, p. 611), as did the few gravity data available (King, Dietz, and Alldredge, 1964, p. 1,554-1,555). The latter authors, however, note that "magnetic data provide convincing evidence that the floor of the Arctic Ocean on the North American side of the Lomonosov Range is formed by a large sunken block, or blocks, of continental material, a large part probably consisting of a Precambrian complex similar to that of the present shield areas," and that "the seismological results can largely be accounted for if the Eurasian Basin is a genuine oceanic basin with a thin crust" (ibid, p. 1557), thus giving new validity to the concept of Ancient Arctica.

An alternate suggestion (W. P. Brosgé, written communication, Sept. 25, 1957), that the conglomerate and shale represent river bar or channel deposits interbedded with marshy floodplain sediments implies nonmarine deposition at an unknown distance from a marine shoreline. Data now available are insufficient to prove either hypothesis.

After the Middle (Early?) Devonian beds were deposited, some structural movement tilted the strata, which now dip 35° to 60°. This dip may be associated with the folding of the argillite at the Barrow and Simpson test wells. After the Devonian strata were folded, and subsequent erosion had beveled them, 270 feet of red beds were deposited in the Topagoruk area. They are unfossiliferous, probably of terrestrial origin, and cannot, at present, be dated accurately. Their presence does indicate, however, that deposition took place in the Topagoruk area after the post-Middle Devonian faulting and erosion, and before about 400 feet of Permian beds were laid down. If the beds are nonmarine, they may be the terrestrial equivalent of marine Carboniferous or Permian beds found in the Brooks Range, and could have formed part of the land on which the Permian sea, presumed source of the Permian beds described below, advanced.

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The youngest Paleozoic beds found in the subsurface of northern Alaska are the Permian strata in Topagoruk test well 1. The rock is siliceous siltstone and sandstone, with a little chert conglomerate in the middle of the section. An orthoquartzite, the rock was doubtless derived from a low-lying well-weathered land mass where less durable minerals had been altered or removed by solution. The grain size suggests that most of the rock was laid down not too far from shore, or in a shallow sea---the size of the grains presumably varied with the proximity of the shoreline.

Assuming that no major sedimentary units were removed from the northern part of Alaska in late Paleozoic time, the rocks now present there suggest a transgressing sea. The shoreline presumably moved northward from the area of the present Brooks Range, to a shore somewhere between Barrow and Topagoruk during Permian time.

Lower and Middle Triassic rocks are very rare in northern Alaska (Patton and Tailleur, 1964, p. 435-437). Nevertheless, the Upper Triassic beds in northern Alaska are conformable structurally with the underlying Permian strata, indicating that the area, although probably above sea level at least part of the time, was not subjected to orogenic movement.

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Upper Triassic (Norian) rocks, however, are widespread in northern Alaska, and, in the subsurface, contain a greater proportion of limestone than any of the other stratigraphic units penetrated. The limestone is everywhere interbedded with shale and calcareous siltstone, some of which is glauconitic. Foraminifera, mostly of the family Lagenidae, and the pecten-like pelecypods <u>Halobia</u> and <u>Monotis</u> are common. The limestone, glauconite, and microfaunal assemblage all imply clear seas, and the glauconite, particularly, suggests normal marine water of shallow to moderate depth, with a high organic content in slowly accumulating bottom sediments (Cloud, 1955, p. 484). In addition to glauconitic beds like those in the other test wells, Triassic sediments in South Barrow test well 3 contain beds of limonite oolites, and thin layers of coquina; Foraminifera common elsewhere are missing. This appears to be a shoreline facies of the glauconitic and limy beds found in other areas. The high iron content which resulted in the formation of glauconite on the sea bottom also supplied iron for limonite in the more oxidizing environment of turbulent water along shore---an environment suited to the formation of oolites and coquina. The shoreline suggested by these sediments was probably the northern margin of a sea which covered northern Alaska in Norian time, but which withdrew (or else left no surviving evidence of its presence) in latest Triassic (Rhaetic) time, before the advance of Jurassic seas.

The earliest known Jurassic beds in the subsurface were identified in South Barrow test well 3, and have been dated as Hettangian on the basis of microfossils; they disconformably overlie Norian beds of late Triassic age. Bentonite found in them suggests that some volcanism accompanied the earliest stage of the Jurassic sedimentation, although no contemporaneous strata of volcanic origin have been reported elsewhere on the Arctic Slope of Alaska. In fact no other rocks of Hettangian age have been identified (Imlay, 1955, p. 81) anywhere else in northern Alaska.

In Sinemurian, Pliensbachian, and Toarcian times very argillaceous, glauconitic, pyritic, marine sandstone followed by claystone was deposited over a much larger region, including the Topagoruk, Simpson, and Barrow areas as well as much of the area south to the present Brooks Range. Deposition continued unbroken into the Bajocian (lowermost Middle Jurassic), with a pyritic micaceous clay shale in the Topagoruk area. The Jurassic beds were penetrated by so few test holes that little can be determined from them alone about the conditions of deposition. However, they appear to represent onlap onto the Barrow area which was still high at this time (Payne and others, 1951, sheet 3). The sediments are slightly coarser in the north and probably were derived from a low-lying northern land mass, settling in an east-trending trough lying between the Barrow Platform area and the rising ancestral Brooks Range (Imlay, 1955, p. 75).

Ralph W. Imlay, in his paper on the Jurassic mollusks from northern Alaska, has an excellent discussion of the ecology of the Jurassic seas (Imlay, 1955, p. 75-78). He concludes (p. 82) that "faunal and lithologic relationships suggest that much of the Jurassic sea bottom in northern Alaska sloped moderately basin-ward and was stagnant and at least as deep as the lower part of the neritic zone". He also states that the macrofauna of Early Jurassic and early Middle Jurassic time indicate "fairly warm" water (op. cit., p. 82).

No Upper Bajocian or late Middle Jurassic beds have yet been found in the subsurface, or in the outcrops of northern Alaska (Imlay, 1955, p. 73).

The pebble shale, a sequence of beds with distinctive lithology which ranges in age from Late Jurassic (Oxfordian) to Early Cretaceous (Albian) is described in detail in the stratigraphy section (p. 13 ff.). It is difficult to explain the mechanics of sedimentation of such a peculiar lithology. Grains of quartz of fairly uniform size were deposited singly in a matrix of clay, over a long period of time through a thick section. A satisfactory explanation of such an oddly sorted deposit probably involves factors other than the transporting agent, one of which may be the source from which the sediments are derived. Most of the sediments found in the older beds in the subsurface of northern Alaska were probably derived from Ancient Arctica, the land mass which may have occupied much of the basin of the present Arctic Ocean. During at least part of this time, the Barrow area was a sort of hinge line, with a slowly sinking basin to the south and the eroding land to the north. At times the Barrow area may have been emergent, or may have been at the strand line (Norian stage of the Late Triassic). The pebble shale was probably also derived from this low, well-weathered land. Pebble-shale sediments of Late Jurassic age occur (in the Tiglukpuk Formation) as far south as the headwaters of the Siksikpuk River, in the present Brooks Range. The transition from latest Jurassic to earliest Cretaceous, however, is not represented in northern Alaska by pebble shale or any other rock, probably because this was a period of great orogenic activity during which the ancestral Brooks Range was formed (Payne and others, 1951, sheet 3). By Valanginian time this Range was furnishing coarse clastics to the basin forming along the northern front of the mountains, while farther north, in the latitude of Oumalik test well 1, the sea still received pebble-shale sediments from the northern platform. Slightly later, the whole region was uplifted or the sea retreated, and there are no sediments of Hauterivian, Barremian, and Aptian stages known north of the Brooks Range. In early Albian time, as a result of renewed uplift of the ancestral Brooks Range, vast quantities of sediments flooded the re-established geosynclinal trough from the south, and clastics of the Fortress Mountain and Lower Torok Formations were deposited near the mountain front while finer silt and clay making up the Oumalik Formation extended north to the Oumalik test wells. The northern land mass, the shoreline of which was now north of Barrow, continued to furnish some sediments, however, and a thin deposit of typical pebble shale was laid down at Barrow, Simpson, and Topagoruk in early Albian time, contemporaneously with the graywacke type of sediment forming the Oumalik Formation farther south. The shoreline was probably not far from Barrow, as it supplied pebbles for a thin basal conglomerate there. A few coarse rounded grains of quartz in the Oumalik Formation in Oumalik test well 1 represent the greatest known southern extent of pebble shale sedimentation in lower Albian beds. The pebble shale in the Barrow area is the youngest deposit in Alaska which was derived from Ancient Arctica, and the final disappearance of this old land mass is marked by the overlap of lower Albian graywacke of the Oumalik Formation on the pebble shale as the land sank or was overwhelmed by sediments from south of the geosyncline. To summarize, the authors believe that the

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pebble shale had a single source, Ancient Arctica, which was probably a very low peneplained land area on the surface of which almost every megascopic mineral fragment except quartz and black chert had been destroyed by weathering. Source, rather than transporting agency, determined the mineral content and grain size. The fact that the grains are so well rounded indicates that they may be second generation or older in origin. The possibility that the pebble shale might have been derived from the south, with some sort of selection for the rounded chert and quartz grains, does not seem likely. Considering the heterogeneity of sediments available in the ancestral Brooks Range and the evidence for very rapid deposition shown by some of the formations of the same age as the pebble shale it is hard to see what agent could single out chert, quartz, and clay alone, much less explain how the sand and granules, and clay, were carried and deposited from that direction without the inclusion of intermediate grain sizes.

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Deposition of the pebble shale probably was very slow, and it continued intermittently for a long time. Reducing conditions on the sea bottom may have existed part of the time, as black shale, abundant pyrite, and some glauconite are found. Faunas are varied both in abundance of specimens and in age, as explained in the paragraphs on stratigraphy.

The Oumalik Formation is the first of a very thick sequence of sediments (including also the Topagoruk, Grandstand, and Chandler Formations) which was deposited during a relatively short period of time in the Albian stage of Early Cretaceous time. This sequence is a product of typical geosynclinal sedimentation, the deposition of which took place following a major uplift of the ancestral Brooks Range. The coarse sandstone and conglomerate of the Fortress Mountain Formation and the slightly less coarse Lower Torok Formation (Patton, 1956b, p. 219 and 222) represent the early proximal deposits in the basin. Their probable subsurface equivalent, the Oumalik Formation, represents a finer clastic axial phase of the same period. Deposition was continuous in the center of the basin, but in the north the top of the Oumalik Formation is marked by an unconformity of at least local importance. North from Oumalik test well 1 a large thickness of the Oumalik Formation is lost---the unit decreases from 6,000 feet at Oumalik to 2,700 feet at Topagoruk, 1,700 feet at Simpson, and 400 feet or less at Barrow. Much of this loss may be the result of nondeposition as the sediments gradually advanced over the land to the north, but the upper section seems to have suffered the greatest decrease. This, plus small changes in dips between the Oumalik and overlying Topagoruk Formations in some test wells, and seismic evidence of unconformity, strongly indicate uplift in part of the Reserve. This movement marks the boundary between lower and upper Albian time. A substantial faunal break has been noted at about this horizon by Imlay (1961, p. 4) in samples gathered mostly from outcrops farther south, in the foothills north of the Brooks Range; a change in the microfaunal assemblage has been noted as well.

The basin filled rapidly as siltstone and shale of the Topagoruk Formation followed the Oumalik Formation; they resemble the foreset beds of a vast deltaic coast. Figure 8 implies that the deepest part of the basin in which these sediments collected was probably somewhere east of the northeastern corner of the Reserve. (Neither Kaolak test well 1 nor Meade test well 1 completely penetrated the Topagoruk Formation, however, and its thickness near and west of the Meade Arch is unknown.) The discordant dips within the Topagoruk Formation (described on p. 44) are commonly inclined in the direction of the easterly thickening. This, and their nonconformity with the gentle dip of the formation boundaries, suggest that they may be the result of sedimentary processes rather than structural movement. Deltaic foreset bedding or turbidity currents, or both, probably played an important part in the distribution of the sandy and silty lenses which probably caused the seismic reflections. "Swirly" bedding, noted in several places in the formation, also suggests the presence of currents crossing the sea bottom. The upper part of the Topagoruk Formation contains the most prolific Cretaceous mega- and microfauna found in the subsurface. Its outcrop equivalent, the Tuktu sandstone, is also very fossiliferous, with many similar genera. The fauna of the Tuktu Formation, according to Imlay (1961, p. 15-16) appears typical of the shallow part of the neritic zone and that of the Topagoruk Formation of slightly deeper water. The _Verneuilinoides_ _borealis_ shallow-water microfaunal assemblage containing many arenaceous species is most abundant and diversified in the siltier beds of the Topagoruk Formation within 500 feet of

the base of the Grandstand Formation. Some of the Albian cephalopods "are identified with species that lived in the shallow seas that covered the western interior of Canada and the Yukon area of Alaska...the scarcity and small size (of gastropods), coupled with the complete absence of oysters, indicates that the sea waters were not warm." (Op. cit., p. 16).

As sediments continued to pour into the Cretaceous geosyncline, the basin did not sink as rapidly as it was filled and the sea became gradually shallower. Deposits in the central and southern part rose close to wave base, and the resulting increase in turbulence caused the argillaceous material to be carried farther northeast into the basin and sand was deposited in the area, replacing mud as the major sediment. The sand beds thus formed constitute the Grandstand Formation, which encroached on and took the place of the Topagoruk Formation in younger Albian time. Retreat of the sea was slow and intermittent, as the water level fluctuated and clay or silt alternated with sand. In the easternmost part of Naval Petroleum Reserve No. 4 the water was never turbulent or shallow enough in Early Cretaceous time to leave well sorted sandstones or nonmarine beds. The shoreline during the time the Grandstand Formation was being deposited moved gradually eastward, but probably never varied much in direction from its generally northwesterly trend, except between the Umiat area and Grandstand test well 1, where great similarity in the sandstone-clay shale sequence (pl. 2) suggests a more nearly north-south strike. This change in strike may have been caused by an embayment east of the Chandler River. Much of the Grandstand sandstone contains argillaceous cement, but high porosity of the sandstone in the northernmost holes suggests a particularly effective winnowing action (presumably by wave action on or near shore) in that area. The accompanying prolific microfauna, which has a high proportion of calcareous Foraminifera compared to the southern assemblage of the same age (H. R. Bergquist, personal communication,

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1956) implies clearer, less muddy seas. In the vicinity of Simpson Seeps the upper beds of sand are particularly coarse and well sorted, and may mark the location of off-shore bars. Some thin coal beds in the upper part of the Grandstand Formation are forerunners of later, more extensive subaerial deposition.

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The flood of sediment which raised the level of the sea bottom in the central part of the Cretaceous basin resulted in even more rapid deposition nearer the source in the southwestern part of the area, and the sediments in that region reached and eventually rose above sea level. Thin beds of coal, and clay ironstone, both more common in the Grandstand Formation in Topagoruk test well 1 than in East Topagoruk test well 1, probably reflect the intermittent eastward extension of subaerial deposition in later Albian time, as far as Topagoruk test well 1, with the shoreline fluctuating between the two tests for much of the time.

While the Grandstand sands were being deposited near the shoreline, the Chandler Formation was laid down in fresh-water swamps, lakes, and streams inland from the sea. Swamps, rich in vegetation, were large enough and endured a long enough time to form deposits which were altered to thick, extensive coal beds, particularly in the western part of the Reserve. Charophytes and other plant fragments attest to the general abundance of plant life beyond the boundaries of the swamps. A few arenaceous Foraminifera which are tolerant of brackish water record rare minor incursions of lagoonal waters, particularly in the earlier stages of deposition. The Killik Tongue of the Chandler Formation overlapped the Grandstand Formation just as the Grandstand beds had advanced over the Topagoruk strata, but they did not extend as far east and north as the Grandstand Formation. In latest Albian time, when the land was at its greatest extent, the shoreline probably extended from the vicinity of the Gubik wells northwest toward Topagoruk and Simpson test wells. Much the thickest section of nonmarine beds is in Kaolak test well 1, far to the west, where subaerial deposition was nearly continuous and probably was contemporaneous with deposition of much of the Topagoruk and Grandstand Formations to the east.

This retreat of the sea marks the boundary between Early and Late Cretaceous time in this area. The Ninuluk Formation, laid down in a shallow body of marine or brackish water, contains fossils of Cenomanian age. Conditions of deposition were probably similar to those of the Grandstand Formation, in that no marine beds were being deposited simultaneously to the south and west: in the outcrop and perhaps in Titaluk test well 1, which has the thickest Cenomanian section of any test well, nonmarine beds of the Niakogon Tongue of the Chandler Formation interfinger with and overlie the Ninuluk strata. Here and elsewhere the microfauna, which consists mostly of two species of arenaceous Foraminifera, indicates an environment which was apparently too brackish to support any but the most tolerant forms, suggesting shallow embayments or very near-shore or intertidal areas (Tappan, 1960, p. 280) instead of the more open sea recorded by the Grandstand Formation. Large _Inoceramus_ shells in coarser clastics found in outcrops of the Ninuluk Formation (Brosgé, oral communication) indicate, however, that some of the formation was deposited in open sea water. A small amount of bentonite indicates minor volcanic activity.

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Close to the end of Cenomanian time the land rose above sea level and erosion removed some of the Ninuluk beds, especially in the east and north. Folding in the southern part of the basin resulted in an angular unconformity between the Ninuluk and younger beds, with a discrepancy of as much as 41° in dip in outcrops at the type locality in the Chandler River region (Detterman, Bickel, and Gryc, 1963, p. 268). When the sea returned in Turonian time, in several places such as Simpson Seeps and Gubik it reworked the Ninuluk sandstone, and some basal sands of the Seabee Formation are very similar to the earlier deposits. Volcanic activity, which occurred rarely in late Cenomanian time, increased rapidly in the Turonian, and bentonite is a common constituent of Seabee strata. The silica-rich water also supported a radiolarian fauna. The marine water advanced rapidly, and a fauna including _Inoceramus labiatus_ Schlotheim suggests clear, open seas. The planktonic foraminiferal assemblage containing _Heterohelix globulosa_ (Ehrenburg) and _Hedbergella loetterlei_ (Nauss) near the base of the formation in the north is evidence of rather deep water (Tappan, 1962, p. 96), and of open seaways connecting this inundation with the marine seas which submerged much of North America in Turonian time.

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Some time after the deposition of the Grandstand Formation, and before the Gubik Formation was laid down, a structural disturbance of at least local importance resulted in the complex faulting and possibly in the cryptovolcanic structure in the Barrow area. In the Simpson Peninsula, Seabee sedimentation was interrupted by a period of apparent submarine erosion which cut a steep canyon into older Seabee Formation and Nanushuk Group beds, and removed them entirely north of the canyon, in the direction of North Simpson test well 1. These events and their possible cause are discussed more fully in the sections on the Barrow and Simpson oil fields.

Deposition of the marine Schrader Bluff Formation and the equivalent nonmarine Prince Creek Formation occupied Coniacian(?), Santonian, and Campanian stages. (There is apparently some doubt about the presence of beds deposited during Coniacian time. Jones and Gryc (1960, p. 153) found no species of <u>Inoceramus</u> diagnostic of this interval, and no microfossils have yet been identified that are exclusively of this age (Tappan, 1962, p. 115). Stratigraphic charts in these publications puts the Rogers Creek in the Santonian stage in the former and in both stages in the latter). As in earlier Cretaceous time, the sea level fluctuated, and deposition of marine sandstone and shale alternated with nonmarine beds. The Tuluvak Tongue, the lower unit of the Prince Creek Formation, extended farther northeast than any other nonmarine beds, and shows that the greatest recorded retreat of the Late Cretaceous sea took place just after its extensive advance during Seabee time. Wherever it occurs, the Tuluvak Tongue contains numerous beds of bentonite, which, with the tuffaceous, bentonitic marine sediments of the lower part of the Schrader Bluff Formation, are evidence of continuing volcanic activity. The Tuluvak Tongue also contains much coal. Fossils found in these beds in Square Lake and Gubik test wells suggest that they were plants "inhabiting well-watered sites, perhaps gentle slopes, in a warm temperate climate" (R. W. Brown, written communication, 1955). (That the climate may have been warm is borne out by the studies of world-wide paleotemperatures of the post-Albian Cretaceous by the oxygen isotope method by H. A. Lowenstam and S. Epstein (1954), which showed a progressive rise in ocean temperature from the Cenomanian to a climax in the Coniacian-Santonian stages.)

The youngest Cretaceous sediments in Naval Petroleum Reserve No. 4 continue to record fluctuations of sea level, with beds of the Kogosukruk Tongue of the Prince Creek Formation interfingering with the Sentinel Hill Member of the Schrader Bluff. A gradual change in the nature of the volcanic sediments is the only appreciable variation from the older Upper Cretaceous beds. In the lower part of the Upper Cretaceous deposits bentonite is the dominant volcanic material. In the lower beds of the Schrader Bluff Formation, particularly in the Rogers Creek Member, bentonite is present but some tuff was also noted. In the upper part of the undifferentiated Schrader Bluff Formation altered volcanic shards are abundant, and in the uppermost division, the Sentinel Hill Member, the shards are both abundant and unaltered. Increasing alteration of the pyroclastic material appears, in this case, to be related to increasing age of the deposits.

The Sentinel Hill Member and the Kogosukruk Tongue are lower Campanian in age, and if any later Cretaceous beds were laid down in this part of Alaska they have not yet been identified. Subsurface data furnish no evidence of the age of emergence and folding which took place before the Pleistocene epoch. The movement was orogenic in the south, with the rise of the Brooks Range accompanied by the folding and reverse faulting which formed the anticlines that now parallel its northern flank. Farther north, folding was progressively less pronounced but regional uplift raised the area above sea level and except for some Tertiary sedimentation (recorded by deposits in the White Hills, east of the lower Colville River) which was apparently limited to the eastern part of the former Cretaceous basin, the area was subject to subaerial erosion until Pleistocene time.

The dominantly marine Gubik Formation of Pleistocene age spreads as a thin mantle over most of the Arctic coastal plain (Black, 1964, p. 59) ranging in thickness from a few tens of feet to about 120 feet. It was probably laid down under conditions similar to those found just off the Arctic coast today but records a period of greater submergence than there is at present. Variation in lithology can be attributed to the location of the mouths of major streams, barrier beaches, and offshore bars, and to the general ocean current circulation. At Simpson, for instance, the basal part of the Gubik Formation is made up of coarse, gravelly beds whereas at Barrow, fine sediments predominate near the base.

The sands and gravels themselves contain only grains and pebbles of the most resistant nature, and probably have been reworked in more than one sedimentary cycle, judging from the roundness of many of them. Sorting is poor to fair---the sand is much mixed with clay. Peat and a very small amount of clastic coal occur here and there. The coal was probably derived from nearby Cretaceous beds and the peat may record a time during the Pleistocene when the climate was more mild than at present. Large logs of spruce several feet long and several inches in diameter have been found in outcrops of the Gubik Formation (G. Gryc and L. Spetzman, personal communication, and R. Black, 1964, p. 65). Such trees are nonexistent on the Arctic Slope today, although similar logs, probably originating in the Mackenzie River valley, occur along the coast and on river bars near the coast.

The Foraminifera are marine but "an offshore environment is not necessarily implied by the calcareous assemblage, as most of the genera are notably tolerant of brackish water, and no pelagic genera are present" (Tappan, in Payne and others, 1951, sheet 3). The ostracods are of types found in a cold marine neritic environment of moderate depth, having "living relatives in the North Atlantic and Arctic Oceans, in water generally more than 10 fathoms and less than 100 fathoms deep" (F. H. Swain, written communication, 1949). Although the present Coastal Plain has been emergent since the Pleistocene epoch, deposition in the Arctic Ocean bordering the present coast has probably continued uninterrupted from the late Pleistocene into the present. Little change in the nature of the material laid down is noticeable except that in some places nonmarine alluvial gravels and mud have superseded the marine deposits. There is evidence that the shoreline today, after the relatively recent general emergence, is retreating (McCarthy, 1953, p. 44 ff.)

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ECONOMIC GEOLOGY

Oil and gas

Introduction

The objective of the recent exploration of Naval Petroleum Reserve No. 4 was to make a reasonable evaluation of the petroleum potentialities of the Reserve and adjacent public lands. In the course of nine years of drilling, three oil fields and two gas fields were discovered and almost all of the test wells had faint to good shows of oil or gas. The oil discovered, however, is of little present commerical value because the fields are not exceptionally large and the distance from markets is too great. One gas reservoir at Gubik is probably large enough to warrant development and a smaller field near Barrow has furnished gas enough to heat the military and construction camp there for several years. Gas is being furnished to Barrow village, as well. The oil and gas fields are described in detail in the following pages and the more important shows in other areas are also summarized.

Geology of the Barrow area and gas field

The term "Barrow area" in this report includes the northern tip of the Arctic Coastal Plain province of Alaska within a radius of 20 miles of Point Barrow. Seven test wells and four shallower holes were drilled in the area, the first one in 1944 and the last in 1964; some additional very shallow holes (125 feet or less in depth) were drilled for permafrost and shallow stratigraphic information. (See pl. 5 for locations.)

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Stratigraphy of the Barrow area.--Rocks in the Barrow area range in age from pre-Mesozoic through Pleistocene, but, largely because of structural complexity, no one test drilled a complete sequence. The oldest beds, of Paleozoic or older age, are argillite, harder and more steeply dipping (except in structurally anomalous Avak test well 1) than the Mesozoic strata. They, and the other stratigraphic units, have been described in detail for each well (Prof. Paper 305-K) and their salient features are discussed in the section on stratigraphy of this report.

Only one hole, South Barrow test well 3, encountered beds of Triassic age, but in that hole nearly 200 feet of strata containing Triassic pelecypods included such unusual rock types as limonite oolites and coquina. The Jurassic rock consists mostly of clay shale and olive gray silty sandstone containing a large number of ammonites. Almost 800 feet of it is present in South Barrow test well 3, and an uncertain amount (its thickness was undeterminable because of erratic dips and faulting) in Avak test well 1. Jurassic beds of silty sandstone have been identified in the gas wells (test wells 2, 4, 5, and 6), but none were definitely identified in South Barrow test well 1.

Pebble shale is the oldest Cretaceous rock unit in the holes and is the only one to maintain a nearly constant thickness and character (again possibly excluding Avak test well 1, in which it is much disturbed by faulting). Above it, the Oumalik Formation, represented by dark clay shale, is more than twice as thick (about 700 feet) in South Barrow test well 1 than in the southern test wells; this, and younger Cretaceous strata are lacking in Avak test well 1, which drilled into pebble shale directly beneath the Pleistocene Gubik Formation.

In South Barrow test well 1, the Topagoruk Formation is 1,700 feet thick, and consists of clay shale with some siltstone and a few thin beds of sandstone. Here, and in Arcon Barrow core test 1, it is capped by 250 and 300 feet, respectively, of the sandy Grandstand Formation. To the south, the gas wells penetrated some 1,600 feet of the Topagoruk Formation, but the Grandstand Formation and the upper few feet of the Topagoruk Formation have been removed by erosion. Still farther south, at South Barrow test well 3, erosion has cut even more deeply, and only 1,000 feet of the Topagoruk Formation remains.

The marine Gubik Formation blankets the whole area and is composed of sand, gravel and clay consolidated only by ice. It contains abundant Foraminifera and other fossils of Pleistocene age. Its thickness varies, although it averages about 100 feet, because of irregularities in the contact with underlying Cretaceous beds and in its own upper surface. The three shallowest holes were not drilled much below the base of this formation.

Structure.--The area is the most complex structurally of any so far encountered in the subsurface in Naval Petroleum Reserve No. 4, and because the surface is largely marshy or lake-covered, all the available stratigraphic and structural information (except for bedrock exposed in a low sea-cliff near Skull Cliff core test 1) is from the geophysical work and the test holes. Three types of geophysical surveys have been made in the area: a magnetometer survey made in 1945 by the U.S. Navy and the U.S. Geological Survey; a gravity meter survey, made in 1946 by the United Geophysical Co., Inc.; and seismic studies, made in 1948 and 1949 by the same company. The magnetic intensity shows very little change across the area, the slight decrease in intensity from northeast to southwest averaging less per mile than that across any area of equal size in the Reserve. The observed gravity, however, shows the Barrow area to have the greatest observed gravity of any part of the Reserve, with the maximum near the southwest corner of Elson Lagoon, and an abrupt decrease to the north (fig. 14). An anomalous pattern just south of the point of maximum

Figure 14. Observed gravity map of the Barrow area.

gravity consists of a small circular area (3 miles in diameter) of unusually high gravity surrounded on 3 sides by a belt of low gravity -- a shape suggestive of a salt dome, but with a central area of high gravity instead of the low-gravity center of the typical salt dome.

Several seismic lines across the Barrow area furnish additional details on the gravity anomaly, as well as a picture of the structural complexity beneath the flat surface (fig. 15). According to the profiles (Woolson, 1962, p. 16), the gravity anomaly consists of a central structurally high area cut by small concentric faults downthrown

Figure 15. Seismic map of structure of the shallow Cretaceous beds in the Barrow area.

toward the periphery, surrounded by a high ring of complex faulting with concentric faults downthrown primarily toward the center. Radial faults, many with the downthrown side to the south, extend outward from the ring. South Barrow test wells 2, 4, 5, and 6, the gas-producing wells, are just north of one of the radial faults; Avak test well 1 is north of the central high area of the anomaly, in an area of complex faulting. Beds of Early Cretaceous age are disturbed by the faulting, and displacement of earlier beds is apparently no greater than on the Cretaceous formations, indicating that the movement took place in post-Early Cretaceous time.

Cryptovolcanic structures as described by A. J. Eardley (1951, p. 237-238) are nearly circular, with a "central uplift with intense structural derangement, and a marginal, ring-shaped depression with irregular and local faulting. Including the marginal ring, they range in diameter from two to eight miles (the Barrow structure is about 5 miles across). The inner intensely deranged core may be only part of a mile across in some, but in others up to 2 miles. The faults make both an approximate concentric and radial pattern". This description fits what is known about the anomaly at Barrow. Metamorphism or other evidence of igneous activity is lacking at Barrow, as it is in most cryptic volcanoes, and the cause of the upheaval is uncertain. Robert S. Dietz (1960, p. 1,781) suggests, however, that many cryptic volcanoes result from a high-velocity impact probably caused by a very large meteorite. If this were the cause of the Barrow complex, it might not be amiss to speculate that such an impact, by causing a tsunami-like wave, could result in the formation of Simpson Canyon, a "fossil" canyon discussed in the paragraphs on the geology of Simpson Peninsula. The gravity "high" is, perhaps, caused by buried remains of a meteorite.

Seismic evidence showing the Barrow area to be the highest region, structurally, of any part of the coastal plain within the Reserve, is corroborated by data from the test wells, which penetrated pre-Mesozoic rock at comparatively shallow depths. The highest part of the regional structure (except for a possible southwestern extension in the vicinity of Skull Cliff core test 1) is a structural ridge trending roughly east-northeast and crossing the area in the vicinity of South Barrow test well 3, just south of the complex fault zone. The test well was drilled on a local culmination of this regional fold. South of the fold seismic records show beds dipping gently into the Cretaceous basin which occupies most of the Reserve; to the north, they dip more steeply toward the Arctic Ocean (pl. 5, cross-section I-I'). The pre-Mesozoic surface, cut in this area on argillite of possible early Paleozoic age, dips in a similar fashion, although more steeply than the overlying deposits. The highest point of this surface, however, is somewhat farther north than South Barrow test well 3. Plate 5 shows the wedge of Jurassic and Triassic beds, thickening southward from a knife-edge near the gas wells to more than 1,000 feet at South Barrow test well 3, and separating the Cretaceous beds from the pre-Mesozoic argillite.

Geologic history.--The history of the Barrow area is complicated, but data available at present suggest the following sequence of events:

1. Pre-Mesozoic deposition and folding of the argillite, and beveling of the folds by erosion. A weathered surface developed, remnants of which are still preserved in a core from South Barrow test well 1.

2. Deposition, in the vicinity of South Barrow test well 3, of limestone, coquina, sandstone, and oolitic limonite along an upper Triassic shoreline; the northern part of the Barrow area was probably above sea level.

3. Transgression of a Jurassic sea from south to north, depositing progressively younger beds in its northward advance from South Barrow test well 3 to South Barrow test well 1.

4. Complete inundation of the Barrow area, accompanied by deposition of the pebble shale beds on a comparatively level surface underlain by the weathered surface of pre-Mesozoic rocks to the north and the uppermost Jurassic beds to the south.

5. Deposition of the Oumalik Formation, followed by uplift, particularly near the gas wells, and beveling of the Oumalik Formation. Regional evidence (see p. 154) suggests that these sediments, in contrast to the earlier ones, came from the south.

6. Deposition of the Topagoruk and Grandstand Formations.

7. The disturbance of the cryptovolcanic(?) structure and associated faulting, with an increase in dip to the north. This faulting probably formed the structural trap in which the gas was

subsequently trapped.

8. Erosion beveling the Topagoruk and Grandstand Formations, and removing all evidence (if there had been any) of later pre-Pleistocene deposition.

9. Transgression of a Pleistocene sea from the north, and deposition of the Gubik Formation.

10. Retreat of the Pleistocene sea, and subjection of the area to subaerial geologic processes, many of them related to the presence of permafrost, which have continued to the present.

Gas and oil.--The reservoir of gas tapped by South Barrow test wells 2, 4, 5, and 6 probably is limited to a small area between the fault just south of the wells, the northern knife-edge of the Jurassic beds, and a water level which is probably a short distance northwest and down dip from South Barrow test well 2 (which produced a small amount of water with the gas). The gas reserve, which is probably in the Jurassic beds (although some gas may be in fractures in the argillite), was estimated by Everette Skarda of Arctic Contractors in May, 1951, to be 7 2/3 billion cubic feet; the Arctic Contractors estimated 5 to 7 billion cubic feet in May, 1953 (written communications, 1953); a later estimate is 10 billion cubic feet (Miller, Payne, and Gryc, 1959, p. 102). If these Jurassic rocks are equivalent to any beds in South Barrow test well 3, they are represented there by sediments which are probably too fine-grained to produce an appreciable quantity of gas, even if they were tapped in a structurally favorable position. In South Barrow test well 3, located on a small anticline delineated by a seismic survey, the upper part of the Jurassic sequence had only a faint gas show.

The four gas wells are only a few hundred feet apart, and South Barrow test well 5, drilled in 1955 by the U.S. Air Force, is between numbers 2 and 4. It is producing gas at present (1964); South Barrow test well 2 was destroyed by fire, and South Barrow test well 4 is shut in, a standby well for the producer. Of the three wells, number 5 has been the most successful so far as a producer, partly because of experience in production practices gained from the other two wells. It is furnishing sufficient gas to heat the U.S. Government installations at Barrow, having an estimated maximum stabilized production rate of 7,900,000 cubic feet per day, with no water. The gas is 97 to 98 percent methane, but a minor amount of condensate, with an A.P.I. gravity of 48.3°, and consisting mostly of gasoline and naptha, was also produced. Production details and fluid analyses of the gas wells are given in Prof. Paper 305-K (Collins, p. 605-606, 624-625). South Barrow test well 6, located 1,925 feet S 73° E from test well 5, is 2,363 feet deep and had an initial production of 9.6 million cubic feet of gas from 2,276 to 2,363 feet, through a 2-inch pipe from the same horizon as the other wells. It was drilled largely to supply gas to Barrow Village and it was completed in the summer of 1964 by the U.S. Navy.

Geology of the Fish Creek oil field

Fish Creek test well 1, drilled at the northeast corner of the Reserve in 1949, penetrated 130 feet of interbedded clay shale and sandy siltstone which contains some dark, heavy oil. The test, which is described more fully elsewhere (Robinson and Collins, 1959), was drilled near an oil seep on the marshy tundra of the Arctic coastal plain. The area has no outcrops of consolidated rock, and the structure of the underlying beds has been studied by means of seismograph, gravimeter and magnetometer surveys. Magnetic intensity is rather uniform over the area, but the gravity map shows an area of unusually high gravity in the vicinity of the seep (Woolson and others, 1962, pl. 2). Seismic work, however, showed no evidence of an anticline, and indicated that the region is underlain by sedimentary rocks dipping gently (about 50 feet per mile) eastward; strata at a depth of 10,000 feet dip somewhat more steeply southward. The older rocks are presumed to be basal Cretaceous or Jurassic, and the upper ones are younger Cretaceous beds.

After drilling through sediments of the Colville Group, consisting predominantly of clay shale with some bentonite and tuff, the top of the Topagoruk(?) Formation was penetrated at 2,890 feet, and the oil-bearing beds at 2,920 feet. At the total depth of 7,020 feet the test had drilled a long section of Lower Cretaceous shale, so the hole was plugged back and sidetracked through the producing zone. Pumping equipment was installed, and the well averaged 9 to 12 barrels of oil with no water for about 3 weeks, before the equipment was removed and the hole abandoned. The brownish-black oil, analyzed by the U.S. Bureau of Mines, has an A.P.I. gravity of 13.9°, pour point of 25° Fahrenheit, and contains 1.92 percent sulphur; road oil, lubricating oil, and diesel fuel could be obtained from it. No estimate of reserves was made.

The extent of the deposit is unknown, but the lack of structural complexity suggests that it could be large. The characteristics of the oil imply that its lighter constituents may have left the reservoir, the oil now found there being the heavier residue. If a fault cut the oil-bearing beds and reached the surface of the ground at the seep, it might furnish a means by which the more volatile components could escape from the reservoir and create the seep. If it were to parallel the strike, it might also trap the oil by preventing westward migration up the east-dipping beds, forming a barrier against which the petroleum could accumulate. The unusually thin (about 130 feet) sandy siltstone section forming the reservoir indicates another possible explanation for the presence of the oil: if the reservoir beds have been truncated by an unconformity, the resulting stratigraphic trap could be sealed by overlying impermeable strata. Either type of trap could be of considerable extent, and would presumably be elongate parallel to the strike, roughly north and south. The western edge would perhaps be a mile or so from the well, in case of a faulted trap, and at an unknown distance, if it were a stratigraphic trap. The eastern boundary in either case would depend on the location of the oil-water contact, which is probably down dip an unknown distance from the well. The hole produced water-free oil during a 3-week pumping test (except for a little salt water recovered during the first 4 hours), so the oil-water contact is probably not very close to the well. If it were a stratigraphic trap, the location of the eastern boundary would be affected by the position of the unconformity, as well.

Geology of the Gubik gas field

Geography and development of the area.--In 1944, 1945, and 1947 U.S. Geological Survey field parties recognized a number of east-west trending anticlines and synclines southeast of the Reserve. They mapped westward plunge on one of these structures near the Colville River and named it the "Gubik anticline". The anticline is situated at the northern edge of the Northern Foothills section of the Arctic Foothills physiographic province, approximately 16 miles northeast of Umiat, in an area of low rolling hills with a relief of about 500 feet. The flood plain of the Anaktuvuk River crosses the Gubik structure in a broad valley flanked by low bluffs, but the Chandler River is a little narrower, with slightly steeper hills to the side.

In 1950, the seismic program carried out by the United Geophysical Co., also defined north-south reversal and a westerly dip on the structure west of the Chandler River. Closure at the east end of the anticline was mapped during the same summer by W. A. Fischer and A. N. Kover who were assigned the study of this structure as a special project by the U.S. Geological Survey. This work, plus stratigraphic considerations which indicated that the near-surface producing sands in the Umiat field would be approximately 2,800 feet lower if present at Gubik (and well below the permafrost level), prompted further geophysical exploration in the Gubik area in early 1951. A total of 75 profiles were shot between January 29th and March 5th of that year. A closed structure was defined and the seismic information provided the basis for making the location of Gubik test well 1.

Gubik test well 1, drilled in the summer of 1951, is located on the west side of the Chandler River about 1 1/2 miles above its junction with the Colville River. Gas in commerical quantities was discovered in the Tuluvak Tongue of the Prince Creek Formation and also in the Chandler and Ninuluk Formations undifferentiated. After making some tests the well was shut in.

A second well, Gubik test well 2, was drilled in the fall of 1951. The primary objective of Gubik test well 2, which is located just a little more than a mile southeast of Gubik test well 1, was to find oil in the sandstones which were gas-bearing or which appeared to have favorable reservoir characteristics in the first hole. Secondary purposes were to determine the extent of the gas deposit in each gas-bearing sandstone and to determine any gas-oil, gas-water, or oil-water contacts present.

The second test well produced gas from the younger sandstones but no oil was found. The older sandstones were water-bearing. While the well was being tested it caught fire, and the rig was burned down. After about 4 days the hole bridged itself and was allowed to freeze. The remainder of the equipment was moved away and no further drilling was done in the Gubik area by the government.

Stratigraphy of the Gubik gas field.--The section is similar in the two Gubik wells as they were drilled relatively close together. They are described in detail elsewhere (Robinson, 1958a), and the following is a summary with emphasis on correlative beds.

Topagoruk Formation.--The oldest formation penetrated by these tests is the Topagoruk Formation. Gubik test well 1 penetrated 2,265 feet of it but Gubik test well 2, a shallower hole, drilled through only 595 feet of the formation. In the detailed report referred to above approximately 600 feet of the upper part of the Topagoruk Formation as described here was designated the Grandstand Formation. The authors now prefer to include it all in the Topagoruk Formation, because there is not enough sandstone in this upper 600 feet to warrant calling it the Grandstand Formation. It is, however, thought to be the time equivalent of the Grandstand Formation as it occurs in the Umiat area. The clastics of the Grandstand Formation become gradually finer toward the northeast from Umiat until only clay shale, siltstone, and a few very thin beds of sandstone are found in this part of the section in the Gubik area.

The Topagoruk Formation at Gubik is mostly a silty, medium to medium dark gray, medium hard, (but mostly noncalcareous) clay shale that is also slightly bentonitic. The upper 600 feet contains a few beds of medium light gray siltstone and a very few thin layers of very fine grained light gray sandstone. The Verneuilinoides borealis microfauna is found throughout these marine beds in varying abundance.

Correlation between the two wells is good both lithologically and by the electric log. The upper section in Gubik test well 2 is approximately 200 feet shorter than the similar section in Gubik test well 1. The sandstone at 3,957 feet in Gubik test well 1 is 240 feet lower in Gubik test well 2, yet the siltstone at 4,213 feet in test well 1 probably correlates with the silty sandstone that is only 98 feet lower in Gubik test well 2; the discrepancy is probably due to a fault (which is discussed further in the section on structure).

Chandler and Ninuluk Formations undifferentiated.--The Chandler and Ninuluk Formations undifferentiated is 430 feet thick and is composed almost entirely of sandstone and siltstone. The lower producing sandstone is nearly 200 feet thick and is separated from over- and underlying siltstones and sandstone by a few thin beds of clay shale.

Fossils are found in the section only within the upper 130 feet and consist of a few species of Foraminifera, some of which are typical of the Ninuluk Formation, and a few very rare pelecypod fragments. This portion of the section may be considered part of the marine Ninuluk Formation. The barren, very sandy beds below contain some carbonaceous material and ironstone. As there is no evidence that the sandy beds are marine they have been tentatively assigned to the Chandler Formation and the whole 430 feet has been combined into one undifferentiated unit. A precise contact between the two formations is impossible to locate with the evidence available. In this unit, lithologic, paleontologic, and electric log correlations between the two Gubik wells is excellent.

Seabee Formation.--Overlying the Chandler and Ninuluk Formations undifferentiated is about 1,550 feet of the Seabee Formation. It is made up mostly of dark colored clay shale with silty and sandy beds near the top and bottom. Biotite, a mineral typical of the sandstones of much of the Colville Group, is fairly common in the Seabee beds in the Gubik area. Bentonite and a few thin limestone beds are characteristic of the section. Inoceramus labiatus Schlotheim, Radiolaria, a few Foraminifera, and fish bone fragments have been recovered from the Seabee Formation in these wells.

As in the Lower Cretaceous beds, the lithologic, paleontologic and electric log correlation between the two Gubik test wells is excellent. The bentonitic, fossiliferous, medium dark gray clay shale at -2,654 feet in Gubik test well 1 and about -2,887 feet in Gubik test well 2 is an especially good marker. Similar beds are found in the Seabee Formation at Umiat, Simpson Seeps, and elsewhere. Microfossils found within 300 feet of the top of the formation in Gubik test well 2 are like those found in the Ayiyak Member of the Seabee Formation as it is described from surface exposures (Detterman, 1956b, p. 254), but this member is not clearly differentiated in the Gubik area.

Prince Creek Formation, Tuluvak Tongue.--This tongue overlies the Seabee Formation in the Gubik area. It is about 870 feet thick and consists mainly of sandstone with some conglomerate, clay shale, coal and bentonite. The sandstone varies from very fine to coarse-grained, and in general is coarser than most of the sandstones in the Cretaceous strata of the subsurface elsewhere in the Reserve. Some of the sandstone beds are quite calcareous. Gas is produced from sandstone beds in the lower half of this formation.

Beds of coal as much as one foot thick were cored. The beds of coal shown on the graphic log of Gubik test well 1 (Robinson, 1958, pl. 15) are probably not as thick as they were plotted; cutting samples were probably contaminated by the first coal penetrated. Individual coal beds probably correlate poorly over any great distance but the coal-and-bentonite zones might be better. Beds of bentonite are found in at least three horizons (at 1,430 feet, 1,760 feet, and 1,880 feet in Gubik test well 2) which are traceable between the two wells. Other beds present may be equally continuous but the evidence is not clear. Thin conglomerates are found in several places in the sandstone. Samples from the two wells suggest that they vary considerably from place to place in thickness and grain size. Electric log correlation is particularly good in this formation between the two wells, as shown on plate 6.

Schrader Bluff Formation, Rogers Creek and Barrow Trail Members.--About 1,100 feet of the Schrader Bluff Formation is present in Gubik test well 2 and some 200 feet less in test well 1, because the latter is higher on the anticline. The formation is marine and in the Gubik area consists of two members:

The Rogers Creek Member is almost entirely medium light gray, medium hard clay shale which is almost 600 feet thick. It contains two very distinctive beds of tuff---the first, at 590 feet in Gubik test well 2, is a light greenish gray and is speckled with carbonaceous particles. The second, a zone of tuffaceous shale with its top at 870 feet in the same Gubik well, has layers of white to very light gray tuff which is hard and contains biotite plates. Another layer of white tuff at 1,045 feet in this well was not noted in Gubik test well 1. (It may have been missed in the cutting samples in the latter hole.) Bentonite is also found in the Rogers Creek Member.

The Barrow Trail Member contains three beds of sandstone which probably account for its more resistant nature and distinctive outcrop. The sandstones typically have a very bentonitic matrix, distinguishing them from other sandstone beds in the Upper Cretaceous of the subsurface, and they also contain many volcanic shards.

The Sentinel Hill Member of the Schrader Bluff Formation and the Kogosukruk Tongue of the Prince Creek Formation, the uppermost parts of their respective formations as found on the surface, are not in the Gubik wells, but are probably present on the flanks of the Gubik structure.

Quaternary deposits.--Approximately 70 feet of Recent river alluvium is at the top of the wells. Sand and a small amount of gravel are the major constituents.

<u>Structure</u>.--The Gubik anticline extends from a point about 6 miles west of the Colville River eastward to the Anaktuvuk River, approximately across the mouth of the Chandler River. It is about 6 miles north of, and roughly parallel to, the larger Umiat anticline, and is separated from it by the Kutchik syncline (Payne and others, 1951, sheet 1).

Geophysical work suggests that the structure is relatively symmetrical and simple, about 14 miles long and 3.2 miles wide at its widest, as measured on a -4,600-foot closed contour. Closure, as shown on figure 16 which depicts the structure as contoured by United

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Figure 16. Gubik anticline,

Geophysical Co. Inc. on a seismic horizon in the upper part of the Topagoruk Formation, is in excess of 500 feet and encompasses an area of approximately 30 square miles. The seismic reflections were good on the sides of the structure but poor on the crest. As most of the section below 4,000 feet is shale, no satisfactory reflections were obtained below this depth. Figure 16 shows the location of the seismic shot points and lines as well as the depth of the contoured horizon.

Dip on the north side of the anticline from the crest to the -4,600 foot contour is about 300 feet per mile; below -4,600 feet it steepens to 800 feet per mile. On the south flank the beds dip about 500 feet per mile. The latter figure is equivalent to a six-degree dip, and is in accordance with those recorded in the cores of Gubik test well 2 at the depth of the seismic contour horizon.

The east end of the Gubik anticline plunges at the rate of 140 feet per mile and the west end, which is not as steep, plunges 85 feet per mile. Additional seismic control, particularly at the west end of the structure, might add some 300 feet more closure in addition to the possible 500 feet shown on the map.

Gubik test well 1, which is located near the crest of the anticline (see pl. 6) has dips ranging from about 1° to 6° down to approximately 1,800 feet. Below this, the beds dip 1° or are flat-lying through the Seabee, Chandler, and Ninuluk Formations, and the upper part of the Topagoruk Formation, to about 4,500 feet. In the lower 1,500 feet of the Topagoruk Formation the dips are steeper, ranging from 10° to 16°. This steepening of dips may reflect the "zone of discordant dips" described on page 54.

In Gubik test well 2, which is on the south flank of the anticline, average dips are slightly steeper than in the first well. They range roughly from 4° to 9° down through the Seabee Formation, but in the Chandler and Ninuluk Formations are slightly lower, being mostly between 1° and 3°. Dips in the upper part of the Topagoruk Formation are as high as 7° and the lowest 150 feet of the formation contains dips of about 13°. The steeper beds in the lower part of the Topagoruk Formation are in the upper part of the same zone of discordant dips mentioned above.

As mentioned in the discussion of the Topagoruk Formation, nearly 170 feet of section is missing at about 4,280 feet in Gubik test well 2. No unconformity has ever been described at this horizon in the section so it is assumed that the beds are cut out by a normal fault. Slickensides are found in cores both above and below the postulated position of the fault, lending support to this theory. The direction of strike or amount of dip of such a fault is unknown. The fault is not shown on the map, figure 16, as seismic data neither confirm nor deny its presence.

Gas and oil.--Gubik test well 1 is the discovery well of the Gubik gas field. Gas was first noted in the ditch when the hole was drilling at 1,215 feet in the Tuluvak Tongue. The gas flow increased steadily and a drill stem test from 1,438 to 1,495 feet produced a fair flow (see details on pl. 6 and in Robinson, 1958a, p. 228). A test in the lowest sandstone of the Tuluvak Tongue produced a flow of gas calculated at 2,060,000 cubic feet per day. Similar tests on the thick sandstone in the Chandler and Ninuluk Formations between 3,488 and 3,608 feet also produced a substantial flow of gas.

Gubik test well 2 is located 235 feet structurally lower on the top of the Tuluvak Tongue and 275 feet lower on the top of the Chandler and Ninuluk Formations. The Chandler and Ninuluk sandstone beds in this test proved to contain salt water but most of the Tuluvak sandstone beds contained gas. Most of the thicker sandstone beds in the discovery well have been given a letter designation on the cross section, plate 6, for ease in reference. Sandstones A through D in the Schrader Bluff Formation had no shows in this well and they would probably not be productive anywhere on the structure; their porosity and permeability must be very low because of the bentonite in the matrix. The Schrader Bluff Formation makes an excellent impermeable cap over the anticline for the gas-containing sandstones below. Sandstone AA is an additional dry sandstone in this formation which was not present at Gubik test well 1 because of the well's position higher on the structure.

Sandstone E at the top of the Tuluvak Tongue was not tested in Gubik test well 1 and there is little in the drilling reports or on the electric log to suggest that it contains much gas. The well geologist did report gas breaking the mud sheath of cores from this sandstone in Gubik test well 2. Concerning the drill stem test on this sandstone in Gubik test well 2, C. L. Mohr, Arctic Contractors' exploration manager, commented (written communication, March, 1952), "Core analyses show permeabilities sufficient for fluid production, and the electric log suggest water saturation. The sand appears to have been mudded off, so that the test was inconclusive."

Sandstone F was not tested in Gubik test well 1 although when the cores were studied in Fairbanks a faint petroleum odor and a very pale cut was obtained from this horizon. The porosity and permeability is good and the electric log suggests the presence of some gas in it in Gubik test well 1. Gas-cut drilling mud was recovered from the sandstone in drill stem tests in Gubik test well 2. Good oil cuts were obtained from the sandstone but the cores were not saturated. C. L. Mohr (op. cit.) says of the drill stem tests from 1,308-1,351 feet and 1,355-1,402 feet, "Core analyses show permeabilities sufficient for fluid production, and the electric log indicates gas or oil saturation. Since the cores did not have oil saturation, the sand is obviously gas-bearing and was mudded off, so that it did not respond readily to the drill-stem test. Apparently the recovered fluid was in part filtered drilling fluid. If the tester had been left open for a longer period, gas probably would have been recovered." No water level was definitely indicated for this sandstone.

As mentioned previously gas in the ditch in Gubik test well 1 was noted when the test penetrated sandstone G. The drill stem test from 1,431-1,502 feet in Gubik test well 2 recovered 500 feet of gas cut water. The water was of the same salinity as the drilling fluid. Mohr says (op. cit.), "The electric log suggests saturation by water of low salinity. Although the recovered fluid obviously came from the sand, there is doubt as to whether it is filtered drilling fluid or formation water."

Sandstone H was not cored in Gubik test well 1 so the interval was not thoroughly tested for shows or for porosity and permeability. The electric log suggests that the upper 10 feet of the section might contain gas. The porosity and permeability are probably fairly high as some conglomerate is present. The portion of this sandstone tested by the drill stem test 1,504-1,554 feet in Gubik test well 2 was dry and no odors or cuts were noted in the cores.

Sandstone I is probably very silty and impermeable.

A fair amount of gas was produced on a drill stem test of sandstone J in Gubik test well 1 but only drilling fluid was recovered in a test in Gubik test well 2. Mohr says of this test from 1,674-1,737 feet (op. cit.), "The core analyses show permeabilities sufficient for fluid production, and the cores evolved gas and yielded cuts of oil with solvents but no free oil. The electric log indicates questionable saturation by gas or by water of very low salinity. It appears that the sand was mudded off, and that if the tester had been left open longer, a sample of the formation fluid should have been obtained."

Cuttings show sandstone K is coarse grained in Gubik test well 1 but no cores were taken and no tests were made. Sandstone K is the best gas producing horizon in Gubik test well 2 and has a permeability at one place, of 3,780 millidarcys. A test produced an estimated rate of 8 million cubic feet of gas per day on a 1-inch orifice. The shut-in bottom hole pressure was 1,050 pounds per square inch. Mohr says (op. cit.) of a drill stem test from 1,844-1,885 feet which recovered oil cut mud in addition to gas near the bottom of this sandstone, "The cores showed fair oil staining and bled a little free oil from 1,856 to 1,873 feet, but the oil seemed to be limited to the slightly permeable portion of the sand." The test from 1,876-1,885 feet produced a small quantity of water. The water level in this sandstone may be close to 1,876 feet (-1,713 feet). This is believed to be the sand which blew out in Gubik test well 2 (Robinson, 1958a, p. 255).

Sandstone L is one of the two best producing horizons (the other being in the Chandler and Ninuluk Formations undifferentiated) in Gubik test well 1, but unfortunately the sandstone produced salt water plus a small quantity of gas and oil cut mud in Gubik test well 2. The water level in sandstone L is probably close to 1,928 feet (-1,765 feet).

Sandstone M in the upper part of the Seabee Formation had no adequate test for petroleum. No other sandstone in the Seabee Formation was tested except P. A very pale cut was found in Gubik test well 1 but water was produced from Gubik test well 2. The permeability in this sandstone is very low.

The appearance of the electric log and the faint odors and very pale cut that were obtained suggest that gas may be present in sandstone Q in the Chandler and Ninuluk Formations undifferentiated.

Sandstone R of the Chandler and Ninuluk Formations, which is 165 feet thick, is the thickest penetrated by either well. It is the lower producing horizon of the Gubik gas field, with an estimated flow of 2,046,000 cubic feet per day through a 1/2-inch orifice in Gubik test well 1. Only salt water was recovered from this sandstone in Gubik test well 2. The water level may be as low as -3,618 feet.

No substantial amount of oil was produced in the tests of the sandstones of the Tuluvak Tongue or Chandler and Ninuluk Formations, undifferentiated. In sandstone R the lowest gas was tested at -3,452 feet and the highest water at -3,618 feet. This leaves an untested interval of 166 feet in which oil might be found by a test hole drilled between the two wells.

There is a possibility of obtaining some oil from the sandstones T and U in the upper part of the Topagoruk Formation. These silty sandstones had some of the best oil shows in the Gubik wells. Samples of sandstone T, which was cored in Gubik test well 2, were bleeding green oil when received in the Fairbanks laboratory, and an excellent odor and good cut were noted. A drill stem test of this sandstone recovered 60 feet of oil cut mud, but the sandstones in the Topagoruk Formation are too impermeable in the test wells to produce oil. A location on the west end of the Gubik anticline might drill into these sandstone beds of the Topagoruk Formation under more favorable conditions of porosity and permeability because they are the approximate equivalent of the Grandstand sandstone beds which produce oil at Umiat.

Figure 16 shows the limit of gas production to be expected from the Tuluvak sandstone beds as determined by Arctic Contractors in 1951. They estimated that the gas-bearing zones underlie 7,160 acres. The gas-bearing zone of the Chandler and Ninuluk Formations undifferentiated underlies a smaller area, the maximum outer limit being somewhere between the test wells.

The presence of the possible fault in Gubik test well 2 could have an effect on the total production possibilities of the field. Theoretically, somewhere near Gubik test well 2 there is a 200-foot upthrown fault block which might prove productive in the Chandler and Ninuluk sandstones that are waterbearing in that well, because the well is on the downfaulted side. The best shows of oil were near the fault in sandstone T.

Arctic Contractors estimate the reserves of the Gubik field as follows (written communication, 1953): A revised estimate of the reserves in the Gubik field places them at 222,000 million cubic feet in the sands upon which successful tests were made and a possible 295,000 million cubic feet if sands are included which appear on the electric log to have similar characteristics.

Geology of the Simpson Peninsula and the Simpson Seeps Oil Field

Geography and development of the area.--Four large oil seeps are located on the "Simpson Peninsula", about 50 miles southeast of Barrow (see fig. 1 and pl. 7). It is a flat, marshy strip of land bordering the Arctic Ocean between Dease Inlet on the west and Smith Bay on the east. Cape Simpson, on the east side of the peninsula, was named by P. W. Dease and Thomas Simpson in 1837 in honor of Sir George Simpson, long-time governor of the Hudson's Bay Company. Seep 1 is 3 miles northwest, Seep 2 is two miles west, and Seep 3 is about 5 miles southwest of Cape Simpson, and they are therefore frequently called the "Simpson Seeps".

These three oil seeps are located on prominent mounds which rise 15 to 30 feet above the coastal plain, as shown in figure 17. The

Figure 17. Reconnaissance topographic map of the Simpson Seeps area based on shot point and core hole elevations. This map shows the mounds on which the seeps are located.

roughly oval mounds are nearly aligned in a north-south direction. Seep 1 (after a description by Ebbley, 1944, p. 419) is 500 yards south of the Arctic Ocean and has a southeasterly asphaltic surface flow (see fig. 18) of about 200 by 800 feet, although hardened pitch

Figure 18. General view of Simpson Seep 1, the northernmost of three large oil seeps found in the Cape Simpson area. Summer, 1948.

underlies the tundra for 1,200 feet in a north-south, and for 800 feet in an east-west direction. Seep 2 flows south out of a mound into a small lake, following a channel about 150 feet wide and 600 feet long (Hanna, 1963, pl. 1). At Seep 3 small pitch pools are present nearby and petroleum residue underlies the tundra for a distance of 700 feet north-south and about 1,000 feet east-west, although the exposed flow is smaller than the first two seeps, being 300 by 100 feet. Other small seeps may be present in the area but only 2A, located three miles southwest of Cape Simpson, is customarily referred to by number.

The seeps were probably known to the Eskimos and may have been mined for fuel before the coming of white men. It is possible that whalers who had visited the area since the 1850's also knew of their existence, but Charles D. Brower, long-time trader at Barrow, visited the seeps in 1886 and claims to have been the first white man to have seen them (Brower, 1950, p. 84). The first mention of the seeps in print was made in 1909 by A. H. Brooks of the U.S. Geological Survey (1909, p. 61). His information came from E. deK. Leffingwell, who had spent from 1906 to 1914 on the Arctic coast while engaged in scientific investigations, but apparently did not visit the seeps in person. Mention was also made of the seeps by George C. Martin (1921, p. 68) in a summary report on petroleum in Alaska.

One who did a great deal to call the seeps to public attention was Alexander Malcolm "Sandy" Smith who first saw the area in the winter of 1913-1914 and who promoted interest in them on the part of a group of bankers in California. In the summer of 1921 Max Steineke and Harry A. Campbell of the "Adams Expedition", guided by Smith, staked 42 claims on the north and east side of the peninsula near the seeps, just a few days ahead of a rival expedition representing a major oil company (Smith, oral communication, 1955). They were not able to hold these claims as a large amount of land in northern Alaska, including the Simpson Peninsula, was set aside by President Harding in 1923 as Naval Petroleum Reserve No. 4.

At the request of the U.S. Navy, the U.S. Geological Survey sent several parties north to study the geology. Of these, Sidney Paige was the first government geologist to visit and describe the Simpson Seeps (Paige, Foran, and Gilluly, 1925, p. 23). A summary of the results of the Survey's explorations in the Reserve through 1926 and a detailed discussion of the known petroleum occurrences can be found in "Geology and Mineral Resources of Northwestern Alaska" by Philip S. Smith and J. B. Mertie, Jr., (1930, p. 274-286).

Nothing further was done about the Simpson Seeps until World War II when interest was revived in Naval Petroleum Reserve No. 4. In 1943 Norman Ebbley, Jr., of the U.S. Bureau of Mines and Henry R. Joesting of the Alaska Territorial Bureau of Mines made a field trip to northern Alaska to investigate all the reported oil seeps. The Simpson Seeps as well as five other seeps were located and described (Ebbley, 1944, p. 415-419).

In 1944, when the Navy initiated its program for the exploration of the Reserve, Simpson area was one of the first ones to be considered. A camp was to be set up at Cape Simpson and shallow core drilling carried on in order to obtain stratigraphic information preparatory to drilling a deep test well. Equipment was shipped, but upon arriving at Cape Simpson in August, the beach, the weather, and the ice conditions were considered unfavorable for landing and the parties returned to Barrow where a permanent camp was set up. Drilling on the Simpson Peninsula was postponed until the following summer.

Drilling equipment and supplies were moved to the area early in 1945. An important discovery of the first trip was the desirability of traveling to a place like Cape Simpson on sea ice rather than over land. The first tractor train left for Simpson on January 22, 1945, and the fourth successful trip had been completed by the middle of April.

A gravity meter and a seismograph party went into operation at Cape Simpson in the first part of June, 1945, and continued working through most of the summer. A total of 317 seismic profiles were obtained for subsurface coverage of 26 miles on the western one third of the peninsula. Oil from a depth of 75 feet was collected in the slush pit from one shot hole, and gas showings caused the abandonment of another.

Twelve shallow core holes (from 116 to 580 feet deep) were drilled by a Navy Construction Battalion on the west side of the peninsula between June 25 and August 29, 1945, and shows of oil were found in four of them. Freezing in the holes, caused by the permafrost, was the only source of serious difficulty in drilling these holes.

Seismic work was continued in the Simpson area in 1946 to cover a gravimetric high discovered the previous year. The results of the geophysical work and the shallow core tests determined a site for a deep test well on the west side of the peninsula. The hole, Simpson test well 1, was drilled from June 1947 to June 1948 and reached a total depth of 7,002 feet, in pre-Mesozoic rocks (Robinson, 1959b). This was the first major test well in the Reserve in which drilling was continued throughout the winter. It was completed as a dry hole although a few shows of oil were obtained in shallow rocks of Cretaceous age.

In 1948, the U.S. Geological Survey sent a geologist to examine the surface exposures near the seeps, but no bedrock was found in place (Patton, 1948). By 1949 a new program, including the drilling of many shallow test holes, was initiated.

In the course of the next three years 32 core tests ranging in depth from 290 to 2,505 feet were drilled in the Cape Simpson area, and were numbered consecutively with the early core tests to the west. The reflection seismic work done in 1946 indicated an elongate syncline centered under Lake Minga, located five miles west of Cape Simpson. This anomaly was believed to be caused by a decrease in velocity of thawed surface sediments rather than a structural feature. Minga velocity test 1 was drilled during the spring of 1950 on the lake ice in order to test this theory. No permafrost was found, so the theory was correct and no syncline existed under Lake Minga. A seismic high on a deeper horizon (see Robinson, 1959b, p. 525) centered about 10 miles northwest of Cape Simpson was tested in the late spring of 1950 by North Simpson test well 1, a dry hole which was drilled to a depth of 3,774 feet in Cretaceous rocks. Sandstone reservoir beds expected in the hole were absent under an unconformity (described in more detail on p. 183 ff.).

Fairly good shows of oil or gas in beds of Cretaceous age were found in 5 core tests in the vicinity of Seep 2 and in 6 core tests near Seep 3. Core test 26, near Seep 3, was the discovery well of the Simpson Seeps oil field; core test 31 at Seep 2A was also a producing well. Following the drilling of core test 31 in March 1951 the flowing wells were shut in and drilling on the Simpson Peninsula ceased.

Stratigraphy of the Simpson Peninsula.--Simpson test well 1 is the only hole on the Simpson Peninsula that went deep enough to reach pre-Cretaceous rocks; they have been described elsewhere in this report (p. 16ff). The Cretaceous formations are described briefly below, and details are available in other papers (Robinson, 1959b and 1964).

Oumalik Formation.--North Simpson test well 1 penetrated the Oumalik Formation, as well as Simpson test well 1. In both holes it consists of medium dark gray clay shale that is slightly darker and less silty than the overlying Topagoruk Formation, and has different characteristics on the electric log. It contains pyritic specimens of *Lithocampe* sp., a radiolarian diagnostic of the formation and the lower part of the Torok Formation. The formation is 1,710 feet thick in Simpson test well 1, which drilled through the complete section; North Simpson test well 1 only penetrated the upper 185 feet of it.

Topagoruk Formation.--This unit consists of medium gray to medium light gray clay shale and light to medium light gray siltstone, with a few very thin beds of silty sandstone near the top. It contains 3 beds of medium gray, hard, silty limestone, which are less than 2 feet thick. Coal is absent and clay ironstone is very rare. Fossils, including *Inoceramus* prisms and the *Verneuilinoides borealis* microfauna, are abundant. *Textularia topagorukensis* Tappan, a foraminifer typical of the lower part of the formation, is present in both test wells. At Simpson test well 1, which drilled through a complete section of the formation, it is 2,580 feet thick, but at North Simpson test well 1 all but the lowest 820 feet was removed by erosion during Seabee time (see p.183 ff).

The Topagoruk Formation is the oldest stratigraphic unit penetrated by any of the Simpson Seeps core tests, on the east side of the peninsula, and is found only in core tests 25, 27, and 28. The lower sections of these tests were considered a part of the Grandstand Formation in Professional Paper 305-L (Robinson, 1964), but regional studies have prompted the authors to revise the correlations and include the beds in the Topagoruk Formation. The thickest section of the Topagoruk Formation in the Simpson Seeps area is in core test 28, where the interval from 1,655 to 2,505 feet (the total depth) closely resembles the upper part of the type section of the Topagoruk Formation in Topagoruk test well 1. A tentative correlation with Simpson test well 1 suggests that the contact between the Grandstand and Topagoruk Formations is at about the same horizon on both sides of the peninsula, although the Topagoruk Formation in the test well contains much less sandstone.

In all three of these core tests there is a short section just below the top of the Topagoruk Formation with a very low spontaneous potential reading on the electric log which makes a good marker horizon. A trace of bentonitic clay found in cutting samples from these beds in core test 28 could account for the low potential.

Grandstand Formation.--This formation in Simpson test well 1 includes interbedded sandstone, siltstone, and shale, with a basal sandstone member more than 200 feet thick; the formation there is 965 feet thick. Core tests 1 to 10, located just east of and down dip from Simpson test well 1 on a small local structure, probably contain slightly younger strata: the presence of bentonite suggests that a few beds of the Ninuluk and Seabee Formations undifferentiated are present, but the samples are very poor and contacts cannot be drawn. For convenience all beds below the Gubik Formation are included in the Grandstand Formation in these core tests. Despite the poor samples, good correlations can be drawn between the holes on individual sandstone beds (see pl. 8). In North Simpson test well 1 the Grandstand Formation is absent, and beds of the Seabee Formation rest directly on the eroded surface of the Topagoruk Formation.

In the Simpson Seeps area on the east side of the peninsula the complete Grandstand Formation was penetrated in only one hole, core test 27, where it is about 965 feet thick. Most of the other holes did not reach the bottom of the formation; in core tests 25 and 27, which did, the upper part had been removed by erosion. The upper boundary of this formation is rather uncertain, and is placed at the top of the uppermost relatively "clean" and medium-grained sandstone. The contact is not well established in all the core tests, as determining its position is complicated by the presence of an unconformity, with associated slump blocks and possible reworked sediments, in addition to poor or contaminated samples from some of the tests. Unfortunately the uppermost sandstone bed was not sampled in core test 27, but in core test 14 most of it was cored, and elements of the *Verneuilinoides borealis* microfauna appear below it and a few Radiolaria common in the Upper Cretaceous were found above. Correlation of the sandstone beds within the formation is good in the Simpson Seeps area between holes that are close, and also from seep to seep. The cross section, plate 9, shows that they increase slightly in thickness toward the north and a sandstone bed lacking in Simpson core test 27, at the south, is present farther north (at -645 feet in core test 14 and about -720 feet in core test 23). The proportion of sandstone to shale also appears to increase slightly toward the north. Correlation of individual beds with those in Minga velocity test 1, only a few miles west, is questionable, however, and with Simpson test well 1, 16 miles west, it is impossible and only sandstone groups and paleontology are reliable.

One excellent local horizon marker in the Simpson Seeps area is the worm tube, Ditrupa cornu. The uppermost occurrence of this fossil is near the bottom of the second major sandstone bed below the top of the formation. It is found in sandy and silty beds, most of the grains of which are made of white and clear quartz. A clear yellow mineral is also especially common in these beds as well as a few grains of red garnet. The Verneuilinoides borealis fauna is sparse near the top of the formation but increases with depth, and Inoceramus prisms are common.

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Ninuluk and Seabee Formations undifferentiated.--Overlying the Grandstand Formation in most of the Simpson Seeps core tests is a group of beds with characteristics of both the Ninuluk and Seabee Formations. These beds are absent at Simpson test well 1 (where the Grandstand Formation is overlain by the Gubik Formation) and at North Simpson test well 1 (where the Topagoruk Formation is overlain by the Seabee Formation), and are only doubtfully present in core tests 1 to 10 (where a small portion of the section that might be Ninuluk and Seabee Formations undifferentiated is placed in the Grandstand Formation). In the Simpson Seeps area, however, this unit is about 300 feet thick, and the top is determined by the unconformity described below (p. 183 ff.). It was cored in Simpson core test 27 from 146 to 450 feet, and in core test 30 from 143 to 445 feet, and is present, at least in part, in several other tests. In addition to the sandstone and clay shale, the lower half of the unit contains thin beds of coal and ironstone and the upper portion contains two distinct bentonitic horizons, each about 50 feet thick, and a few thin beds of limestone or aragonite. The bentonite beds are excellent markers and can be correlated with great accuracy between Seeps 2 and 3. Even in the absence of good lithologic samples their presence can be detected by the lowered self-potentials of the electric logs.

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The lower bentonitic horizon is associated with coaly beds which might represent the northernmost extent of the nonmarine Chandler Formation, but coal is found associated with bentonite in the marine Ninuluk Formation elsewhere, and the thin coal beds on the Simpson Peninsula are interbedded with strata containing marine fossils. Consequently, the authors prefer the interpretation that these beds are Ninuluk in age and that the Chandler Formation is absent.

The upper bentonite zone is very fossiliferous and contains the pelecypod Inoceramus labiatus Schlotheim (diagnostic of the Seabee Formation), the ammonite Borissiakoceras sp., fish scales and fish bone fragments, and several species of Radiolaria.

Mid-Seabee unconformity.--During Seabee time deposition was interrupted and an unconformity was formed, partly on the Seabee Formation and partly on older rocks, which has a maximum vertical relief greater than 4,500 feet. The presence of the unconformity was first recognized from seismic data, (Woolson, 1962, p. 17) and contours of its surface shown on plate 7 are based in part on that data. Lithologic and faunal evidence confirm its presence, and demonstrate its age and extent. A steep seaward break in slope on the unconformable surface coincides roughly with the present outline of the Simpson Peninsula and might possibly control the shape of the peninsula, as the strata deposited above the unconformity are very soft, easily eroded clay shale and those below contain beds of slightly harder sandstone. On the west side of the peninsula the unconformity slopes toward Dease Inlet at the rate of about 2,000 feet per mile. This slope flattens considerably at the north end of the peninsula to about 1,000 feet per mile and is interrupted by a small ridge in the vicinity of North Simpson test well 1. On the east side of the peninsula a deep north-south canyon (Simpson Canyon) with the axis located just a little east of Lake Minga, was developed. What happens to the unconformity east of Cape Simpson is unknown.

On the west side of the peninsula and south of core tests 11 and 12 (which are on the steep slope of the unconformity and penetrated only the overlying Seabee Formation), erosion has removed most or all of the Ninuluk and Seabee Formations undifferentiated, and at Simpson test well 1 surficial deposits rest directly on the Grandstand Formation.

On the east side of the Simpson Peninsula the surface of the unconformity is very irregular, and its northerly dip is interrupted by a canyon which extends 10 miles to the south. The gradient of the floor of the canyon averages about 5°, and the slope of the west wall between Minga velocity test and Simpson core test 19 is about 15°. On the other side the canyon bifurcates, with a small tributary channel coming in from the southeast. The slope of the east wall of the main channel between core tests 25 and 26 is 18°, and the wall of the secondary channel between core tests 14 and 22 slopes about 13°. The interpretation of this unusually rugged surface as a buried or "fossil" canyon was first made by T. G. Payne and Helen Tappan Loeblich in the summer of 1950 (Payne, 1950, personal communication).

The age of the canyon, and hence of the unconformity, is determined with considerable accuracy because of the distinctive characteristics of the beds under- and overlying it. The normal sequence of the strata which have been cut by the unconformity in this area, and the distinctive horizons within them, are summarized as follows:

1. The Topagoruk Formation, a clay shale containing the Verneuilinoides borealis microfauna and Inoceramus prisms in abundance.

2. The Grandstand Formation, consisting of sandstone with some interbedded shale, containing the Verneuilinoides borealis microfauna and with the worm tube Ditrupa cornu present, in the Simpson Seeps area, from about 250 feet below the top of the formation on down.

3. The Ninuluk and Seabee Formations undifferentiated, which contain a little coal and clay ironstone in the lower part, and two distinctive bentonitic zones in the upper part. The lower of the two zones is coaly; the upper one, which is very fossiliferous, with ammonites and other fossils diagnostic of the Seabee Formation, is referred to here as the Borissiakoceras-Inoceramus zone. The Ninuluk-Seabee section is about 300 feet thick.

The unconformity is overlain by a rather uniform clay shale. Borissiakoceras sp. is present in it at Simpson core test 18 and at North Simpson test well 1, and as these beds are undisturbed and the fossils are too fragile to have been reworked from the strata below, the shale is also part of the Seabee Formation. The unconformity, therefore, must represent a comparatively short period of erosion which took place during Seabee time.

The depth of the unconformity in each hole is located by a change in lithology, where the drill went from overlying clay shale into one or another of the distinctive beds below. Associated with the surface of the unconformity are other features, some of which furnish additional evidence of its age. In Simpson core test 29, a breccia found just above the unconformity includes angular rock fragments which contain Inoceramus prisms, a large fish scale, and distinctive lithologic characteristics of the Borissiakoceras-Inoceramus zone, as well as fragments of clay shale containing microfossils of the Ninuluk and Seabee Formations undifferentiated. Core tests 22 and 25, also located on the canyon wall (see pl. 10), contained similar breccias; in core test 22, it consisted of fragments of bentonitic clay shale, siltstone, coal and clay ironstone. Associated beds dip 60° and contain slickensides. In core test 25, the angular fragments included clay shale with coal chips and yellow clay ironstone; associated shale beds dip 25°, and are separated from the sandstone breccia, at one point in the core, by a 1/16-inch thick layer of dark clay shale that dips 70-75°. Steeply dipping slickensides are present in the clay shale beds in this hole, as well. In core test 21, located near the bottom of the canyon, a slumped block of the Grandstand Formation 55 feet thick rests on the unconformity; beds in it dip 45° to 50° and it contains many slickensided fracture surfaces. In core test 13, beds of the Borissiakoceras-Inoceramus zone are nearly 300 feet lower than their normal position, dip from 10° to 25°, are somewhat distorted, and contain slickensides. They, too, are interpreted as being in a

block which slipped down the side of the canyon. Steeply-dipping beds of the Borissiakoceras-Inoceramus zone are present just above the unconformity in many core tests, and probably represent fragments of breccia or slumped blocks. Below the unconformity, beds of the same zone are flat-lying.

The east-west cross section, plate 10, shows the relation of the unconformity to the beds above and below it, in the vicinity of the canyon. Part A (of pl. 10) shows Minga velocity test on the west side, core tests 19 and 18 within the canyon (neither reached the bottom), and core test 13 on the east side. Core test 14, on the ridge between the main and tributary canyons, has shows of the oil trapped in sandstones near the top of the ridge. East of core test 14 is the tributary canyon. The beds in the core at the bottom of core test 22, within the tributary canyon, dip 60°, contain slickensides, and are in part a breccia, suggesting that the core test stopped just above the unconformity surface. At Simpson core test 28, nearly in the middle of the tributary, the Seabee Formation rests directly on the Grandstand Formation. The contact between the two formations is shown clearly by both the cutting samples and the electric log. The uppermost 80 feet of Ditrupa-bearing beds have been removed by erosion associated with the unconformity. Core test 20 shows a slight rise in the canyon floor toward the east. The unconformity is placed 27 feet higher than in core test 22 because of a change in lithology at that depth.

Plate 10B shows the east side of the canyon farther south, in the vicinity of Simpson Seep 3. Cores from core test 25 show initial dips in the Seabee Formation above the unconformity as high as 30°. Some slumping has taken place along a small fault. Breccia with angular fragments as much as 2 inches in diameter was noted as high as 110 feet above the unconformity. Ditrupa cornu here is 160 feet lower than normal, the higher Ditrupa-bearing beds having been removed by erosion. At Simpson core test 26, the discovery well of the Simpson Seeps oil field, the unconformity is just under the Gubik Formation; a little farther east, core test 27 crossed it about 53 feet lower.

Such a pronounced unconformity is not recognized within the Seabee Formation farther south in the Reserve, and its cause is uncertain. An interesting speculation, however, is that it is related to the possible cryptovolcanic structure at Barrow. That structure was formed in post-Grandstand, pre-Gubik time, and may well record the impact of a large meteorite. Such a catastrophe may have caused earth tremors and a tsunami-like disturbance of the shallow sea which covered the area, resulting in a short-lived period of submarine erosion and slumping like that discovered underlying the Simpson Peninsula. The sediments there are (and must have been then) poorly unconsolidated, and a sudden rush of water could remove a large quantity of them with little difficulty. Presumably the area between the peninsula and Barrow would have been even more drastically affected but no holes have been drilled between the two areas, and post-Cretaceous erosion in the Barrow area has removed evidence of such effects except the structural disturbance of the Lower Cretaceous and older beds.

Seabee Formation.--The Seabee beds deposited on the unconformity contain some bentonitic and sandy beds made up of reworked material from the soft underlying sediments but for the most part they consist of clay shale. The high resistivity curve on the electric log of core test 23 and many of the other core tests (Robinson, 1964, pl. 44-46) is related to the presence of permafrost in the clay shale. In Minga velocity test, where permafrost was absent, the resistivity in the upper few 100 feet was low. Initial dips of this part of the Seabee Formation on slopes of the unconformity surface are high. The beds are dated, as mentioned above, by the occurrence of <u>Borissiakoceras</u> sp. in Simpson core test 18; the strata overlying the unconformity on the west side of the peninsula are considered to be of Seabee age by analogy to the Simpson Seeps area. They postdate the unconformity, but other evidence of their age is lacking. In North Simpson test well 1 this part of the Seabee Formation is 1,220 feet thick and is composed almost entirely of clay shale although a few bentonitic and calcareous beds are found. <u>Inoceramus</u> prisms and fishbone fragments and scales are common, and <u>Borissiakoceras</u> sp. is found in about the middle of the formation. The beds have a steep initial dip, as they rest on the north-sloping surface of the unconformity, which here is cut into the Topagoruk Formation. Individual beds cannot be correlated from hole to hole within the Seabee Formation above the unconformity.

Schrader Bluff Formation.--This formation is 1,460 feet thick on the Simpson Peninsula in North Simpson test well 1. The transition from the Seabee Formation to the Schrader Bluff is gradational and the contact, based on gradual change, is arbitrarily chosen. The formation is clay shale but contains volcanic glass shards and an abundant microfauna consisting of both Foraminifera and Radiolaria. It is also less silty than the underlying Seabee Formation. The strata are designated part of the Schrader Bluff Formation because they contain an Upper Cretaceous microfauna and the shards common in that formation farther south, and because they overlie the Seabee Formation. In part, they could be younger than Schrader Bluff.

Quaternary deposits.--In the subsurface of the Simpson Peninsula the Quaternary materials consist of relatively unconsolidated clay, silt, sand and gravel in varying proportions, and lenses of ice are included within them. Olive gray clay is probably the most common constituent. It is recorded in many descriptions as being "blue-gray", the color it commonly assumes when frozen or wet. Sand made up of rounded grains of white, clear, and yellow quartz, and vari-colored chert is also abundant. Gravel consisting of pebbles of black chert, quartz, ironstone, quartzite, limestone, and a few other rock types occurs in thin layers. The small amount of coal is detrital and is probably derived from the underlying Cretaceous strata. Bentonite or bentonitic clay are also probably reworked from bentonitic beds in the Cretaceous sediments nearby. This material is all included in the Gubik Formation, although a small part of it may be Recent in age. Marine fossils such as fragile, chalky-white pelecypod and gastropod shells are relatively common, as are calcareous Foraminifera and Ostracoda. Unless Pleistocene fossils are found there is no way of differentiating between the Pleistocene and Recent beds.

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On the west side of the peninsula these deposits range from 8 to 80 feet thick. The thinnest section is in Simpson test well 1 where the Gubik-Cretaceous contact is indicated by the first occurrence of Cretaceous Foraminifera only 8 feet below the surface (Robinson, 1959b, p. 532). The deposits are unusually thin in this hole, as almost all the core tests nearby penetrated a thickness of 60 feet or greater. As can be seen by the cross section, plate 8, there is a slight increase in thickness of the Gubik Formation toward the north. The lithology of the formation is variable, but there is a gradual increase in the proportion of sandy beds toward the north. The basal part of the Gubik Formation is generally the coarsest, with beds containing black chert pebbles.

At North Simpson test well 1 the Quaternary beds are approximately 75 feet thick and are made up mostly of sand with clay beds near the top and gravel near the bottom.

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On the east side of the peninsula, near the crest of the mounds where the seeps apparently have their source, W. W. Patton dug two pits at Seep 1, four at Seep 2, and one at Seep 3. They ranged in depth from 9 to 13 feet. Patton observed (written communication, 1948) that:

"Below the frost line three types of material were encountered: blue-gray yellow clay, yellow-brown silt commonly containing rounded chert and quartzite pebbles, and ice. The clay and silt appeared to be interbedded. Above the frost, which occurred at a depth of two feet, was a cover of pitch, pitch-bound silt and moss.

"Some limey shale, limestone and ironstone float on several of the mounds has prompted several geologists (Paige, Foran and Gilluly, 1925, p. 23) to suggest that these peculiar topographic features are directly underlain by hardrock. However, no consolidated bedrock in place was encountered in any of the test pits. An occasional isolated fragment of shale or limestone was unearthed. It seems probable that these as well as the surface float were brought up from some depth by frost action.

"At the northern end of the mound from which Seep 1 emerges, a 20-foot section through the mound is exposed in a beach bluff. The mound-forming material here is blue-gray clay and massive blocks and wedges of ice. No consolidated bedrock was found."

Microfossil samples from these test pits sent to Mrs. Loeblich for determination produced only a few species of calcareous Pleistocene Foraminifera.

In the core tests of the Simpson Seeps area the Gubik Formation and Recent sediments are usually 75 to 80 feet thick although Simpson core test 23 drilled through about 95 feet, and core test 31 about 100 feet. These variations are probably very local, as core test 24, near number 23, has only 77 feet of these beds. The thickness under Lake Minga in Minga velocity test 1 is 73 feet, measuring from the bottom of the lake (which is 12 feet below sea level), is similar to that of the other tests.

The Gubik Formation was cored in four of the holes in the Simpson Seeps area. The most coring, 67 feet, was done in Simpson core test 13. Here the beds are largely light yellowish (limonite-stained) gray clay with beds of silt and sand mostly under 1 foot thick but ranging up to 4 feet in thickness. Rounded pebbles and granules of black chert and quartzite are in both the clayey and sandy beds but are not very abundant. The lowest 50 feet of the strata at Simpson Seeps, as on the west side of the peninsula, contains coarser sand beds than the upper part. Clay cores from the Gubik Formation in core tests 21, 23, and 29 suggest that the cutting samples give a poor impression of the formation: samples now indicating sand may have originally represented soft beds of clay with thin sand layers. The sand remains when the cutting samples are washed in the laboratory, but the clay washes away with the drilling mud.

At Simpson Seeps some of the surficial material was bulldozed into mud pits and used in the drilling mud, thus commonly contaminating the cutting samples and even a few of the soft shale cores. Many of the core tests were drilled without setting surface casing and contamination by slough from the near-surface sediments was common. This contaminating material is usually readily identifiable, but, because of it, the Gubik-Cretaceous contact is hard to determine in some of the core tests.

Structure.--Strata underlying the Simpson Peninsula below the mid-Seabee unconformity are shown by seismic data to dip gently eastward (Woolson, 1962, pl. 11). Lithologic and faunal correlations across the peninsula agree with the direction of dip, but show that it averages less than 50 feet per mile, compared to 100 to 200 feet per mile on the seismic contours. On the west side of the peninsula local variations cause the beds to dip southeast; a cross section through the core tests there shows the southerly component of dip (pl. 8). The dips shown by the seismic contours on a horizon a short distance below these holes is slightly steeper than that shown by the cross section: the contours have about 130 feet of difference in elevation between core tests 8 and 10, where the cross section shows only 78 feet, implying that the dip steepens with depth. The cross section also shows the slope (exaggerated) of the mid-Seabee unconformity between core tests 10 and 12. This slope, beveling the Grandstand Formation, forms a stratigraphic trap made of the Grandstand sandstone beds and the impermeable shale overlying the unconformity. Unfortunately post-Cretaceous erosion has removed impermeable beds capping the trap in the vicinity of Simpson test well 1 and core tests 1 through 10, and although a few oil shows were seen most of the oil probably escaped to the surface through the porous Gubik Formation (or perhaps directly on to the surface before the Gubik Formation was laid down).

North Simpson test well 1 is located on the northern slope of the mid-Seabee unconformity, on a small hill or ridge in the Topagoruk Formation. This hill is not a structural flexure in the underlying Oumalik or older rocks, for dips in them, determined by the seismic data, are very gentle or flat and the dip of 2° in the Oumalik Formation in the test well (like that at Simpson test well 1) is probably part of the regional southeasterly dip. The Topagoruk Formation, however, has dips of 7° in both seismic profiles and cores (Robinson, 1959b, pl. 37) that might have originated as follows: Following the deposition of the Oumalik Formation, there may have been a period of erosion during which a high area was left in the vicinity of this test well. The Topagoruk Formation was then deposited over the hill, with initial dips of about 7°. Much later the mid-Seabee erosion removed the Ninuluk and Seabee Formations undifferentiated, all of the Nanushuk Group, and at least 1,700 feet of the Topagoruk Formation (as compared to Simpson test well 1) in this locality. Following this the Colville seas inundated the whole area, but a small hill of the Topagoruk Formation still remained under the Colville sediments, and it is on this "structure" that North Simpson test well 1 was drilled.

The north-south cross section in the Simpson Seeps area, plate 9, suggests a slight northerly component to the gentle easterly dip. The seismic data corroborates this direction of dip but, as on the west side of the peninsula, again suggests a dip about twice as steep as the good faunal and lithologic correlations indicate.

Oil and gas.--West side of the peninsula.--In this area shows of oil were found in the Grandstand Formation (possibly partly Ninuluk and Seabee Formations undifferentiated---see p. 178) in Simpson core tests 6, 8, 9, and 10 as well as in Simpson test well 1 and in a seismic shot hole (no. 53, line 4, 1945) located about halfway between the test well and core test 6. Details of the shows and tests in these core tests have been published elsewhere (Robinson, 1964, p. 714). From the rather meager information on oil occurrence available from these core tests and the test well it seems that each sandstone bed in the Grandstand Formation has a separate water level which may be affected locally by the presence of permafrost. The cross section, plate 8 (on which the sandstone beds have been given letters to facilitate their identification), and the data from core tests 6 and 9 show that sandstone H could have a water level as low as -114 feet, and sandstone I as low as -215 feet. Sandstone J contains oil in core test 8 down to -170 feet, in core test 9 to -112 feet, but in core test 10 it contains oil to -89 feet and water immediately below that. The occurrence of water so high in sandstone J in the latter test might be explained by the location of the test close to the unconformity surface. Sandstone K may contain oil to -190 feet. Data for sandstones L and M are probably the most reliable, and sandstone L contains oil in core test 10 down to -311 feet but was dry in test 8 at -380 feet. The uppermost occurrence of oil in it is in Simpson test well 1 at about -180 feet, so the oil column in sandstone L could be in excess of 130 feet. Sandstone M had a slight show of oil in core test 10 down to -467 feet and was dry in test 8 at -530 feet. Both sandstone L and sandstone M contain a very slight amount of gas in Simpson test well 1, which is located near the highest point of the "trap" formed by impermeable shale resting on the beveled edge of Grandstand sandstones. At one time this area on the west side of the peninsula may have had a sizeable reservoir of oil but most of the petroleum has long since escaped. Today there remains only a small amount of residual petroleum in the Grandstand sandstone.

About 6 miles south-southwest of Simpson test well 1 a small seep, Admiralty Seep (also called Dease Inlet Seep) was described by Ebbley (1944, p. 418) as consisting "of a heavy petroleum residue coming from a low mound, the residue also being found beneath the moss in several places around the mound. Most of the material had apparently been long exposed to the air and was almost hard enough to walk on with the air temperature at 35° F. Several hundred sacks of pitch have been mined from a pit for fuel by the natives in the area. Some fresher material of lower viscosity was found near the center of the seep...

"About 200 yards east of the deposit pitch-soaked moss and silt were found along a low bench for a distance of 300 feet. Pitch was also found under the moss at several places on the bench."

The conditions at this locality must be similar to those at the core tests---i.e., oil in a local high on the Grandstand Formation trapped under the unconformity either by frozen ground or by impermeable Upper Cretaceous shale.

North Simpson area.--The North Simpson test well had no shows at all. The mid-Seabee unconformity cuts down into the Topagoruk Formation and all the sandy reservoir beds found near the Simpson Seeps are absent. The occurrence of oil reported in the shot holes southeast of North Simpson test well 1 is hard to explain unless it has migrated through the Gubik Formation from some point along the unconformity. If so, it has probably moved a long way.

Simpson Seeps area (Simpson Seeps oil field).--The oil seeps here were formed at points along the eastern edge of Simpson Canyon where oil is trapped within 350 feet of the surface and where fractures in the permafrost have permitted some of it to escape. The core tests which contained oil are located on the top or upper slopes of this "ridge" of sandstone, formed by eastward dip on one side and westward sloping canyon wall on the other. The oil-bearing sandstone beds, truncated by Simpson Canyon, have retained their oil because the impermeable shale which fills the canyon and covers the permeable beds on both sides of it prevented the fluid from moving (except at the location of the seeps, as described above). The source of the oil is uncertain; if it migrated up the regional dip of the Cretaceous sandstone beds some movement, at least, must have taken place after the canyon was filled with shale. If any oil was present there before the mid-Seabee erosion, some of it must have escaped when the canyon was cut, although if the erosion interval was short (which might have been the case if it resulted from a catastrophic event) the loss may have been small.

A brief description of the three main seeps in the Cape Simpson area is found on page 170. W. W. Patton described the oil coming into 7 pits dug in the vicinity of the seeps as follows (Patton, 1948, p. 3):

> "Below the surficial cover of pitch, fresh green oil was found to be oozing up through steeply dipping fissures in the frozen ground. These fissures vary in width from several inches to a foot and are filled with loosely compacted, oil saturated silt or clay. Both down-dip and along the strike the fissures are highly irregular and do not appear oriented in any particular direction. There is evidence that a small amount of movement may have taken place along some of these fractures. When the pits were first opened, oil flowed freely from small pockets along the fissures but, in most cases, ceased after several hours. Gas bubbles accompanied some of the flowing oil."

Patton collected a gallon sample of the oil and an analysis of it was made by the U.S. Bureau of Mines, Bartlesville, Oklahoma (table 1). A comparison of this analysis with the one made by the Bureau of Mines of a sample of crude oil taken from Simpson core test 31 at 345 feet (Robinson, 1964, p. 717) shows a great similarity between the two crudes. As could be expected, however, the sample from the seep contains a larger percentage of heavier components.

In 1944 Ebbley (1944, p. 418) wrote concerning the use of the petroleum residues found at the seeps:

"Arctic-slope Eskimoes have been mining pitch from these seeps for a number of years, some 3,000 100-lb sacks being mined each summer. The material is sticky and difficult to handle but it is burned successfully in the Point Barrow area."

Shows of oil or gas were found in all the core tests in the Simpson Seeps area except core tests 14A, 18 through 23 inclusive and Minga velocity test 1. Oil was also reported in a few shot holes in the area, as shown in plate 7. A detailed list of these shows is available in Professional Paper 305-L (Robinson, 1964, p. 714-715). Some of the shows are also indicated on the cross sections, plates 9 and 10.

Three separate reservoirs were shown by the drilling to be present at Seeps 2, 2A and 3. A fourth is probably present near Seep 1 but it was not discovered by drilling probably because core tests 23 and 24 near Seep 1 are located a little too low on the slope of Simpson Canyon.

The Ninuluk-Seabee sandstone beds are rather "dirty" and fine-grained but the sandstones of the upper Grandstand Formation are relatively free of argillaceous material and contain medium-sized grains. All the sandstones are soft and friable. Most have very good porosity and 385 millidarcys air permeability was measured in one sample. The porosity and permeability may be even higher than that in some places because tests were not conducted on the most friable samples. Calcareous and sideritic cementing material is relatively rare and would not affect possible production. All the sandstones are well within the permafrost zone, and the cold temperature keeps the oil very viscous and causes ice to form in the tubing and valves.

At Seep 2 oil is found in the various sandstones of the Ninuluk and Seabee Formations undifferentiated and upper Grandstand Formation to a depth of about -550 feet. An oil column approximately 370 feet thick (from -550 feet to -180 feet, the highest point on the surface of the unconformity) for the combined sandstones could be present. No water was reported in the formation test of core test 16. Shows of oil down to -758 feet in core test 13 and to -605 feet in core test 17, which are farther down the slope of Simpson Canyon, are unusually low but probably are the result of the migration of the oil along the unconformity or along possible fissures created by slumping. No actual production was obtained at Seep 2 but core test 16, which is high on the surface of the unconformity, flowed a small amount of gas intermittently for over a year until the hole froze up. If the gas pressure has not been exhausted it is possible that a marginal flowing well might be completed nearby. At best, however, much of the oil must have already escaped at Seep 2.

At Seep 2A, core test 31 was drilling at -346 feet close to the top of the Ninuluk-Seabee producing sandstone when it began flowing oil. On a 65-hour test it flowed at an estimated rate of 120-125 barrels of 21° gravity oil and 2,000 to 4,000 cubic feet of gas per day, the best production in the Simpson Seeps area. Freezing caused trouble during the production test but no water was produced. Core test 31 is probably on a separate closure along the crest of the ridge east of Simpson Canyon as the top of the Ninuluk-Seabee producing sandstone is nearly 30 feet lower than at Seep 3. Seep 2A is a small one, which might be an indication that better oil production could be found along the ridge where seepages are absent. It seems to be true that the bigger the seep, the smaller the production.

Conditions at Seep 3 are almost identical with those at Seep 2 except that the impermeable cap has been more effective near Seep 3. Or perhaps the beds abut against the unconformity (and hence against the overlying impermeable shale) to a greater depth. The Ninuluk-Seabee producing sandstone beds are a little higher structurally than at Seep 2. The production in core test 26, atop the east slope of Simpson Canyon came mostly from a sandstone at -274 to -310 feet. Water with only a trace of oil was recovered when the hole was bailed from -335 to -535 feet. On an early production test, core test 26 flowed through a 2 1/2-inch pipe at an average rate of 110 barrels of oil per day. The gravity was 20° A.P.I., the oil temperature 21° F., and the casing pressure 47 psi. On a 13-day test made five months after completion, the well produced at an average rate of 92 barrels of oil with 2,500 to 3,000 cubic feet of gas per day, bottom hole pressure was 195-215 psi, and well-head pressure 25 psi.

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Simpson core test 30, also near Seep 3, had good shows of oil in the Ninuluk-Seabee producing horizon penetrated at -298 feet and shows in the Grandstand Formation in sandstones at -430 and -606 feet. A bailing test from -145 to -335 feet recovered oil at the rate of only 6 barrels per day. Its twin hole, 30A, was bailed from -85 to -350 feet at only 5 barrels per day with a very small amount of gas. No water was reported but ice was present in the hole. Core test 27 had good shows of oil in the Ninuluk-Seabee discovery horizon (top at -304 feet) but only 3 barrels were bailed per day when the hole was at a depth of -357 feet.

Shows at -815 feet in core test 25 were deeper than normal; that hole, like core tests 13 and 17 at Seep 2, is low on the slope of Simpson Canyon. Shows were also found in core test 29 in some silty beds of the upper part of the Seabee Formation, from -280 to -350 feet; these beds lie above the unconformity but directly across it from the oil-producing horizon at core test 26, and by abutting against the oil-bearing beds have received oil that has seeped across the unconformity along the permeable beds.

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Geology of the Umiat Oil Field

<u>Development of the area</u>.--The Umiat field, the first oil field discovered in Naval Petroleum Reserve No. 4, is near the southeastern corner of the Reserve, about 175 miles southeast of Point Barrow. It is in the Northern Foothills section of the Arctic Foothills province, an area of moderate relief: elevations near Umiat range from 335 feet in the Colville River flats to 941 feet 3 miles to the northwest (fig. 19). The structure of the underlying rocks has determined the

Figure 19. The Umiat anticline contoured on the top of the Grandstand Formation.

topography, and sandstone ridges alternate with valleys eroded in less durable beds of shale.

The earliest evidence of petroleum known in the Umiat area was an oil seep about a mile west of Umiat Mountain, on the north side of a small lake. It was known to the Eskimos, and visited in 1943 by Norman Ebbley, Jr., of the U.S. Bureau of Mines and Henry R. Joesting of the Alaska Bureau of Mines (Ebbley, 1944, p. 417). The seep had been reported to flow 4 to 5 barrels a day, but in 1943 it consisted of a slow steady seep of light distillate, with bubbles of gas. Some sand and gravel on the river bank south of the lake was soaked with oil, and a little oil and gas also rose from a lake bed about a mile to the west.

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In the spring of 1944 a Navy reconnaissance party under Lt. W. T. Foran visited the Reserve and noted evidence of an anticline near Umiat Mountain; later the same year he returned and made a study of the structure. A U.S. Geological Survey field party mapped exposures along the Colville River at the same time. Early in 1945 the drilling rig for Umiat test well 1 was freighted across the frozen tundra from Barrow camp to Umiat, and in June the Navy began drilling at a location based on the field work. Field parties mapped the Umiat anticline during the summer and the U.S. Geological Survey and the U.S. Navy cooperated in making an airborne magnetometer survey of much of the Reserve, including the Umiat area. In September, drilling was suspended for the winter, and when it was resumed in the spring of 1946, it was carried on by Arctic Contractors. Although a few minor shows of oil were found, the test was abandoned as a dry hole at a total depth of 6,005 feet.

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The U.S. Geological Survey mapped the anticline in some detail in 1946, and the United Geophysical Co., Inc., crossed the structure with two seismic survey lines. Umiat test well 3 (then designated as Umiat core test 1) was drilled near the crest of the structure late in the year, and it produced a small amount of oil, and Umiat test well 2, another deep test, was drilled just southeast of test well 3, but was abandoned at 6,212 feet. Lack of production from this hole discouraged further drilling, and the next test was not started until 1950. In that year, three comparatively shallow cable-tool holes (Umiat test wells 4, 5, and 6) produced oil from Cretaceous sandstone on the structure, and a fourth (Umiat test well 7) defined the southern edge of the producing area by producing only salt water. These holes, particularly test well 5, which was only a few feet from Umiat test well 2, suggested that the sandstone drilled in the earlier test contained oil but that fresh water in the mud circulated through the rotary drilling tools made the beds impermeable by causing constituents of the argillaceous interstitial material to swell.

Umiat test wells 8 and 10, cable-tool holes drilled in 1951, produced oil and gas, apparently from a separate fault block, on the crest of the structure. Umiat test well 9, the westernmost oil producer, was also drilled in 1951; it demonstrated the value of using oil-base mud with rotary drilling, compared to a water mixture.

Umiat test well 11, the last hole drilled at Umiat before exploration was suspended, was low on the north flank, and produced salt water. Oil emulsion mud was used in this 3,303-foot test, which was drilled in 1952.

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Oil was produced from the wells only to test their production capacities, and to obtain oil for oil-base or oil-emulsion mud. The holes that were not dry and abandoned have been shut in.

Stratigraphy of the Umiat oil field.--Cretaceous formations ranging from the Oumalik Formation to the Schrader Bluff Formation, and Quaternary alluvium, were penetrated by various wells at Umiat. Variations in composition and thickness of the stratigraphic units across the field are discussed below, and further details for individual holes are available in Professional Paper 305-B (Collins, 1958a).

Oumalik Formation.--About 400 feet of this formation was penetrated in Umiat test wells 1 and 2, but the other holes were too shallow to reach it. This medium dark gray slightly silty marine clay shale does not crop out in the vicinity of the tests, and its thickness in the Umiat area is unknown. It contains rare thin beds and laminae of light brownish gray impermeable sandstone and siltstone which showed no signs of oil or gas.

Topagoruk Formation.--The Topagoruk Formation is also composed primarily of gray marine clay shale, but it is slightly lighter in color and slightly siltier than the Oumalik Formation, and it contains the *Verneuilinoides borealis* microfauna characteristic of it and of the overlying Grandstand sandstone. (Bergquist, 1958a, p. 200). Five of the Umiat holes drilled into the formation: Umiat test wells 1 and 2 penetrated it completely, test well 11 drilled through a little more than 300 feet of it, and test wells 5 and 9 drilled into the top of the formation. The unit is approximately 2,800 feet thick; the 3,350 feet present in Umiat test well 2 is the result of duplication by a reverse fault (see pl. 11).

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The upper 700 feet of the Topagoruk Formation contains some beds of sandstone and siltstone (less than 10 feet thick) in Umiat test wells 1 and 2. These beds are more numerous to the west, comprising about 10 percent of the rock in test well 1 and about half as much in test well 2. Rare thin beds of sandstone and siltstone, present as much as 1,500 feet below the top of the formation in Umiat test well 1, are absent at depths greater than 1,000 feet below the top (except where repeated by faulting) in test well 2. These sandy, silty beds resemble the sandstone of the overlying Grandstand Formation except for finer grain size and increase in argillaceous material; they contain no shows of oil or gas. No beds are distinctive enough to be correlated from one hole to the other, and it is possible that none are continuous for that distance.

Grandstand Formation.--The marine Grandstand Formation, the lowest unit of the Nanushuk Group, consists of thin to massive sandstone beds separated by intervals of clay shale. Every test well on the anticline drilled in to the upper part of the formation, but only Umiat test wells 1, 2, 5, 9, and 11 reached the base. The complete section includes an "upper sandstone bed" and a "lower sandstone bed" (Collins, 1958a, p. 75), separated by clay shale, and with a few feet of fossiliferous clay shale at the top. On the crest of the anticline, the formation is 655 to 700 feet thick, but in Umiat test well 1, to the west, it is 755 feet thick (excluding the effect of a reverse fault which repeats several hundred feet of strata), reflecting the regional southwestward thickening of the sandy sequence. The cross section, plate 12, shows the changes in the beds from east to west.

In Umiat test well 11, the "lower sandstone bed" makes up the basal 275 feet of the formation; it includes a few thin beds of clay shale, and 20 feet of siltstone which divides the sandstone into two parts. In Umiat test well 9, the sequence is similar except that the sandstone above the siltstone is interrupted near the top by almost 30 feet of clay shale. In Umiat test well 1, the "lower sandstone bed" is further divided by clay shale. A 30-foot siltstone stratum present just below the unit in test well 9 grades into sandstone at test well 1, thus increasing the thickness of the formation because its lower boundary follows the base of the sandstone sequence.

The "upper sandstone bed" is somewhat less variable than the "lower sandstone bed" and also differs from it in thickening to the east and north. In Umiat test well 1, it consists of a massive 50-foot bed of sandstone; in more easterly wells, where it includes a few very thin clay shale beds, it increases to a maximum of 108 feet. In most tests a few thin beds of sandstone are also interbedded with the upper part of the underlying shale.

The sandstone ranges from very fine to medium in grain size, and vertical variations are quite similar from well to well. Porosity and permeability of samples from sandstones in the Grandstand Formation vary greatly, ranging from less than 5 to nearly 500 millidarcys. The upper part of the "lower sandstone bed" is generally the most permeable part of the formation, and its base the least permeable. The "upper sandstone bed" changes in permeability both vertically and horizontally. Both porosity and permeability vary roughly with grain size, but other factors, such as differing amounts of calcareous and argillaceous interstitial material, cause rapid and apparently erratic fluctuations. Fresh water introduced into the sandstone during drilling, or later, reduces permeability sharply, by causing the interstitial clay minerals to swell.

Almost all of the oil found in the Umiat field is trapped in the Grandstand Formation; its occurrence is discussed in a later paragraph (p. 224 ff.).

Killik Tongue of the Chandler Formation.--The Killik Tongue of the Chandler Formation is a nonmarine unit of clay shale with some silty sandstone and a little coal and clay ironstone that overlies the Grandstand Formation. In Umiat test well 1 the tongue is 300 feet thick, and consists primarily of clay shale, with a little interbedded siltstone and sandstone. In the other holes, the tongue is 10 to 40 feet thinner, but the sandstone beds have increased to make up from 1/8 to nearly 1/3 of the rock. There are three sandstone beds, each approximately 10 feet thick, in test wells 9 and 10; in these holes the tongue is only 260 feet thick. In tests 6, 7, and 8 the sandstone beds are 20 to 40 feet thick, and the tongue thickens to 280-290 feet. In Umiat test wells 2 and 11, the uppermost sandstone is interbedded with shale, and in tests 3, 4, and 5 it is missing because the holes spudded below this bed. Data are too scattered to permit comparison of porosity and permeability in various sandstone beds or between holes, but they indicate a range from impermeable to 550 millidarcys, with most of the samples having less than 100 millidarcys permeability. Coal and clay ironstone are present in all the holes east from test well 8, ranging from rare in the upper part of test wells 6 and 7 to common throughout the tongue, in more northerly holes. The four western holes (test wells 8, 10, 9, and 1) have none. The beds are essentially unfossiliferous, except for a few plant spores, charophytes, and coal. Oil shows were noted in the sandstone in most of the tests, and there was a show of gas in the middle sandstone bed in Umiat test well 5.

Ninuluk Formation.--The Ninuluk Formation, the uppermost unit of the Nanushuk Group, was drilled in seven of the holes. In Umiat test well 1 it is comparatively thin (95 feet thick), and consists of interbedded clay shale, siltstone and sandstone. In the other tests, however, the shale is almost lacking, and the formation contains an average of 120 feet of massive sandstone with a few thin beds of shale in the middle and at the top and bottom. In test wells 6 and 10, Foraminifera typical of this formation are present in the shale. Porosity and permeability of the sandstone vary nearly as much as for the lower formations, ranging from impermeable to 435 millidarcys in Umiat test well 8, and from impermeable to 56 millidarcys in test well 11. Oil shows were noted in test wells 7, 8, 9, and 10.

Seabee Formation.--Many of the tests on the Umiat anticline drilled through part of the Seabee Formation, but only Umiat test well 11 penetrated it completely; in that hole, it is about 1,500 feet thick. This section has been named the type section for the formation, (Whittington, 1956, p. 247), and is described in considerable detail on page 82 ff. About 900 feet of the Seabee formation is present in Umiat test well 1, but test wells 6, 7, 8, and 10 drilled only the basal part of it. The unit consists of clay shale with some beds of sandstone, and a small amount of bentonite; it contains marine fossils.

The sandstone beds are not uniform from east to west. A 120-foot sequence of sandstone and siltstone with its base 150 feet above the bottom of the formation in Umiat test well 11 is 20 feet thinner in test well 10, and in test well 1 is represented by clay shale with only a few thin beds of sandstone and siltstone. Another interval of sandstone beds beginning 550 feet above the base of the formation in Umiat test well 11 is 670 feet above the base in test well 1. The sandstone sequence has about the same thickness in both tests, but in the eastern hole it consists of a 60-foot bed of calcareous sandstone underlain by about 85 feet of sandstone beds separated by thin layers of clay shale, while in the western hole the thickest bed of sandstone is 40 feet and it is in the middle of the interval, being overlain and underlain by thinner sandstone beds. This resistant group of beds outlines the Umiat anticline on the surface, forming a ridge on the steeply dipping north flank of the structure, and gentler dip slopes on the southern side (Whittington, personal communication, 1956).

The upper few hundred feet of the formation, consisting of clay shale with a little interbedded sandstone, were drilled only in Umiat test well 11.

The slight indications of oil and gas in the Seabee Formation in Umiat test wells 1, 7, and 11 were insufficient to make any showing when the holes were tested. The lowest sandstone sequence from -1,200 to -1,420 feet in Umiat test well 11 is impermeable and lacks gas and oil there, but it contained a small amount of gas at 80 feet (above sea level) in test well 7. Thin sandstones in the comparable interval in test well 1 (at 60, 240, and 270 feet above sea level) have slight shows of oil. The lowest of these three beds is 20 feet lower, structurally, than the top of the gas-bearing sandstone in test well 7, and the two might be parts of one reservoir. The sandstone present in test wells 1 and 11 is slightly permeable (6-27 millidarcys) in the upper part, but most of it is impermeable. A slight show of gas was noted in it in Umiat test well 1, but there was none in test well 11. Because the sandstone beds in the Seabee Formation are exposed on the Umiat anticline commercial quantities of oil in them are unlikely in the vicinity of the Umiat holes.

Tuluvak Tongue of the Prince Creek Formation.--This is the uppermost unit of the Colville Group present in any of the Umiat test wells. About 500 feet of nonmarine rock is present in test well 11; it consists of sandstone and siltstone with some clay shale, coal, and bentonite. A few layers of shale interbedded with the lower part of the tongue represent the Schrader Bluff Formation (the marine equivalent of the Prince Creek Formation), as they contain a sparse microfauna indicative of a marine environment. A slight show of oil was noted in the basal sandstone.

Prince Creek and Schrader Bluff Formations.--On the surface north of Umiat test well 11, the uppermost 50 feet of the Tuluvak Tongue, and the Rogers Creek, Barrow Trail, and Sentinel Hill Members of the marine Schrader Bluff Formation dip north away from the crest of the Umiat anticline. These rocks, which were not found in the test wells, and which are present only on the flanks of the anticline, have been described by W. P. Brosgé and C. L. Whittington (written communication, 1956). They consist of more than 1,500 feet of siltstone, sandstone, and shale, with some interbedded bentonite and tuff.

Quaternary alluvium.--The holes drilled in the Colville River flats spudded in gravel deposited by the river. This unconsolidated material is 70 feet thick in Umiat test well 2 and about 45 feet thick in test well 7, the only two tests from which samples were kept; approximately 30 feet of gravel was reported in the top of Umiat test well 6. The pebbles are rounded, 1/8 to 1/2 inch in diameter, and consist of gray and black chert; a few are quartzite and sandstone. The samples were unfossiliferous. Holes located north of the valley bottom started in Cretaceous rocks, except for test well 11, which had a few feet of chert gravel above the older beds.

Structure.--The Umiat oil field is situated at the culmination of the Umiat anticline, a long, narrow fold which extends at least 20 miles west-northwest from the Colville River, and which is probably continuous with the anticline tested by Square Lake test well 1, 25 miles from Umiat test well 1. East of the Colville River, it disappears beneath younger deposits, but the steadily plunging fold has been traced eastward for nearly 50 miles by seismograph surveys. The anticline is much higher structurally, in the vicinity of the field, than any of the neighboring anticlines which parallel it to the north, and is only slightly lower than similar structures to the south.

Figure 19 shows the field contoured on the top of the Grandstand Formation. In the test wells, this horizon is determined from paleontologic and lithologic data; elsewhere, its depth is inferred from the elevation of a calcareous sandstone bed in the Seabee Formation. This bed, the top of which is about 1,100 feet above the Grandstand Formation, is resistant to erosion and crops out in much of the area near the apex of the anticline; Umiat Mountain, nearly 600 feet above the Colville River, is upheld by this resistant bed. Except for this stratum, outcrops in the Umiat area are generally discontinuous ledges of sandstone which are difficult to correlate, and which do not give a detailed picture of the size or shape of the structure. The seismic lines which cross the structure just east of the apex showed very few reflections near the crest of the fold, and have little value in defining its size. Field and photogeologic mapping suggest, however, that there is at least 1,200 feet of closure in an area about 10 miles long and 3 miles wide, with its highest point about 1,500 feet southeast of Umiat test well 8 (Brosgé and Whittington, written communications, 1957). The Tuluvak Tongue of the Prince Creek Formation rings the highest part of the anticline on the west, and even younger beds are exposed on the east plunge, while the Killik Tongue of the Chandler Formation appears at the surface at the apex (Brosgé and Whittington, written communication, 1956).

The anticline is asymmetrical, with dips as high as 80° on the northern side and low ones, averaging 5° or 6°, on the south (see pl. 11). The sandstone bed of the Seabee Formation referred to above is exposed as a steeply dipping ridge along the north flank of the structure, but forms a gently dipping slope to the south. The beds flatten out rapidly a short distance north of the axis, however, and at Umiat test well 11 they dip 20° or less; still farther north, dip decreases to 8° to 10°.

Subsurface evidence indicates that at least two thrust faults complicate the structure, besides the minor faulting observed in outcrops. Both faults are approximately parallel to the axis of the anticline and to each other, and they duplicate several hundred feet of strata (see pl. 11). According to the interpretation given here, they have their greatest displacement at depth, with a decreasing throw, especially on the larger fault, as they approach the surface. Although west- or east-flowing tributaries of Bearpaw and Seabee Creeks are in valleys which may be surface expressions of the faults, field work has shown no other evidence of their presence. The faults have separated the oil field into two blocks, both of which have risen relative to the north flank of the structure. The northern segment, with Umiat test wells 8 and 10, would have been on the crest of the fold, if the southern segment, containing the other producing wells, had not been raised even higher by the faulting. The larger fault, between the north flank and the northern block, has a stratigraphic throw of at least 1,100 feet in Umiat test well 2, which it cuts at a depth of 5,100 feet. The fault plane rises slowly to the north becoming somewhat steeper near the surface, and cuts Umiat test well 10 at approximately 1,430 feet, to reach the surface just north of the ridge of resistant sandstone described above, where it has an estimated 500 feet of stratigraphic throw. The smaller fault plane, separating the two segments of the oil field, also rises to the north; cutting Umiat test well 2 at 2,400 feet, test well 8 at 350 feet, and test well 10 at 210 feet, it reaches the surface just north of the latter wells. The fault has a stratigraphic throw of 550 feet in Umiat test well 2 and cuts test wells 8 and 10 with approximately 380 and 400 feet of stratigraphic throw, respectively.

A reverse fault in Umiat test well 1 at 2,010 feet repeats 775 feet of Nanushuk Group strata, but because neither of the previously described faults can be traced on the surface, its relation to them is uncertain. In this report, it is assumed that the single fault in Umiat test well 1 divided, as the displacement increases eastward, into the two faults that cut the eastern wells.

All the Cretaceous beds in the area have been affected by the folding which produced the Umiat anticline; the associated faulting was probably in response to continued pressure from the south. Regional studies (C. L. Whittington, personal communication, 1957) suggest that a slight amount of movement took place in Early Cretaceous time, but most of it was later, presumably at the end of Cretaceous or early in Tertiary time. Quaternary alluvium rests directly and unconformably on Cretaceous rocks throughout the area.

Oil and gas.--Three of the holes on the Umiat anticline (test wells 1, 7, and 11) are outside of the producing area, and establish the limits of the pool; the only other dry hole, Umiat test well 2, is offset by a producing well. Two wells, test wells 8 and 10, are apparently separated from the rest of the field by a fault, and the former is the only test to produce gas as well as oil.

In most of the wells, it was difficult to determine which sandstone layers produced the oil. Umiat test well 9, which produced oil before the casing was set, produced nothing after it was set and perforated by stages in order to locate the oil-bearing beds, and test well 5, the only other cased well in the main part of the field, was not tested after casing was set. Three other producing wells, Umiat test wells 3, 4, and 6 were not cased, and water in Umiat test well 6, although not encountered until the drill was at 825 feet (-488 feet) could not be shut off with plugs set as high as 783 feet (-446 feet). A summary of production data for the Umiat tests is given in table 2.

The principal reservoir rock in the field, however, is apparently the sandstone of the Grandstand Formation. Within the producing area the sandstone is concentrated in two beds, described previously as the upper and lower sandstone beds (see p. 212). The two beds probably do not form a single reservoir south of the faults. Nevertheless, the mutual oil-water contact in the main part of the field may be close to 465 feet below sea level in both beds: water was first encountered at -465 feet, near the top of the lower sandstone bed, in Umiat test well 5, and near the same depth, but in the base of the upper sandstone bed, in Umiat test well 6. On the other hand, no water was produced from either sandstone bed in test well 9, although it was drilled to a depth of 666 feet below sea level, and oil production seemed to come from sandstone below -465 feet as well as above. The other wells, test wells 3 and 4, with total depths at -212 and -357 feet respectively, were too shallow to reach the water-bearing beds. In the fault block containing Umiat test wells 8 and 10, the two sandstone beds are separate reservoirs; the former well produced oil from the upper sandstone bed, and only gas from the lower one. The latter test also produced oil from the upper bed, but the lower one was missing at the bottom of the hole because of the thrust fault, which placed shale in the position normally occupied by the sandstone.

The gas-bearing lower sandstone bed in Umiat test well 8 is lower, structurally, than it is in wells south of the fault, where it contains oil. This suggests that:

1. the oil and gas accumulated before faulting took place, and
2. there was originally a gas cap on the unfaulted anticline (that there may still be one in the main part of the field, up dip from Umiat test well 4, is also suggested by the gas-oil contact in that well), and
3. the upper and lower sandstone beds are separate reservoirs.

Oil shows were noted in the Killik and Ninuluk Formations in several wells but most of the tests did not produce any oil from them. The exceptions are test wells 6 and 7, each of which produced a few gallons of oil during bailing tests of the Killik Formation, and Umiat test well 10 from which bailing tests produced 4 barrels of oil per hour for 22 hours from the Ninuluk Formation, and 183 barrels in 34 hours from the Ninuluk and Killik beds combined. Presumably these formations are too shallow, in the other producing wells, to form adequate traps. Umiat test wells 6, 7, and 10 are all lower, structurally, and are farther from outcrops of the reservoir beds near Bearpaw Creek, than the other tests. Variations in permeability may also have affected the accumulation and production of oil in these beds. In Umiat test wells 6 and 7, the producing horizons are higher than the -465 foot level of the possible oil-water contact of the Grandstand Formation, but whether the reservoirs are connected or not is uncertain.

Between the two faults, the Ninuluk and Killik Formations appear to be separate reservoirs. They produced oil in the lower test (test well 10), and only slight shows in the higher one (test well 8). No important difference in reservoir properties of the sandstone is apparent between the two holes; seepage up dip to the nearby fault plane may have drained oil from these beds in test well 8. No water was found in either hole, and the extent of production in the fault block is not known. The block itself is narrow and dips quite steeply, however, so the productive area cannot be large.

Because of the possible connection of reservoir beds, and the uncertainty of oil-water contacts, the area underlain by oil-bearing rocks cannot be established exactly. Assuming that the contact is at -465 feet in both beds then oil is present in the Grandstand Formation from the southern fault south nearly to Umiat test well 7, west nearly to test well 1, and east as far as Umiat Mountain (see fig. 19), underlying a simi-elliptical area bounded by the intersection of the Upper Grandstand sandstone bed and the -465 foot contour. The slight amount of oil present in the Killik Formation appears to ring this half-ellipse on the south, extending farther down the flank of the structure and being absent near the apex of the anticline.

The steep flank of the anticline north of the faults is probably too low structurally to contain oil, although a minor amount might be trapped in upturned beds against the northern fault. Umiat test well 11, a short distance north of the fault, produced only salty water.

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The only indication of a gas cap in the main part of the field is the presence of gas-cut oil in Umiat test well 4; it is the highest well on the structure, and any gas cap would have to occupy the small area between the well and the southern fault.

Data from holes that drilled completely through the permafrost, and from thermistors installed in Umiat test wells 4, 6, 9, and 11, indicate that permanently frozen ground is present in the Umiat area to a depth of about 900 feet under the hills, and a little more than 700 feet in the Colville River flats. The water-ice contact at the base of the permafrost rises from about 450 feet below sea level in the flats to about 100 feet below sea level beneath the ridges, reflecting the topography. All of the tests drilled through permafrost, and ice formed at some time during drilling or testing in all of the producing wells. Besides causing mechanical difficulties with pumps, flow lines, and other equipment, the presence of ice and the accompanying low temperatures have an adverse effect on the flow of oil from the reservoir rocks. The exact relationship between frozen sediments and oil production was not determined, but a much lower recovery factor has been assumed for the permafrost zone, in making estimates of reserves.

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Analyses of samples from several Umiat wells have been made by the Petroleum Experiment Station of the U.S. Bureau of Mines at Bartlesville, Oklahoma (McKinney, Garton, and Schwartz, 1959, p. 9). These studies have shown that oil produced from the field is green (National Petroleum Association Color Number 4, 4 1/2, and 6, for various samples), has an API gravity of about 36°, Saybolt Universal viscosity of 36 to 37 seconds, and a pour point lower than 5°F (-15° and -25°F, in samples from Umiat test well 3). It is high in naphthenes, but has less than 0.1 percent sulfur. It has a high proportion of gasoline (pour point -80°F) and diesel fuel (pour point -10°F). The oil from Umiat test well 1 differs from that of the other wells in having less gasoline, more kerosene and heavier fractions, and in being more paraffinic and correspondingly less naphthenic. Although some of the difference may have resulted from weathering (the oil collected in the hole after the well stood idle during the winter), there is a difference in types of hydrocarbons present. The sample from Umiat test well 1 is similar to many Mid-Continent crude oils such as that from the Oklahoma City field, Oklahoma, except for the lack of higher fractions.

In the samples from Umiat test well 3, the naphthenic quality is constant in the gasoline fractions, and then increases abruptly, to remain at a higher level through the diesel fuel and lubricating oil range. Other oils, such as that from the Spindletop field, Texas, are naphthenic in the gasoline fractions but not increasingly so in heavier fractions. Athabaska tar sands are also naphthenic in the gasoline fractions.

Several estimates of reserves have been made (by Arctic Contractors, the U.S. Navy, and the U.S. Bureau of Mines) at various times during the exploration of the field, with results ranging between extremes of 2 million and 122 million barrels of recoverable oil (written communications, 1953). An average estimate is 60 million barrels. The most variable figure in the calculations is the recovery factor; its value is affected by permafrost, and hence it is particularly difficult to estimate. Other variable factors are the percent of connate water, the net effective sand, the size of the producing area, and the effectiveness of a possible gas drive. The lack of prolonged production tests, as well as the variables mentioned above, make the oil reserve estimates of the field uncertain. The field is considered to have no immediate commercial value, however, because of its location. Fairbanks, the nearest large town, is about 350 airline miles away, and the cost of transporting the oil is at present prohibitive. A small amount has recently (1964) been authorized for sale to exploration companies who are currently working in northern Alaska outside the Reserve, to save them the difficulty of importing fuel.

Oil and gas in other areas

Shows of oil or gas were noted in several test wells, besides the fields previously described. Information concerning these holes is summarized below. In some cases two or more holes have been drilled near enough together to afford a correlation, and these groups of holes are also discussed in the paragraphs below.

Knifeblade area.--No good oil or gas shows were found in the Knifeblade holes, although test wells 1 and 2A showed faint oil stains on some cores, and a few cores bled gas. Salt water entered both holes while they were being drilled, and no free oil appeared on any of it as it was bailed out. Knifeblade test well 1 and Knifeblade test well 2A (located 28 feet from test well 2, which was abandoned at a total depth of 373 feet) are situated on opposite sides of a thrust fault which roughly parallels the axis of the eastern end of the Knifeblade anticline (Robinson, 1959a, fig. 7). This structure, which is about 65 miles west-southwest of Umiat, is in the northern foothills of the Brooks Range. Knifeblade test well 1 is on the north, or downthrown side, of the fault, and down the north flank of the structure, and therefore contains a much thicker section of the younger rocks of the Chandler Formation. The Chandler beds are nonmarine and here contain numerous beds of coal, some carbonaceous material, plant fragments, and ironstone nodules or concretions. The few sandstone beds characteristically contain much sericite in the matrix. The Grandstand sandstone beds are quite coarse-grained near the top and become finer with depth. Sericite is also common in the matrix near the top of the formation, and some coal is present in the upper 300 feet. Correlation of the individual sandstone beds within the Grandstand Formation between the two test wells is very good (see pl. 13). At first glance it appears that the Grandstand section in Knifeblade test well 2A is thicker than that in test well 1, but this is the result of structural dip rather than stratigraphic thicknesses. Some dips recorded from the cores of test well 2A, particularly near the top, were as high as 40°, and many were more than 20°. Ditrupa cornu, a worm tube, is locally an excellent horizon marker in this formation.

Meade area.--Meade test well 1 is located on an anticline shown by seismic surveys to be about 7 miles long and 3 miles wide, with a closure of 200 feet. Located near the southern edge of the coastal plain about 90 miles south-southwest of Barrow, there were no surface indications of a structure. Gas was encountered in thin sandstone beds of the Grandstand Formation at 2,949-2,969 and 4,134-4,148 feet, and the sandstone also had faint oil stains, although no oil was recovered during testing. The gas flowed at a rate of 1,132,000 cubic feet per day with a 1-inch orifice at 35 psi and 38°F, and reserves were estimated by Arctic Contractors (written communication, June, 1953) as 19,600,000,000 cubic feet. Lithologic and drilling data have been published elsewhere (Collins, 1958a, p. 342-353).

Oumalik area.--Some sandstones near 2,700 feet in the Grandstand Formation and in the lower Oumalik Formation in Oumalik test well 1 were found to contain gas under high pressure, but the producing sandstones were not located accurately nor tested. In general the sandstones have very low porosity and permeability and commercial production is doubtful.

Oumalik test well 1 and East Oumalik test well 1 are located on anticlines discovered by seismic surveys some 100 miles south-southeast of Barrow, on the edge of the Arctic Coastal Plain. Plate 14 shows the suggested correlation between the two holes, which are 12 miles apart. Because of its lower structural position East Oumalik test well 1 has 680 feet of the coaly nonmarine Chandler Formation at the top of the hole. Faunal evidence indicates that very few or none of these nonmarine beds are present at the top of Oumalik test well 1. Both holes contain a complete section of the Grandstand Formation. The sandstone beds in this formation in the Oumalik area are relatively persistent and can be correlated despite the distance between them. This contrasts with the same formation in the Topagoruk test wells (see below) where individual beds cannot be traced from one well to the other. The limestone and sideritic beds in the upper part of the Grandstand Formation at Oumalik are also locally correlative; such a high carbonate content is not particularly characteristic of the formation in other areas. The abundant *Verneuilinoides borealis* microfauna (Bergquist, 1956, p. 65-68) is found in both the Grandstand and Topagoruk Formations, and the top of this fauna and a few other paleontologic markers are shown on plate 14. The base of the Grandstand Formation grades into the more shaly Topagoruk Formation quite rapidly in the Oumalik area, as shown on plate 14. Sandstone beds in the Topagoruk Formation are lenticular and cannot be correlated, but the general sequence is the same---silty clay beds at the base of the formation grading up into the coarser sandy beds near the top, and finally into the Grandstand

Formation. In this area the top of the Oumalik Formation is determined largely on the basis of faunal evidence, although there is a lithologic change from the darker shales of the Oumalik Formation to the lighter silty ones of the Topagoruk Formation.

Square Lake area.--Two gas horizons were discovered by the test well drilled on the Square Lake anticline, which was determined by seismic surveys to have an area of 24 square miles and 300 feet of closure. It is on the southern edge of the Coastal Plain, about 30 miles west-northwest of Umiat. The gas was produced from sandstone beds of the Seabee Formation at 1,646-1,675 and 1,835-1,869 feet, but water was produced simultaneously from both sandstones. Tests were inconclusive because of ice forming in the tester, and estimates of reserves by Arctic Contractors range from 22 to 58 billion cubic feet of gas. Details of geology and testing of this well are published elsewhere (Collins, 1959, p. 424-446).

Titaluk area.--A small amount of gas was found in the Grandstand Formation at 3,000 feet in Titaluk test well 1 but most of the sandstone beds are too thin and are too low in permeability to have merit as reservoirs of oil or gas. The best oil shows in the hole were also in the Grandstand Formation, between 3,200 and 3,450 feet, as described elsewhere (Robinson, 1959a, p. 394).

Topagoruk area.--No shows of oil or gas were noted in any beds of pre-Cretaceous age in Topagoruk test well 1, and although some of the Cretaceous beds have good reservoir qualities none of these contained oil or gas. One impermeable sandstone bed in the Oumalik Formation had a slight oil stain, but testing recovered only drilling mud. Sandstone beds in the Grandstand Formation in East Topagoruk test well 1 had adequate porosity and permeability but there were no shows of oil and only a slight show of gas in this hole.

The two holes are located about halfway between the Oumalik holes and Barrow, on anticlines defined by seismic surveys. Plate 15 shows a correlation of the upper part of Topagoruk test well 1 with East Topagoruk test well 1, 15 miles to the east. Correlation of individual beds in the Grandstand Formation is not demonstrable because of thickness and facies changes, although some beds are probably continuous from one hole to the other. In Topagoruk test well 1, the Grandstand Formation contains many thin beds of coal, most of which are not found in the eastern hole. Clay ironstone common between 600 and 800 feet in Topagoruk test well 1 is also missing from the comparable interval at East Topagoruk. Sandstone beds in the Grandstand Formation in Topagoruk test well 1 are less well defined and massive and contain more interbeds of clay shale than at East Topagoruk, but the top of one bed which seems to be present in both holes is near 600 feet in Topagoruk test well 1 and about 300 feet lower at East Topagoruk. Below this sandstone both holes drilled into a shaly section underlain by more sandstone, although the lower sandy sequence is thicker in the east.

The thin sandstone beds of the Topagoruk Formation appear to be more persistent across the area, although most of them are thinner to the east.

Faunal evidence corroborates the lithologic correlation discussed above. A section containing common fragments of Ditrupa cornu and Inoceramus sp. is a few hundred feet higher in Topagoruk test well 1 than in East Topagoruk test well 1. In addition, the uppermost occurrences of many microfossils of the Verneuilinoides borealis assemblage as well as the section containing the most abundant specimens and species of the assemblage, average about 450 feet higher in Topagoruk test well 1 than at East Topagoruk (Bergquist, 1958b, p. 312 and 314).

Wolf Creek area.--The Wolf Creek anticline has 200 feet of proven closure in an area 5 miles long, with a maximum possible closure of 600 feet over an area 16 miles long, mapped by surface and photogeologic methods. Three holes were drilled on it: Wolf Creek test wells 1 and 3, on the crest, produced gas from the Chandler and Grandstand Formations (see shows on pl. 16), and Wolf Creek test well 2, on the north flank of the structure, produced water with a trace of gas from the same formations. The best gas production was from Wolf Creek test well 1, which produced at a rate of 1,304,900 cubic feet per day through a 1 1/2-inch orifice from a sandstone bed in the Grandstand Formation at the bottom of the hole.

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The correlation of beds penetrated by the three holes is shown in plate 16. Only two of the four formations drilled were penetrated by more than one test well, but correlation of these two, the Ninuluk and Chandler Formations, shows the much greater continuity of beds in the marine Ninuluk Formation, which has sandstone beds that persist with little change across the anticline, compared to the nonmarine Chandler Formation, which has discontinuous, lenticular beds only a few of which can be definitely traced from one test well to another. The relative ease of correlation in a north-south direction is also illustrated, as correlation between test wells 2 and 3 is about as good as it is between test wells 1 and 3, although test well 2 is about 15 times farther away (1 1/3 miles) from test well 3 than test well 1 is.

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Summary of Oil and Gas

No shows of oil or gas were found in Naval Petroleum Reserve No. 4 in rocks of pre-Mesozoic age and Topagoruk test well 1 found no suitable reservoir rocks as deep as 10,503 feet, the total depth of the hole. Triassic sandstone beds, penetrated only in the northern part of the Reserve, have a carbonate cement and are too impermeable to make good reservoir rocks; none had shows. Basal sandstone beds of Jurassic age have a few thin layers of intraformational conglomerate in Simpson test well 1 which have faint shows of oil, suggesting the possibility of additional Jurassic (or older) petroliferous beds on or near the flanks of the Barrow high. In Topagoruk test well 1, Jurassic beds were predominantly clay shale and the sandstone at the base of the sequence had no shows of oil or gas; in South Barrow test well 3, the beds are sandier but still had no appreciable shows. The oldest production found in the Reserve, however, is in beds of Jurassic age in South Barrow test wells 2, 4, 5, and 6, which produce gas. Although South Barrow test well 3 was a dry hole, the numerous faults in the area may have trapped oil or gas in Jurassic beds elsewhere in the vicinity.

Almost all of the oil and gas discovered in Naval Petroleum Reserve No. 4 has been in rocks of Cretaceous age. Gas shows in the lower Oumalik Formation were noted in Oumalik test well 1, but they were poor and the sandstone beds are silty and poorly sorted. The Topagoruk Formation contains heavy, dark oil at Fish Creek test well 1, in thin beds of sandy siltstone which, although they are poor, are the only reservoir beds in the well.

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The best oil-producing zone discovered in the Reserve to date is the Grandstand Formation, which is the reservoir of most of the oil at Umiat field and also had the best shows in other tests. Many of the structures found in the coastal plain and in the foothills contain Grandstand beds within relatively easy reach of the drill, and thus the possibilities for production from them should be numerous. But, except for the Umiat anticline, drilling on these structures has not been especially rewarding; most test wells had shows of oil or gas, but few had appreciable quantities of gas and none produced oil except at Umiat. The matrix of the sandstone beds is especially important; much of the Grandstand Formation is poorly sorted, and has a large amount of argillaceous material in the matrix. Regardless of structure, the adverse factors of porosity and permeability minimize chances of the discovery of oil in such locations as the Grandstand anticline. A comparison of figures 10 and 12, which depict the average porosity and thickness of Grandstand sandstone beds shows that the sandstone has the best reservoir properties in a region extending southeast from Barrow, particularly east of the Topagoruk area, where the greatest sandstone thickness coincides roughly with the greatest average porosity. Reconnaissance seismic work in the area did not locate any structure capable of trapping oil, but some areas, particularly one south of Teshekpuk Lake, have not been studied in sufficient detail to determine the presence or absence of such structures.

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The Grandstand sandstone beds were deposited following deposition of a great thickness of argillaceous, fossiliferous sediments. It seems likely, therefore, that the Grandstand oil originated in the organic remains of the prolific fauna in the upper Topagoruk and lower Grandstand Formations, and then migrated upward into reservoir beds of the Grandstand Formation. Oil at Fish Creek and Simpson Seeps and the gas at Gubik could well have had a similar origin, although the reservoir rocks are of a slightly different age. At Gubik, no Grandstand Formation is present, and the gas is trapped in sandstone beds of the undifferentiated Ninuluk and Chandler Formations, which overlie fine clastics of the Topagoruk Formation and are capped by impermeable shale of the Seabee Formation. At Fish Creek, the Grandstand Formation is also absent; poor reservoir beds of the Topagoruk(?) Formation hold the oil. At Simpson Seeps, the oil has apparently migrated through the very porous, permeable, and friable Grandstand sandstone beds to the top of the section of coarse clastics which is Ninuluk and Seabee undifferentiated in age, and which is overlain, as at Gubik, by shale of the Seabee Formation. The oil in the seeps is at present escaping from these shallow beds, probably through fissures in the permafrost. In each of these instances, the petroleum fluids have apparently moved upward to the top of the sandy section, until they were stopped by impermeable beds above.

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The uppermost producing zone found in the Reserve is in the Tuluvak Tongue of the Prince Creek Formation, which contains much of the gas of the Gubik anticline. Although it is nonmarine, the Tuluvak Tongue is comparable to the Grandstand Formation in that it contains sandstone beds overlying a thick sequence of fossiliferous marine beds (Seabee Formation) which must have contained a large amount of organic material, presumably the source of the gas. Here again, the fluid seems to have formed in the marine shale and migrated upward into overlying reservoir sandstones. The capping rock in this case is the impermeable shale of the Schrader Bluff Formation.

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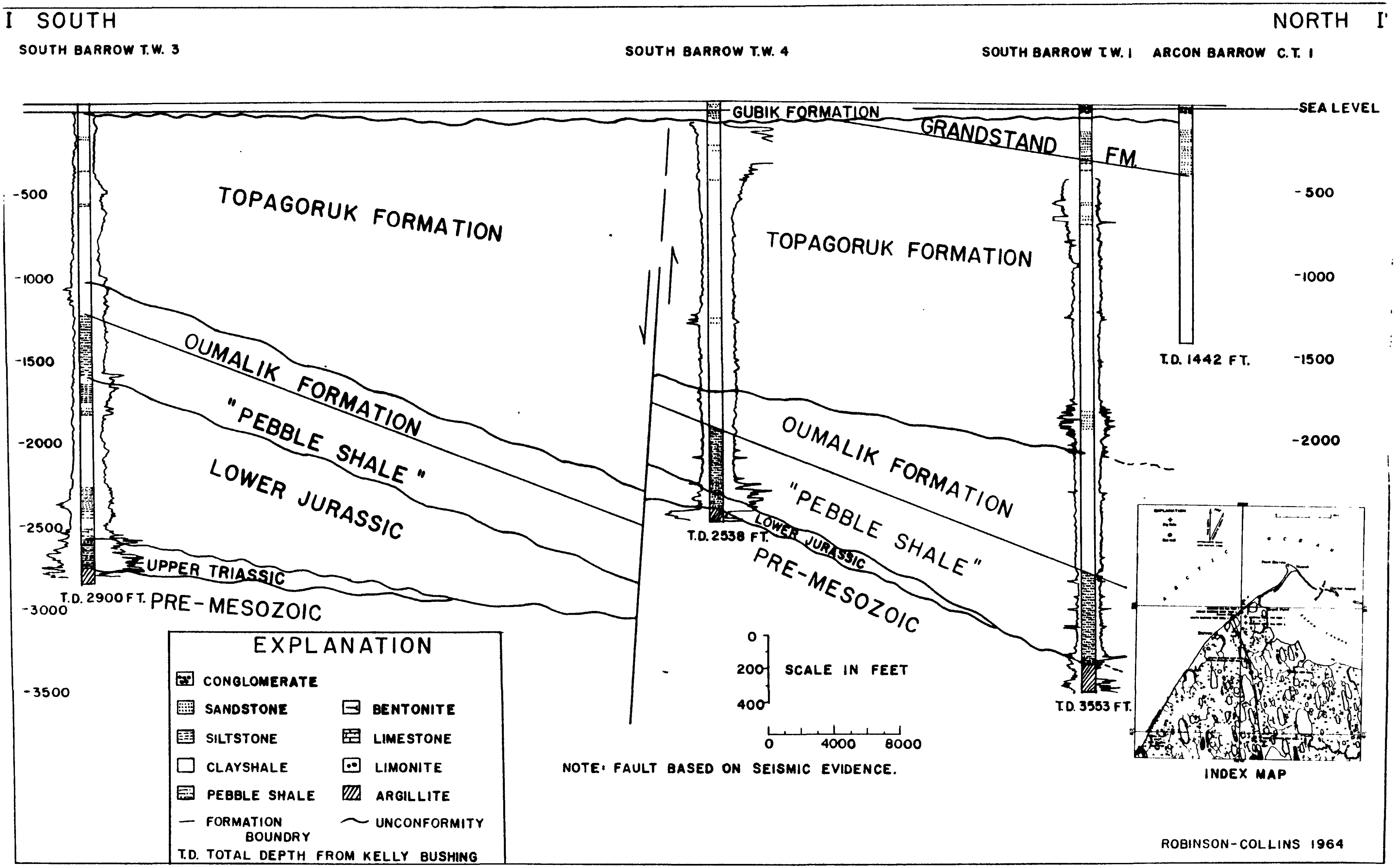
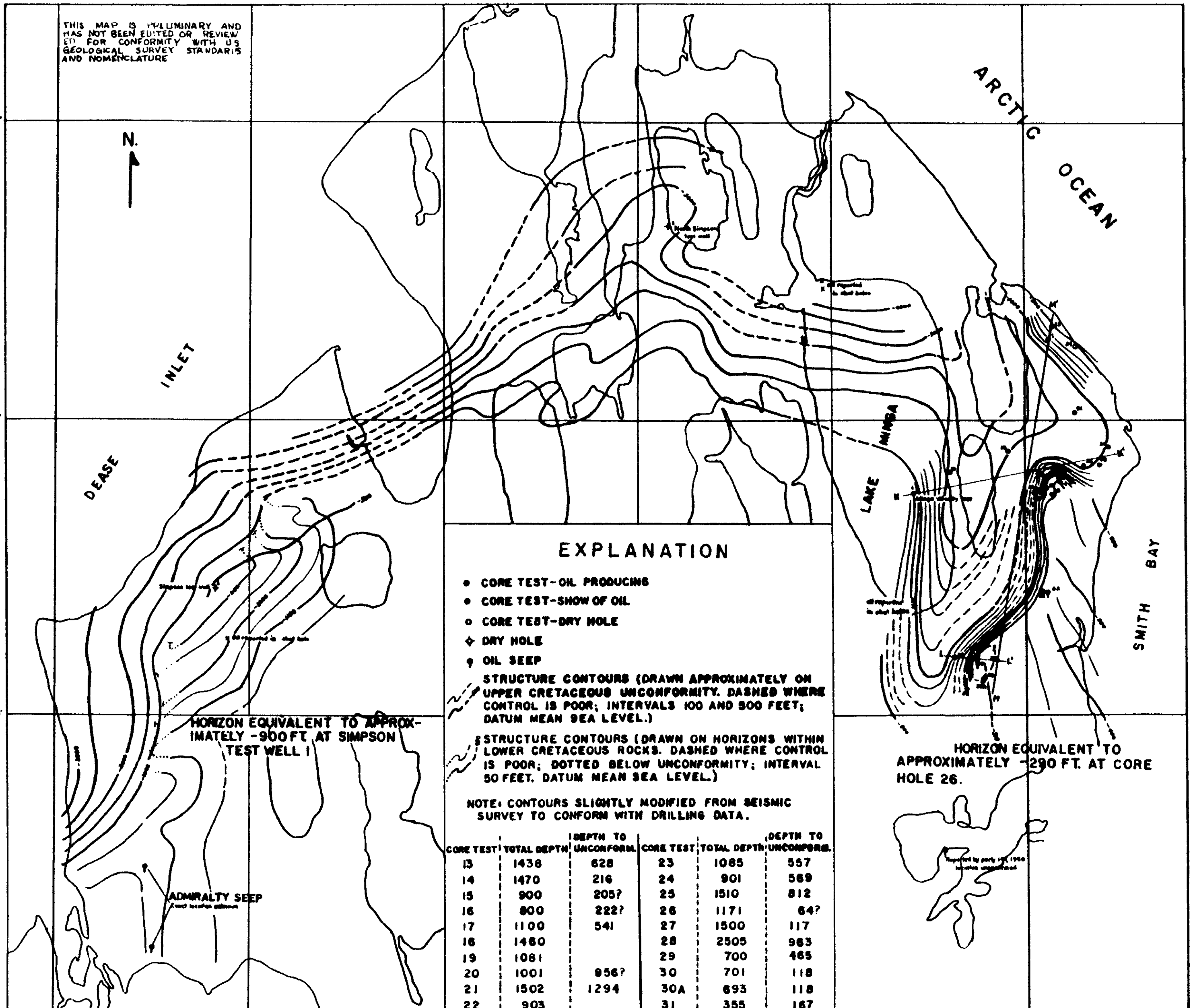


PLATE 5. CROSS SECTION OF THE BARROW AREA



CORE TEST	TOTAL DEPTH	DEPTH TO UNCONFORM.	CORE TEST	TOTAL DEPTH	DEPTH TO UNCONFORM.
13	1436	628	23	1085	557
14	1470	216	24	901	569
15	900	205?	25	1510	812
16	800	222?	26	1171	64?
17	1100	541	27	1500	117
18	1460		28	2505	963
19	1081		29	700	465
20	1001	956?	30	701	118
21	1502	1294	30A	693	118
22	903		31	355	167

PLATE 7. MAP OF THE SIMPSON PENINSULA SHOWING THE LOCATION OF THE CORE TESTS AND TEST WELLS AND OF THE UPPER CRETACEOUS UNCONFORMITY.

ROBINSON-COLLINS 1964

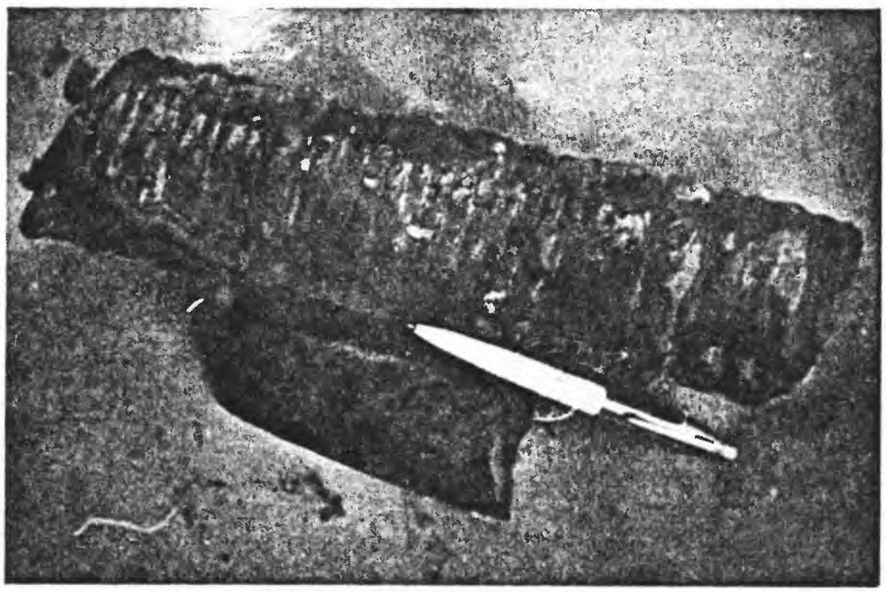


Figure 4. Steeply dipping argillites in Simpson test well 1. The core was moistened with water to bring out color differences.

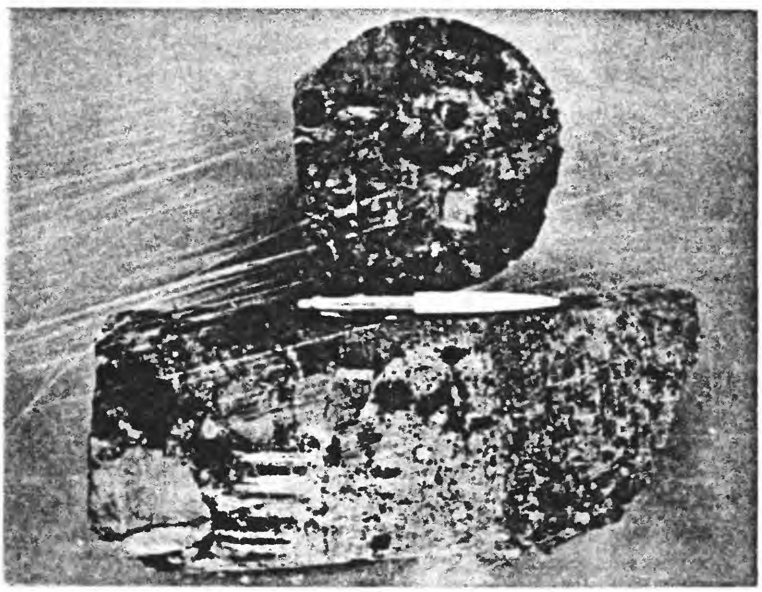


Figure 5. Devonian chert conglomerate from 10,479-81 feet in Topagoruk test well 1. The core was moistened before being photographed, to bring out color differences.

Series	European Stages	Tiglukpuk Creek, central Brooks Range (Patton, 1956a. Bergquist, pers. comm., 1952)	West Fork of Shaviovik River, eastern Brooks Range (Keller, 1961)	Oumalik test well 1	Topagoruk test well 1	Simpson test well 1	Avak test well 1	South Barrow test well 1
LOWER CRETACEOUS	Albian					Foraminifera	Foraminifera	Astarte ignekensis
	Aptian							
	Barremian							
	Hauterivian							
	Valanginian			Buchia "sublaevis"	Buchia "sublaevis"[1] ?			
	Berriasian		Buchia okensis Buchia subokensis					
UPPER JURASSIC	Portlandian							
	Kimmeridgian	Foraminifera ?	Foraminifera ?		Buchia rugosa?[1] Foraminifera ?			
	Oxfordian							

1/ This pelecypod specimen was originally identified as Aucella rugosa? but may be A. sublaevis.

Figure 7. Possible stratigraphic relations of beds having the distinctive lithologic characteristics of the pebble shale.

FIGURE 6. COMPARISON AND POSSIBLE CORRELATION OF LOWER AND MIDDLE JURASSIC BEDS IN TEST WELLS OF NORTHERN ALASKA.

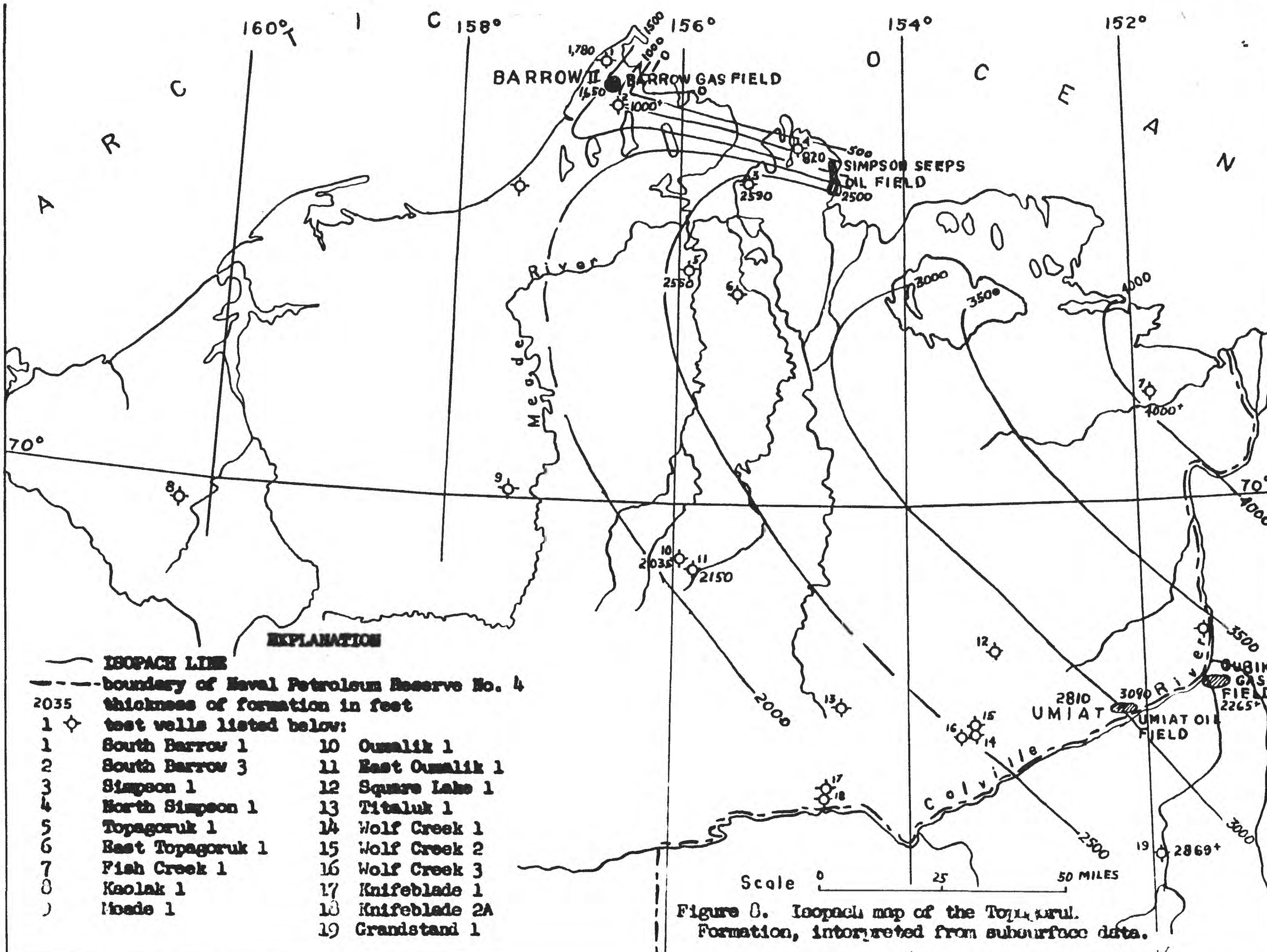


Figure 8. Isopach map of the Topagoruk Formation, interpreted from subsurface data.

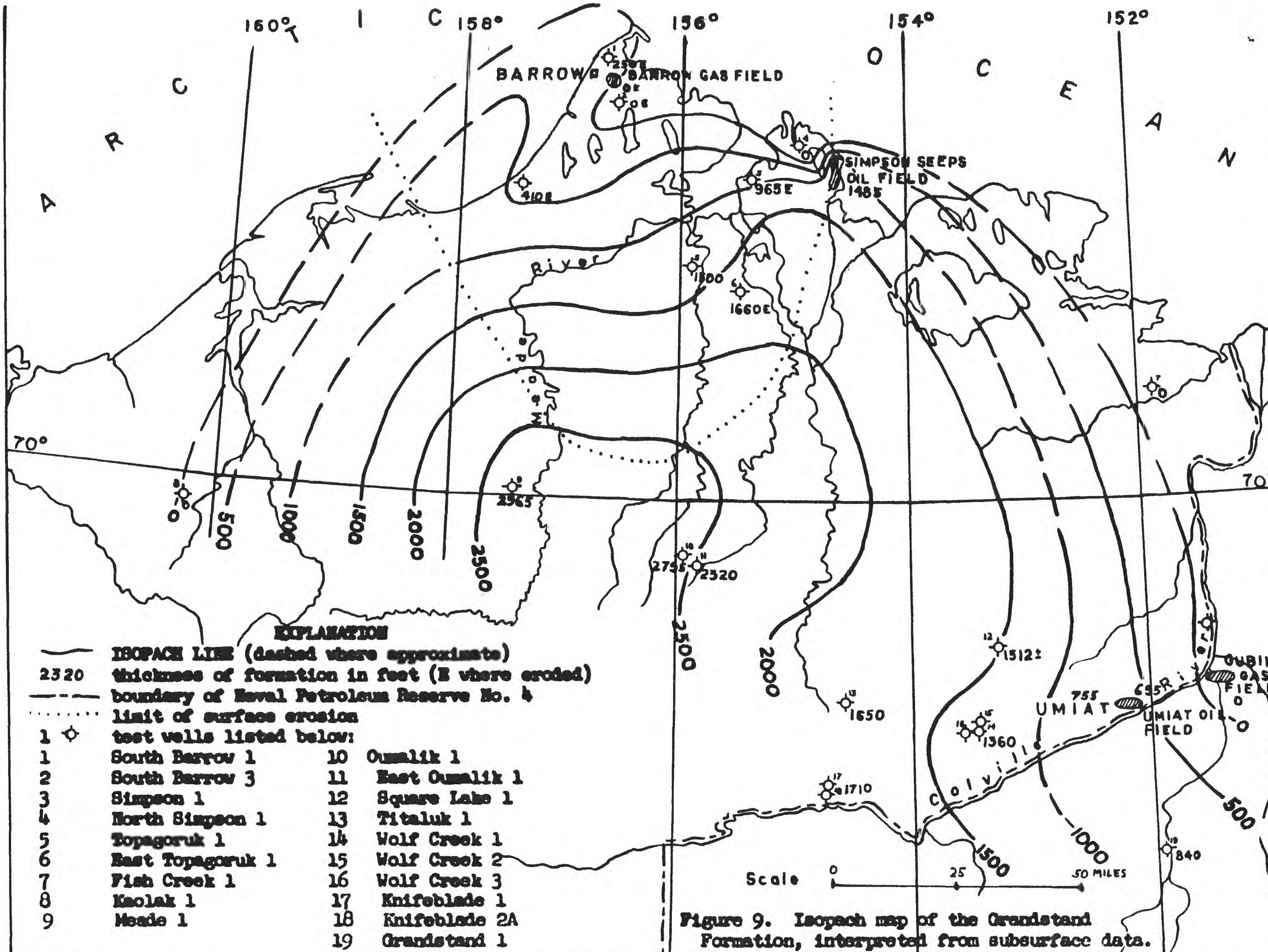


Figure 9. Isopach map of the Grandstand Formation, interpreted from subsurface data.

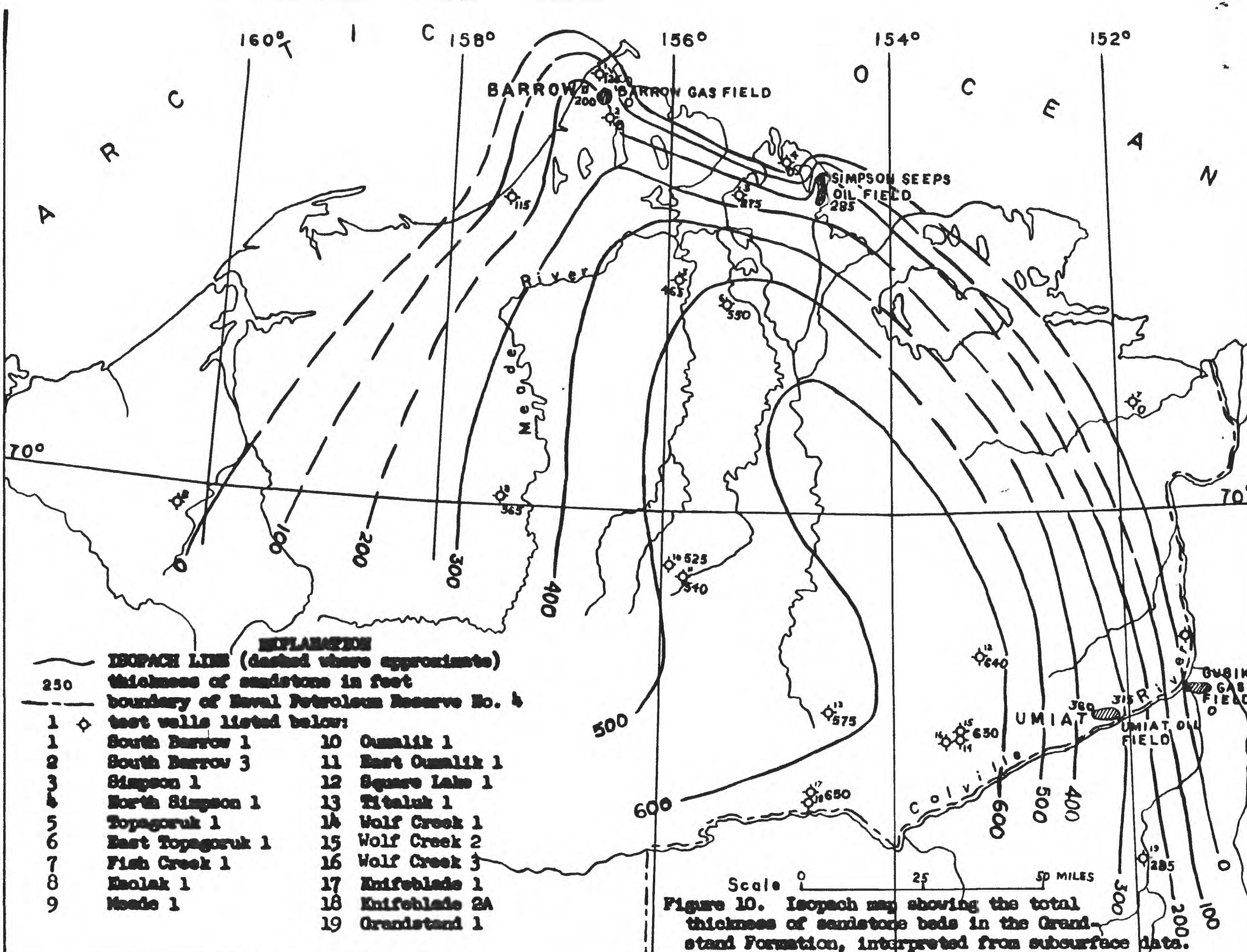


Figure 10. Isopach map showing the total thickness of sandstone beds in the Grandstand Formation, interpreted from subsurface data.

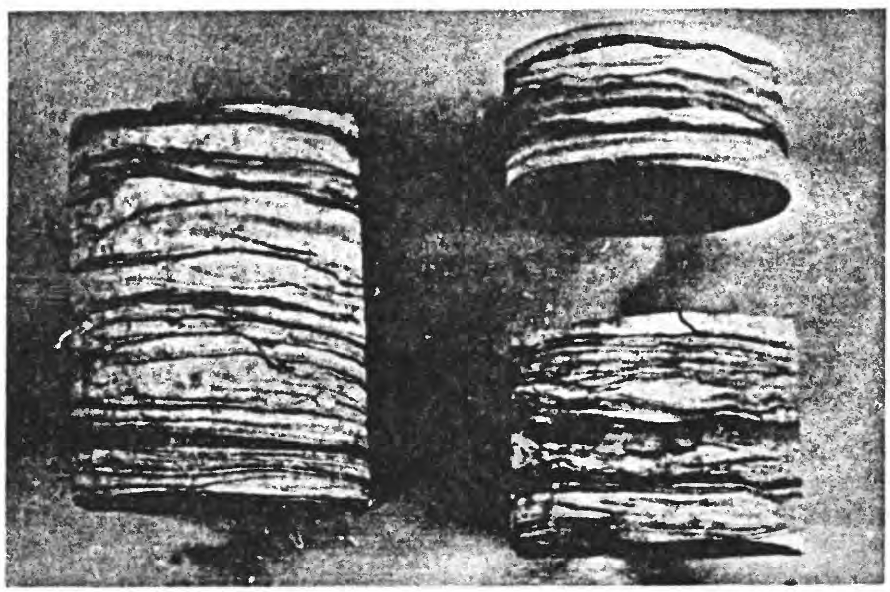


Figure 11. Carbonaceous particles outline laminae and small lenses in siltstone and sandstone of the Grandstand Formation. The core shown here was taken at approximately 2,955 feet in Meade test well 1. Core is about 3 inches in diameter.

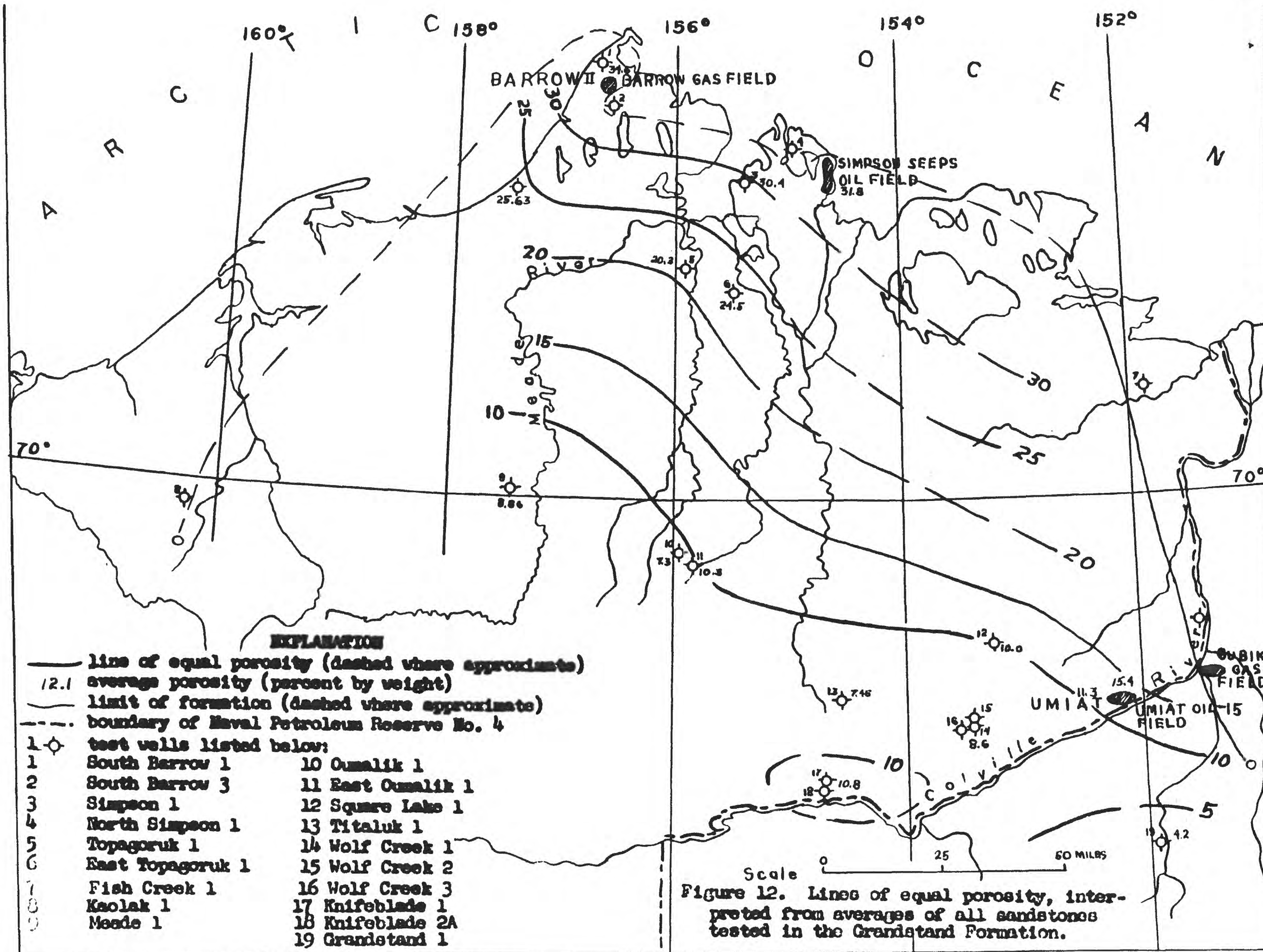


Figure 12. Lines of equal porosity, interpreted from averages of all sandstones tested in the Grandstand Formation.

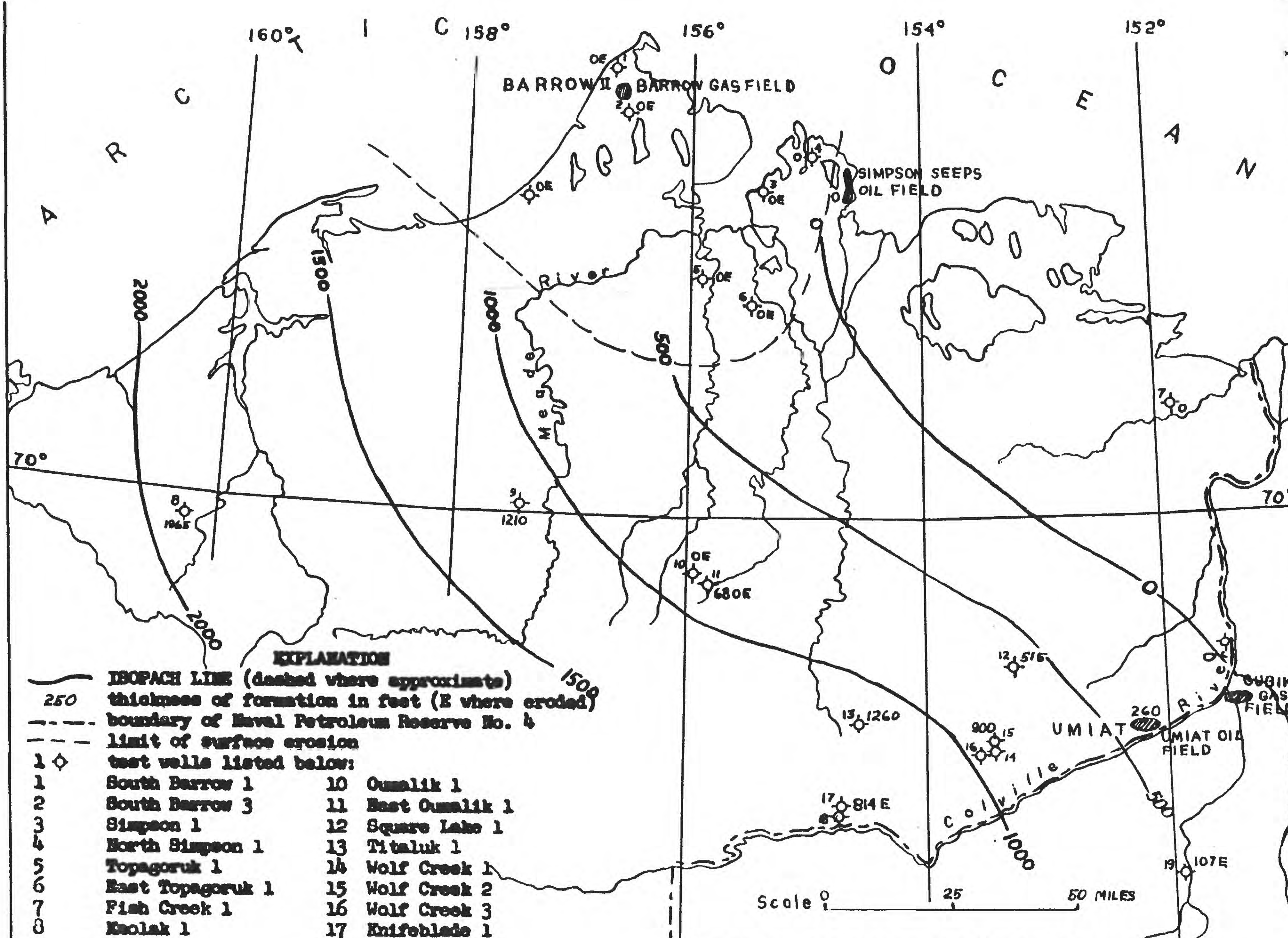


Figure 13. Isopach map of the Chandler Formation, interpreted from subsurface data.

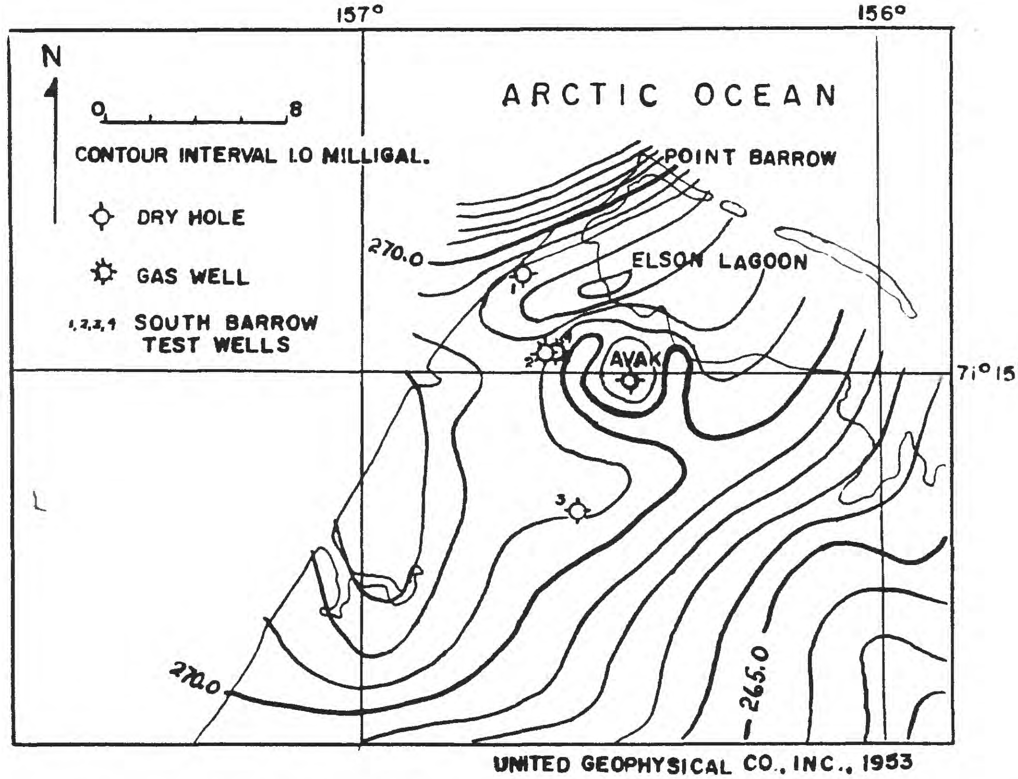


FIGURE 14. OBSERVED GRAVITY MAP OF THE BARROW AREA.

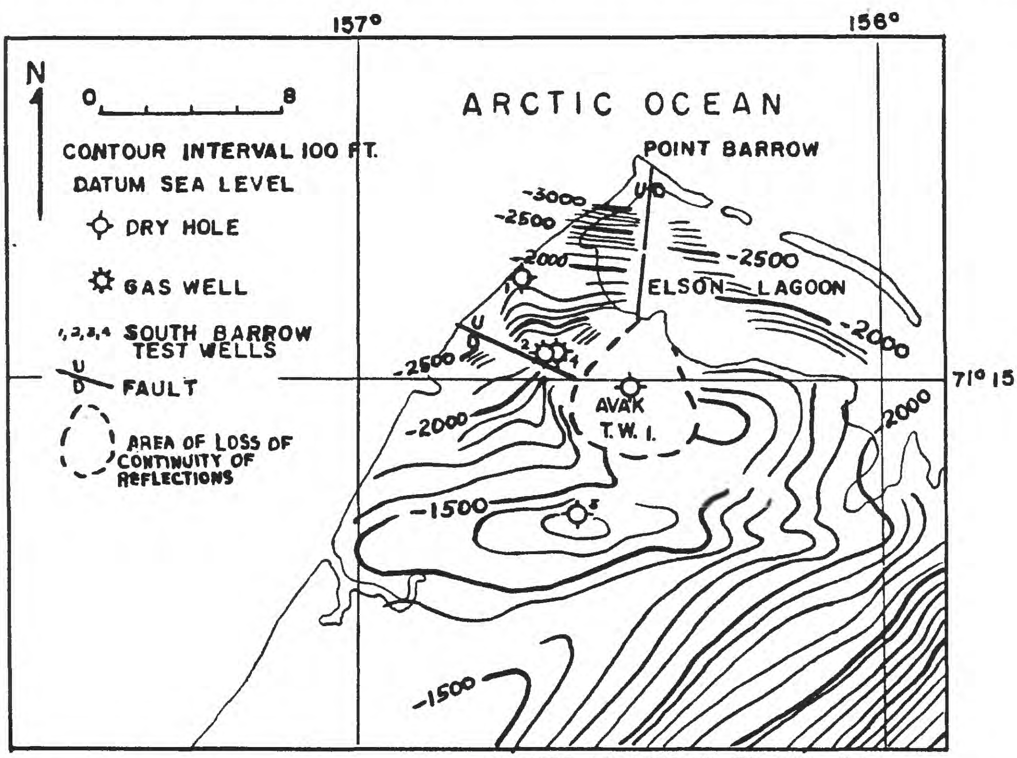


FIGURE 15. SEISMIC MAP OF STRUCTURE OF SHALLOW CRETACEOUS BEDS IN THE BARROW AREA.

ROBINSON-COLLINS
1964

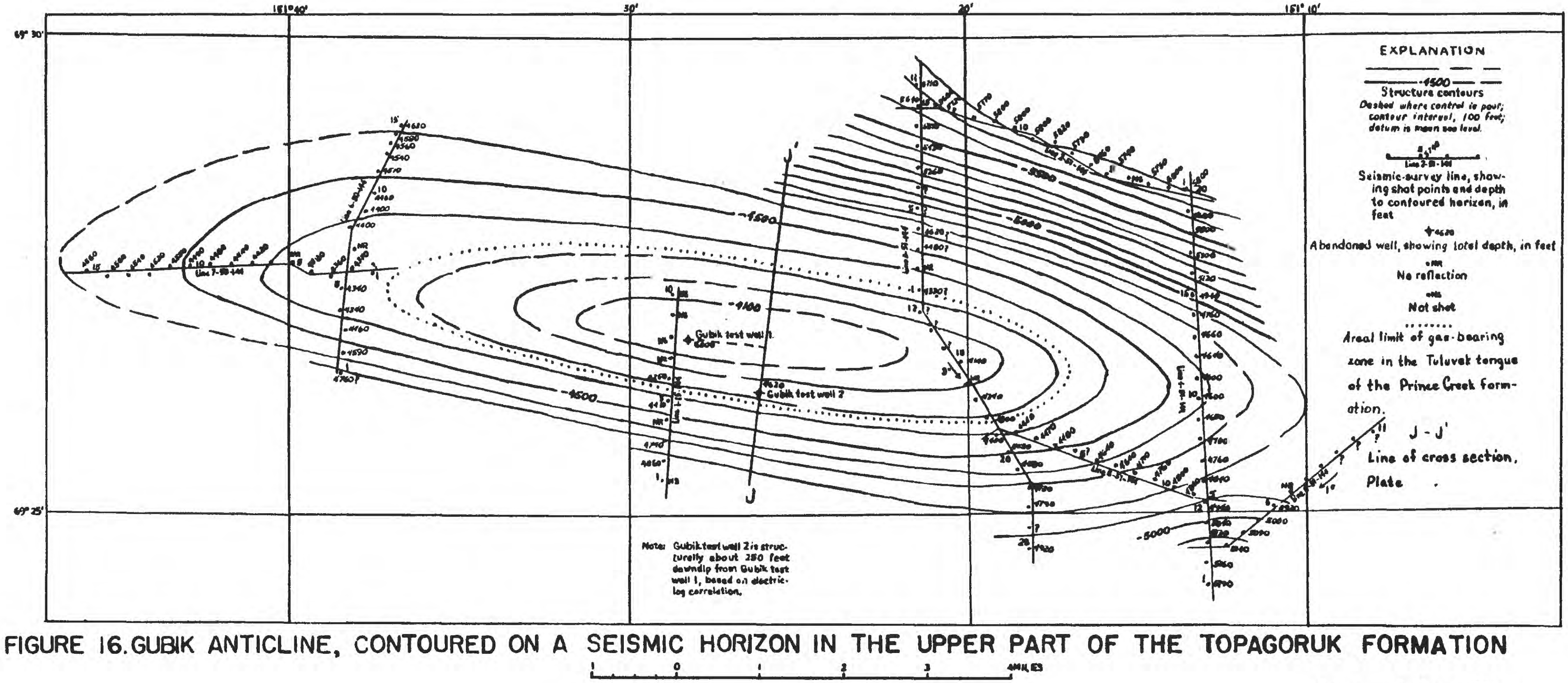


FIGURE 16. GUBIK ANTICLINE, CONTOURED ON A SEISMIC HORIZON IN THE UPPER PART OF THE TOPAGORUK FORMATION

Robinson - Collins, 1964

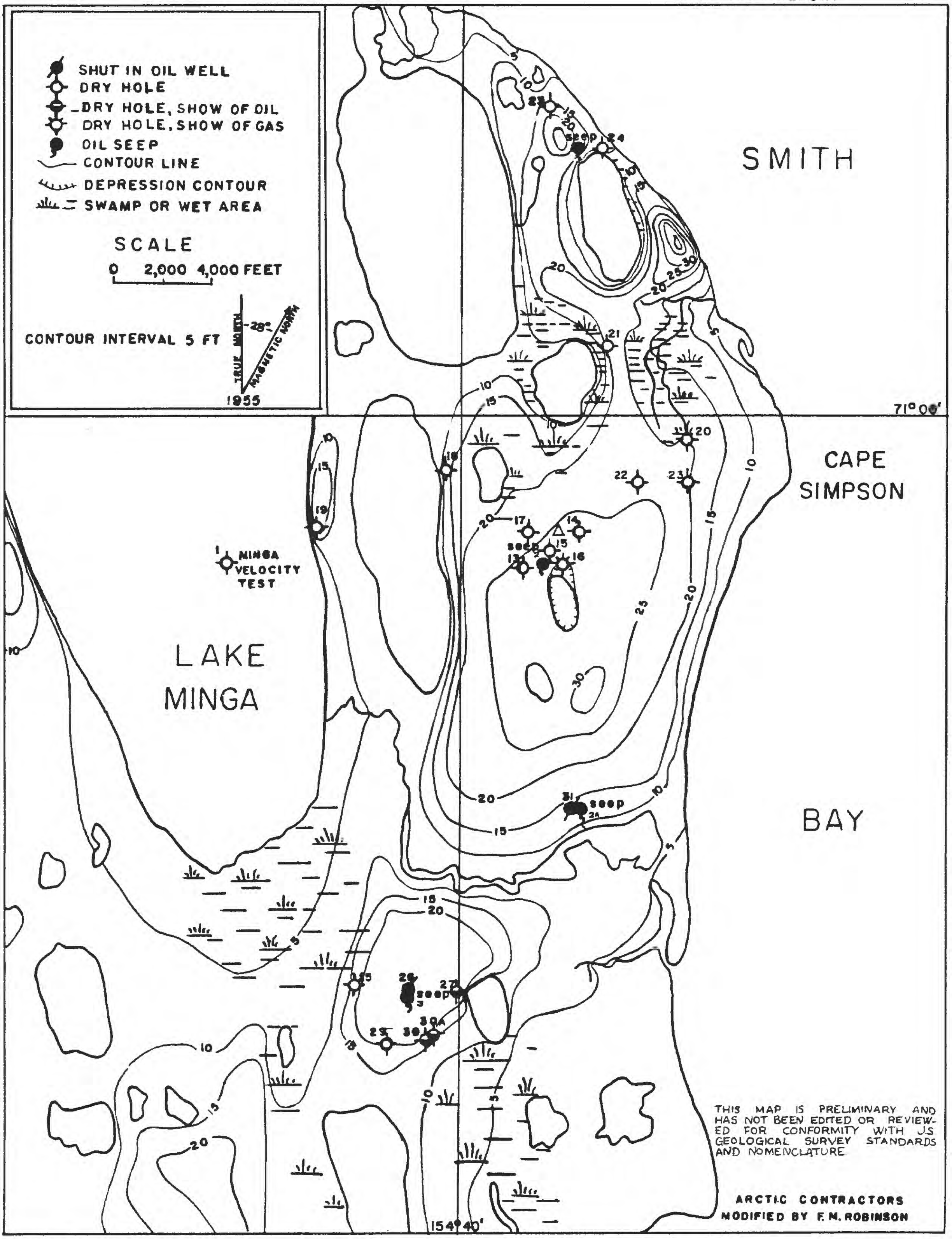
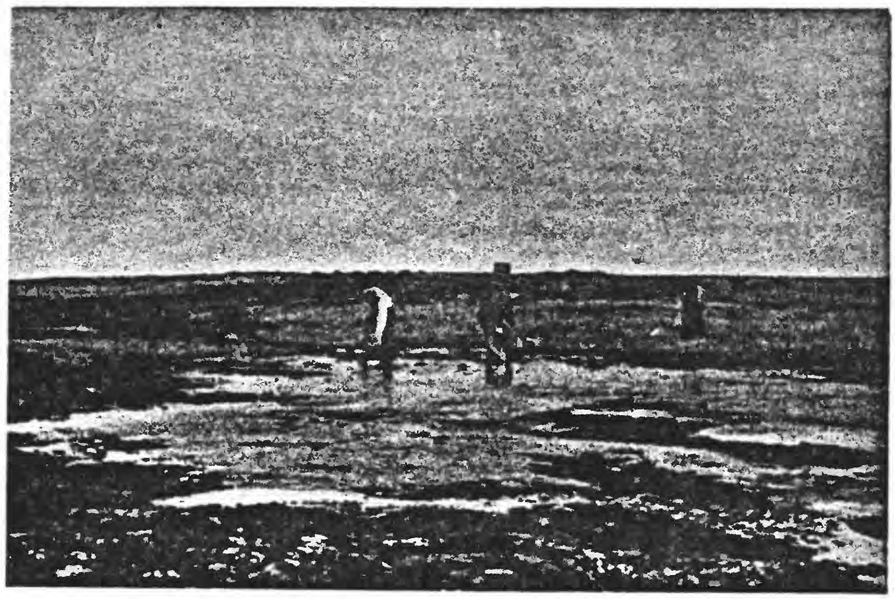


FIGURE 17. Reconnaissance topographic map of the Simpson Seeps area based on shot point and core hole elevations. This map shows the mounds on which the Simpson Seeps are located.



W. W. Patton, Jr.

Figure 18. General view of Simpson Seep 1, the northernmost of three large oil seeps found in the Cape Simpson area. Summer 1948.

THIS MAP IS PRELIMINARY AND HAS NOT BEEN EDITED OR REVIEWED FOR CONFORMITY WITH U.S. GEOLOGICAL SURVEY STANDARDS AND NOMENCLATURE

OPEN FILE REPORT

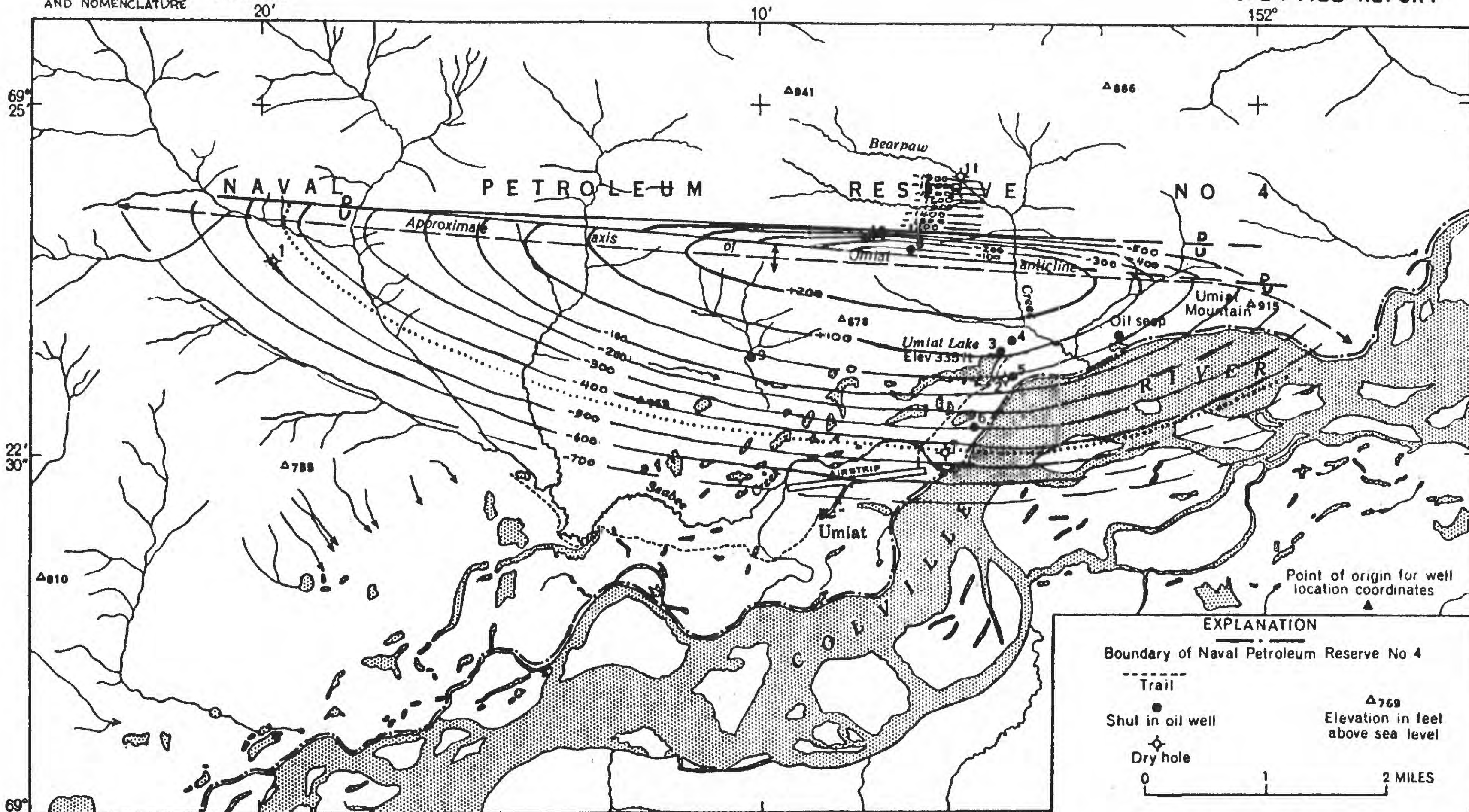


Figure 19. The Umiat anticline contoured on the top of the Grandstand Formation showing the possible southern limit of production

Robinson-Collins 1964

Table 1. An analysis, by the U. S. Bureau of Mines, of crude oil collected from one of the Simpson seeps in 1948.

GENERAL CHARACTERISTICS

Specific gravity, 0.933 A. P. I. gravity 20.2° Pour point, °F below 5

Sulfur, percent, 0.34 Color, brownish green

Saybolt Universal viscosity at 100° F., 640 sec; at 130° F., 260 sec.

DISTILLATION, BUREAU OF MINES ROUTINE METHOD

Distillation at atmospheric pressure, 749 mm. First drip, 217° C (423° F.)

Fraction	Cut at		Percent	Sum	Sp. gr.	°A.P.I.	Corr.	Aniline point	Saybolt Universal Viscosity	Cloud test
No.	°C	°F		Percent	60/60°F.	60°F	Index	°C	100°F	°F
1	50	122								
2	75	167								
3	100	212								
4	125	257								
5	150	302								
6	175	347								
7	200	392								
8	225	437								
9	250	482	3.6	3.6	0.877	29.9	--	58.9		
10	275	527	6.6	10.2	.892	27.1	58	61.6		
Distillation continued at 40mm.										
11	200	392	3.9	14.1	0.907	24.5	61	63.4	49	below 5°
12	225	437	8.8	22.9	.918	22.6	62	62.6	64	do.
13	250	482	8.7	31.6	.928	21.0	64	66.2	105	do.
14	275	527	8.5	40.1	.935	19.8	64	69.4	210	do.
15	300	572	10.1	50.2	.937	19.5	62	75.8	over 400	do.
Residuum			49.2	99.4	0.949	17.6		100.0		

Carbon residue of residuum, 4.0 percent; carbon residue of crude, 2.0 percent.

APPROXIMATE SUMMARY

Light gasoline	Percent	Specific gravity	°A.P.I.	Viscosity
Total gasoline and naphtha	--	--	--	--
Kerosine distillate	--	--	--	--
Gas oil	12.7	0.891	27.3	--
Nonviscous lubricating distillate	13.5	.908-.927	24.3-21.1	50-100
Medium lubricating distillate	8.9	.927-.934	21.1-20.0	100-200
Viscous lubricating distillate	15.1	.934-.938	20.0-19.4	Above 200
Residuum	49.2	.949	17.6	
Distillation loss	0.6			

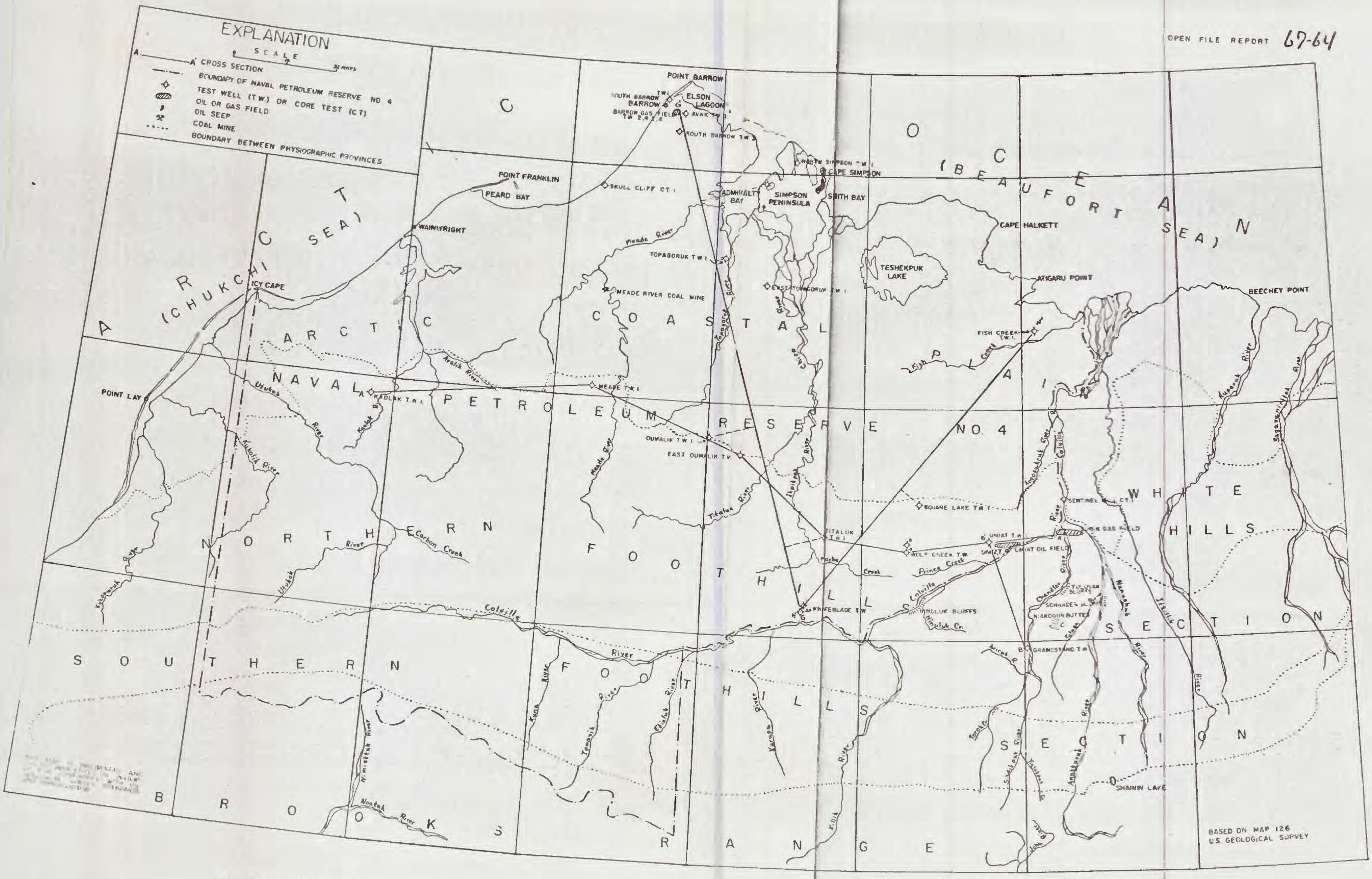


FIGURE I. MAP OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, SHOWING LOCATIONS OF TEST HOLES, OIL AND GAS FIELDS, AND OF REGIONAL CROSS SECTIONS.

6764

TEST	LOCATION: LATITUDE	LOCATION: LONGITUDE	ELEVATION (FEET)[1]: GROUND	ELEVATION (FEET)[1]: KELLY[2] BUSHING DATUM	DATE SPUDDED	DATE COMPLETED	TOTAL DEPTH (FEET)	STATUS	FOOTAGE CORED (FEET-INCHES)	FOOTAGE RECOVERED (FEET-INCHES)	ALLUVIUM OR GUBIK FORMATION	SCHRADER BLUFF FORMATION: SENTINEL HILL MEMBER	SCHRADER BLUFF FORMATION: BARROW TRAIL MEMBER	SCHRADER BLUFF FORMATION: ROGERS CREEK MEMBER	PRINCE CREEK FORMATION / TULUVAK TONGUE	SEABEE FORMATION	NINULUK FORMATION	CHANDLER FORMATION / KILLIK TONGUE	GRANDSTAND FORMATION	TOPAGORUK FORMATION	OUMALIK FORMATION	PEBBLE SHALE	LOWER AND MIDDLE JURASSIC	SHUBLIK FORMATION	PERMIAN	RED BEDS	DEVONIAN	ARGILLITES
Arcon Barrow core test 1	71°19'40"N	156°40'01"W	10.5	18.5	Mar. 29, 1947	May 3, 1947	1,442	Dry and abandoned	280-8	139- 4	8	--	--	--	--	--	--	--	100	410	--	--	--	--	--	--	--	--
Avak test well 1	71°15'02"N	156°26'06"W	1.8	17.3	Oct. 21, 1951	Jan. 14, 1952	4,020	Dry and abandoned	860	624- 7	15.5	--	--	--	--	--	--	--	--	--	--	100?	1,350	--	--	--	--	2,307
Barrow Big Rig test 1	71°19'44"N	156°40'06"W	8.5	16	Oct. 13, 1944	Oct. 22, 1944	685	Dry and abandoned	81	38	7.5	--	--	--	--	--	--	--	90?		--	--	--	--	--	--	--	--
Barrow Core Rig test 1	71°19'25"N	156°39'02"W	10.4	13	Sept. 17, 1944	Oct. 7, 1944	344	Dry and abandoned	44	8- 4	2.6	--	--	--	--	--	--	--	95?		--	--	--	--	--	--	--	--
Barrow Core Rig test 2	71°19'00"N	156°38'59"W	14	16	Oct. 9, 1944	Oct. 17, 1944	236	Junked and abandoned	14	0- 6	2	--	--	--	--	--	--	--	100?		--	--	--	--	--	--	--	--
East Oumalik test well 1	69°47'29"N	155°32'39"W	277	293	Oct. 23, 1950	Jan. 7, 1951	6,035	Dry and abandoned	223	184- 0	16	--	--	--	--	--	--	50	730	3,050	5,200	--	--	--	--	--	--	--
East Topagoruk test well 1	70°34'52"N	155°22'39"W	50	67	Feb. 18, 1951	Apr. 16, 1951	3,589	Dry and abandoned	419	355	17	--	--	--	--	--	--	--	90	1,750	--	--	--	--	--	--	--	--
Fish Creek test well 1	70°19'15"N	151°58'08"W	16.5	31.5	May 17, 1949	Sept. 4, 1949	7,020	Oil well-plugged & abandoned	719	494- 3	15	65	680		1,632	1,655	--	--	--	2,890	--	--	--	--	--	--	--	--
Grandstand test well 1	68°57'58"N	151°55'02"W	645	665	May 1, 1952	Aug. 8, 1952	3,939	Dry and abandoned	803	665- 6	20	--	--	--	--	--	--		110	1,070	--	--	--	--	--	--	--	--
Gubik test well 1	69°26'46"N	151°28'06"W	144	156	May 20, 1951	Aug. 11, 1951	6,000	Gas well-plugged & abandoned	768	637	12	--	67	295	890	1,760		3,305	--	3,735	--	--	--	--	--	--	--	--
Gubik test well 2	69°25'10"N	151°27'26"W	151	163	Sept. 10, 1951	Dec. 14, 1952	4,620	Junked and abandoned	1,421	1,176- 6	?	--	160?	555	1,135	2,010		3,585	--	4,025	--	--	--	--	--	--	--	--
Ikpikpuk core test 1	69°49'36"N	155°41'57"W	170	180	July 9, 1947	July 17, 1947	179	Junked and abandoned	20	9	10	--	--	--	--	--	--	39?	--	--	--	--	--	--	--	--	--	--
Kaolak test well 1	69°56' N	160°14'51"W	164	178	July 21, 1951	Nov. 12, 1951	6,952	Dry and abandoned	848	703- 6	14	--	--	--	--	--	--	113	--	4,600	--	--	--	--	--	--	--	--
Knifeblade test well 1	69°09'04"N	154°43'21"W	993	999	Oct. 13, 1951	Dec. 22, 1951	1,805	Dry and abandoned	83	53- 5	--	--	--	--	--	--	--	6	820	--	--	--	--	--	--	--	--	--
Knifeblade test well 2	69°08'19"N	154°44'12"W	871	876	July 26, 1951	Aug. 5, 1951	373	Junked and abandoned	3	1	--	--	--	--	--	--	--	5	105	--	--	--	--	--	--	--	--	--
Knifeblade test well 2A	69°08'19"N	154°44'12"W	869	874	Aug. 6, 1951	Oct. 7, 1951	1,805	Dry and abandoned	64	32- 4	5?	--	--	--	--	--	--	15	90	--	--	--	--	--	--	--	--	--
Meade test well 1	70°02'30"N	157°29'23"W	197	211	May 2, 1950	Aug. 21, 1950	5,305	Junked and abandoned	259	167- 4	14	--	--	--	--	--	--	25	1,235	4,200	--	--	--	--	--	--	--	--
Minga velocity test 1	70°59'00"N	154°44'56"W	0	5	Apr. 29, 1950	May 10, 1950	1,233	Dry and abandoned	8	7	5	--	--	--	--	85	610[5]	--	740	--	--	--	--	--	--	--	--	--
North Simpson test well 1	71°03'23"N	154°58'06"W	15	30	May 6, 1950	June 3, 1950	3,774	Dry and abandoned	338	264- 9	15	--	90?		--	1,550?	--	--	--	2,770	3,590	--	--	--	--	--	--	--
Oumalik core test 1	69°49'45"N	155°41'30"W	245	255	July 21, 1947	July 29, 1947	392	Junked and abandoned	60	29- 6	10	--	--	--	--	--	--	30?	--	--	--	--	--	--	--	--	--	--
Oumalik core test 2	69°50'18"N	155°59'24"W	178	?	Sept. 8, 1947	Sept. 10, 1947	190	Junked and abandoned	--	--	0	--	--	--	--	--	--	40	70	--	--	--	--	--	--	--	--	--
Oumalik core test 11	69°50'18"N	155°59'24"W	172	?	Mar. 9, 1949	Mar. 22, 1949	303	Dry and abandoned	297-9	188- 3	0	--	--	--	--	--	--	--	14	--	--	--	--	--	--	--	--	--
Oumalik core test 12	69°50'18"N	155°59'24"W	172	?	April 1949	April 1949	300	Dry and abandoned	297	195- 6	0	--	--	--	--	--	--	--	17	--	--	--	--	--	--	--	--	--
Oumalik test well 1	69°50'18"N	155°59'24"W	176	194	June 11, 1949	Apr. 23, 1950	11,872	Plugged and abandoned	892	519-11	18	--	--	--	--	--	--	--	30	2,825	4,860	10,880	--	--	--	--	--	--
Sentinel Hill core test 1	69°36'57"N	151°27'11"W	200 est.	209	Jan. 26, 1947	Mar. 23, 1947	1,180	Dry and abandoned	1,071	939- 9	--	9[3]	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 1	70°55'42"N	155°17'22"W	21	27	June 25, 1945	June 29, 1945	116	Junked and abandoned	108	25- 6	6	--	--	--	--	--	--	--	83?	--	--	--	--	--	--	--	--	--
Simpson core test 2	70°55'39"N	155°17'30"W	11	29	June 30, 1945	July 2, 1945	226	Junked and abandoned	136	96-10	18	--	--	--	--	--	--	--	77?	--	--	--	--	--	--	--	--	--
Simpson core test 3	70°55'35"N	155°17'30"W	?	89	July 3, 1945	July 7, 1945	368	Junked and abandoned	140	71- 7	?	--	--	--	--	--	--	--	80?	--	--	--	--	--	--	--	--	--
Simpson core test 4	70°55'46"N	155°15'52"W	12	14	July 8, 1945	July 10, 1945	151	Dry and abandoned	87	32	2	--	--	--	--	--	--	--	81	--	--	--	--	--	--	--	--	--
Simpson core test 5	70°56'17"N	155°16'45"W	11	17	July 11, 1945	July 12, 1945	130	Dry and abandoned	70	10	6	--	--	--	--	--	--	--	50?	--	--	--	--	--	--	--	--	--
Simpson core test 6	70°55'58"N	155°18'33"W	20	26	July 12, 1945	July 13, 1945	149	Dry and abandoned	130	33- 6	6	--	--	--	--	--	--	--	79?	--	--	--	--	--	--	--	--	--
Simpson core test 7	70°55'49"N	155°18'09"W	14	26	July 15, 1945	July 25, 1945	532	Dry and abandoned	520	160- 4	12	--	--	--	--	--	--	--	72?	--	--	--	--	--	--	--	--	--
Simpson core test 8	70°56'43"N	155°17'38"W	14	16	July 27, 1945	Aug. 3, 1945	580	Dry and abandoned	560	220- 7	2	--	--	--	--	--	--	--	65	--	--	--	--	--	--	--	--	--
Simpson core test 9	70°57'27"N	155°17'31"W	8	11	Aug. 5, 1945	Aug. 7, 1945	320	Dry and abandoned	170	172- 0	3	--	--	--	--	--	--	--	83?	--	--	--	--	--	--	--	--	--
Simpson core test 10	70°57'43"N	155°17'32"W	7	11	Aug. 8, 1945	Aug. 15, 1945	500	Dry and abandoned	480	189- 6	4	--	--	--	--	--	--	--	63	--	--	--	--	--	--	--	--	--
Simpson core test 11	70°58'49"N	155°17'32"W	1	3	Aug. 17, 1945	Aug. 26, 1945	580	Dry and abandoned	480	419	2	--	--	--	--	80?	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 12	70°58'19"N	155°17'30"W	1	6	Aug. 27, 1945	Aug. 29, 1945	460	Dry and abandoned	58	56	5	--	--	--	--	67?	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 13	70°58'58"N	154°38'43"W	27	33	June 9, 1949	July 20, 1949	1,438	Dry and abandoned	1,172	927	6	--	--	--	--	87	--	--	661	--	--	--	--	--	--	--	--	--
Simpson core test 14	70°59'12"N	154°37'36"W	29	34	July 21, 1949	Aug. 12, 1949	1,270	Dry and abandoned	248	220- 9	5	--	--	--	--	85	250[5]	--	550	--	--	--	--	--	--	--	--	--
Simpson core test 14A	70°59'12"N	154°37'38"W	27	30	Aug. 13, 1949	Aug. 15, 1949	290	Dry and abandoned	90	79- 6	3	--	--	--	--	200[4]	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 15	70°59'06"N	154°38'09"W	25	30	Aug. 16, 1949	Aug. 23, 1949	900	Dry and abandoned	9	7- 6	5	--	--	--	--	75	235?[5]	--	555	--	--	--	--	--	--	--	--	--
Simpson core test 16	70°59'00"N	154°37'52"W	24	28	Aug. 24, 1949	Aug. 31, 1949	800	Abandoned-flowed some gas	35	27- 6	4	--	--	--	--	80	250?[5]	--	550	--	--	--	--	--	--	--	--	--
Simpson core test 17	70°59'12"N	154°38'33"W	23	27	Aug. 31, 1949	Sept. 8, 1949	1,100	Dry and abandoned	50	48	4	--	--	--	--	80?	568[5]	--	710	--	--	--	--	--	--	--	--	--
Simpson core test 18	70°59'38"N	154°40'13"W	14	18	Sept. 10, 1949	Sept. 21, 1949	1,460	Dry and abandoned	40	39	4	--	--	--	--	90?	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 19	70°59'16"N	154°42'57"W	15	19	Sept. 23, 1949	Sept. 29, 1949	1,061	Dry and abandoned	--	--	4	--	--	--	--	80	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 20	70°59'49"N	154°35'19"W	20	24	Oct. 5, 1949	Oct. 11, 1949	1,001	Dry and abandoned	--	--	4	--	--	--	--	85	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 21	71°00'29"N	154°36'54"W	22	26	Oct. 13, 1949	Oct. 27, 1949	1,502	Dry and abandoned	241	179- 3	4	--	--	--	--	85	--	--	1,265	--	--	--	--	--	--	--	--	--
Simpson core test 22	70°59'32"N	154°36'15"W	20	27	Oct. 29, 1949	Nov. 5, 1949	903	Dry and abandoned	72	56- 6	7	--	--	--	--	85	--	--	--	--	--	--	--	--	--	--	--	--
Simpson core test 23	71°02'04"N	154°38'02"W	15	18	Nov. 8, 1949	Nov. 16, 1949	1,035	Dry and abandoned	96	77- ?	3	--	--	--	--	110	--	--	575	--	--	--	--	--	--	--	--	--
Simpson core test 24	71°01'46"N	154°37'01"W	8	11	Nov. 22, 1949	Nov. 28, 1949	901	Dry and abandoned	50	34- 6	3	--	--	--	--	85	--	--	580	--	--	--	--	--	--	--	--	--
Simpson core test 25	70°56'10"N	154°42'12"W	17	20	July 3, 1950	Aug. 12, 1950	1,510	Dry and abandoned	1,007	802	3	--	--	--	--	110	--	--	832	1,377	--	--	--	--	--	--	--	--
Simpson core test 26	70°56'08"N	154°41'04"W	20	23	Aug. 13, 1950	Oct. 23, 1950	1,171	Flowed 110 bbl. oil per day, no water, C.P. 47 psi; shut in	128	113	3	--	--	--	--	--	87[5]	--	420	--	--	--	--	--	--	--	--	--
Simpson core test 27	70°56'07"N	154°40'04"W	24	29	Feb. 8, 1951	Mar. 14, 1951	1,500	Bailed oil-abandoned	384	317	5	--	--	--	--	102	146[5]	--	450	1,416	--	--	--	--	--	--	--	--
Simpson core test 28	70°59'33"N	154°40'16"W	20	37	Sept. 5, 1950	Sept. 24, 1950	2,505	Dry and abandoned	115	90	17	--	--	--	--	120	--	--	1,020	1,655	--	--	--	--	--	--	--	--
Simpson core test 29	70°55'47"N	154°41'31"W	20	25	Feb. 8, 1951	Mar. 14, 1951	700	Dry and abandoned	408	384- 5	5	--	--	--	--	85	--	--	490	--	--	--	--	--	--	--	--	--
Simpson core test 30	70°55'49"N	154°40'41"W	20	25	Nov. 30, 1950	Jan. 23, 1951	693	Bailed oil-junked & abandoned	483	390	5	--	--	--	--	85	143[5]	--	445	--	--	--	--	--	--	--	--	--
Simpson core test 30A	70°55'51"N	154°40'35"W	20	25	Jan. 23, 1951	Feb. 5, 1951	701	Bailed oil-junked & abandoned	21	21	5	--	--	--	--	85	143[5]	--	445	--	--	--	--	--	--	--	--	--
Simpson core test 31	70°57'20"N	154°37'44"W	14	19	Apr. 29, 1950	May 9, 1950	355	Flowed est. 120 bbl. oil per day, 2,000-4,000 cu. ft. gas; shut in	240	188-11	5	--	--	--	--	110?	196[5]	--	--	--	--	--	--	--	--	--	--	--
Simpson test well 1	70°57'12"N	155°21'52"W	15	29	June 14, 1947	June 9, 1948	7,002	Dry and abandoned	1,827	1,274- 3	17	--	--	--	--	--	--	--	25	990	3,580	5,290	5,630	6,265	--	--	--	6,543
Skull Cliff core test 1	70°54' N	158°56' W	41	50±	Feb. 2, 1947	Mar. 17, 1947	779	Junked and abandoned	676	465	9	--	--	--	--	--	--	--	50	450	--	--	--	--	--	--	--	--
South Barrow test well 1	71°19'12"N	156°42'16"W	5	18	Aug. 15, 1948	Nov. 11, 1948	3,553	Dry and abandoned	346-3	245-10	13	--	--	--	--	--	--	--	70	320	2,100	2,825	--	--	--	--	--	3,385
South Barrow test well 2	71°15'49"N	156°38'03"W	23.5	34.5	Dec. 18, 1948	Apr. 15, 1949	2,505	Gas well-junked & abandoned	1,094	869- 2	11	--	--	--	--	--	--	--	--	80	1,730	1,930	2,328	--	--	--	--	2,443
South Barrow test well 3	71°09'47"N	156°34'44"W	30	44	June 23, 1949	Aug. 26, 1949	2,900	Dry and abandoned	1,179	908	14	--	--	--	--	--	--	--	--	65?	1,080	1,285	1,645[7]	2,610	--	--	--	2,799
South Barrow test well 4	71°15'51"N	156°37'50"W	24	43	Mar. 9, 1950	May 9, 1950	2,538	Gas well-flowed 1,805,000 cu. ft. per day	210	169	19	--	--	--	--	--	--	--	--	114	1,750	1,970	2,352	--	--	--	--	2,471
South Barrow test well 5	71°15'51"N	156°37'59"W	25	38.3	May 17, 1955	June 17, 1955	2,456	Gas well-flowed 7,900,000 cu. ft. per day maximum	10	8- 8	13	--	--	--	--	--	--	--	--	117	?	?	?	--	--	--	--	2,450?
South Barrow test well 6	1,925 ft. S 73°E of S.B. t.w.5		22.2	40	1964?	March? 1964	2,363	Gas well-initial production 9,600,000 cu. ft. per day	20	?	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Square Lake test well 1	69°34'± N	153°18'± W	324	340	Jan. 26, 1952	Apr. 18, 1952	3,987	Plugged and abandoned	1,048	957	16	--	--	--	25	700	1,885		2,475	--	--	--	--	--	--	--	--	--
Titaluk test well 1	69°25'21"N	154°34'04"W	822	840	Apr. 22, 1951	July 6, 1951	4,020	Dry and abandoned	391	350	18	--	--	--	--	--	40	590	1,850	3,500	--	--	--	--	--	--	--	--
Topagoruk test well 1	70°37'30"N	155°53'36"W	28	42	June 15, 1950	Sept. 28, 1951	10,503	Dry and abandoned	839	586-11	14	--	--	--	--	--	--	--		1,350	3,900	6,600	7,820	8,830	9,380	9,770	10,040	--
Umiat test well 1	69°23'52"N	152°19'45"W	801	810	June 22, 1945	Oct. 5, 1946	6,005	Dry and abandoned	1,620	1,335- 4	--	--	--	--	--	9	(915	(1,010[6] 2,010)	(1,305[6] 2,085)	2,840[6] (1,060? 5,100)	5,650	--	--	--	--	--	--	--
Umiat test well 2	69°23'04"N	152°05'01"W	333	342	June 25, 1947	Dec. 12, 1947	6,212	Dry and abandoned	822	628	9	--	--	--	--	--	--	80	365		4,700	--	--	--	--	--	--	--
Umiat test well 3	69°23'16"N	152°05'14"W	351	360	Nov. 15, 1946	Dec. 26, 1946	572	Pumped 24 bbl. oil per day-abandoned	333	185- 6	9?	--	--	--	--	--	--	60?	225	--	--	--	--	--	--	--	--	--
Umiat test well 4	69°23'20"N	152°04'53"W	482	483	May 26, 1950	July 29, 1950	840	Pumped 100 bbl. oil per day-shut in	26-6	19	1?	--	--	--	--	--	--	40?	320	--	--	--	--	--	--	--	--	--
Umiat test well 5	69°23'05"N	152°04'56"W	334	335	July 5, 1950	Sept. 22, 1950	1,077	Pumped 400 bbl. oil per day-shut in	19-4	15- 6	1?	--	--	--	--	--	?	60?	335	1,060	--	--	--	--	--	--	--	--
Umiat test well 6	69°22'44"N	152°05'40"W	334	337	Aug. 14, 1950	Dec. 12, 1950	825	Junked and abandoned	16	10- ?	3?	--	--	--	--	31?	220	350	630	--	--	--	--	--	--	--	--	--
Umiat test well 7	69°22'33"N	152°06'17"W	326	330	Dec. 14, 1950	Apr. 12, 1951	1,384	Dry and abandoned	24	16- 6	4?	--	--	--	--	50	(390[6] 60 445)	(515[6] 170 555)	795	--	--	--	--	--	--	--	--	--
Umiat test well 8	69°23'39"N	152°06'56"W	735	740	May 2, 1951	Aug. 28, 1951	1,327	Oil and gas well-shut in	68	59- ?	5	--	--	--	--	20			840	--	--	--	--	--	--	--	--	--
Umiat test well 9	69°23'14"N	152°10'11"W	418	424	June 25, 1951	Jan. 15, 1952	1,257	Pumped 217 bbl. oil per day-abandoned	732	648- ?	6	--	--	--	--	--	6?	155	425	1,090	--	--	--	--	--	--	--	--
Umiat test well 10	69°2[illegible]'04"N	152°07'57"W	741	746	Sept. 9, 1951	Jan. 10, 1952	1,573	Pumped 222 bbl. oil per day-abandoned	101	81- ?	?	--	--	--	--	210	(70[6] 645)	765	1,025	--	--	--	--	--	--	--	--	--
Umiat test well 11	69°24'29"N	152°05'58"W	464	481	June 3, 1952	Aug. 29, 1952	3,303	Dry and abandoned	955	855-1?	17	--	--	--	22	545	2,040	2,160	2,420	3,075	--	--	--	--	--	--	--	--
Wolf Creek test well 1	69°23'11"N	153°31'15"W	712	714	Apr. 29, 1951	June 4, 1951	1,500	Junked and abandoned	47	17- ?	5	--	--	--	--	--	10	455	1,350	--	--	--	--	--	--	--	--	--
Wolf Creek test well 2	69°24'17"N	153°31'15"W	437	443	June 6, 1951	July 1, 1951	1,618	Dry and abandoned	32	23- ?	5	--	--	--	--	45	130	650	1,550	--	--	--	--	--	--	--	--	--
Wolf Creek test well 3	69°23'11"N	153°31'25"W	732	750	Aug. 20, 1952	Nov. 3, 1952	3,760	Dry and abandoned	792	717- ?	18	--	--	--	--	--	30	500	1,400	2,760	--	--	--	--	--	--	--	--
						Total footage drilled =	174,360	Total footage cored =	30,949-6	23,321- 3?	= Total footage recovered																	

1/ From mean sea level

2/ Or derrick floor

3/ Kogosukruk Tongue of Prince Creek Formation, 9 to 469 and 840 to 949 feet; Sentinel Hill Member of Schrader Bluff Formation 469 to 840 and 949 to 1,180 feet

4/ In Seabee Formation in first sample at 200 feet

5/ Ninuluk-Seabee undifferentiated

6/ Repeated by thrust faulting

7/ Lower Jurassic only

FIGURE 2. CHART GIVING LOCATIONS, FORMATION TOPS, AND OTHER PERTINENT DATA ON THE TEST WELLS AND CORE TESTS OF NORTHERN ALASKA.

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ERA	SYSTEM	SERIES	EUROPEAN STAGE	GROUP	FORMATION	DESCRIPTION
CENOZOIC	QUATERNARY				RECENT AND GUBIK	Mantle, mostly marine, of unconsolidated olive gray sand, clay, and some gravel. Sand grains characteristically well rounded and composed of varicolored quartz, chert and hard rock fragments. Pelecypods, gastropoda, Foraminifera, and Ostracoda. 0 - 75 feet.
MESOZOIC	CRETACEOUS	UPPER	CAMPANIAN	COLVILLE	PRINCE CREEK; SCHRADER BLUFF	KOGOSUKRUK TONGUE Nonmarine light gray, olive gray, and dark gray claystone and clay shale, 25 percent light gray bentonitic siltstone and sandstone. Bentonite beds common. Coal and clay ironstone rare. 0 - 580 feet. SENTINEL HILL MEMBER Light gray clay shale and very fine to medium grained sandstone, volcanic glass shards and bentonite common. Pelecypoda, Foraminifera, Radiolaria present. 0 - 600 feet.
			SANTONIAN			TULUVAK TONGUE Nonmarine light- to medium light gray, very fine to coarse grained, "salt and pepper" sandstone and siltstone, rare conglomeratic layers, 12 percent medium light- to medium gray clay shale. Soft, light colored bentonite, thin coal beds, and brownish clay ironstone lenses common. Plant fossils. Major gas producing horizon in Gubik wells. 0 - 870 feet. BARROW TRAIL MEMBER Very light to light gray bentonitic sandstone and siltstone, and medium gray clay shale. Fossils rare. 0 - 395 feet.
			CONIACIAN			ROGERS CREEK MEMBER Medium light to medium gray marine clay shale, light colored tuff abundant. Rare Foraminifera and Radiolaria. Inoceramus lundbreckensis. 0 - 590 ft.
			TURONIAN		SEABEE	Predominantly medium- to medium dark gray marine clay shale, some silty "dirty" light gray sandstone near top and bottom of formation. Light colored bentonite common, rare thin beds of limestone. Radiolaria, some Foraminifera, fish fragments, Inoceramus labiatus, Borissiakoceras. 0 - 1,200 to 1,500 feet.
			CENOMANIAN	NANUSHUK	NINULUK	Medium light gray clay shale 60 percent and light gray very fine to medium grained sandstone and siltstone 40 percent, small amount of coal and bentonite. Rare brackish water microfossils, Inoceramus. Oil in Seabee-Ninuluk undifferentiated at Simpson Seeps. 0 - 550 feet.
		LOWER	ALBIAN UPPER		CHANDLER	KILLIK TONGUE Medium gray clay shale with interbeds of sandstone and siltstone, nonmarine; common thin to thick coal beds; clay ironstone common. Charophytes and plant fragments present. Gas in Chandler-Ninuluk undifferentiated at Gubik. Niakogon Tongue of Chandler not recognized in subsurface. 0 - 4,600 feet.
					GRANDSTAND	Massive, medium light gray, medium to fine grained marine sandstone with interbedded clay shale and rare siltstone; thin coal beds very rare. Sand composed of white and clear subangular to subrounded quartz grains, some chert and dark rock fragments. Same fossil assemblage as in Topagoruk Formation. Oil at Umiat, small amount of gas in several areas. 0 - 2,965 feet.
			MIDDLE		TOPAGORUK	Medium to medium dark gray marine clay shale and siltstone. Thin sandstone beds in upper part. Fossils very rare at base, increasing to abundant Verneuilinoides borealis microfauna and common megafossils including Inoceramus and other pelecypods, Ditrupa, ammonites and crinoids. Oil at Fish Creek? 0 - 4,000 feet.
			? LOWER		? OUMALIK ? ?	? ? ? ? ? ? Upper section--beds of monotonous medium to dark gray clay shale with a very few thin beds of siltstone. Microfossils very rare. 0 - 4,400 ft. Lower section--medium to dark gray clay shale, up to 40 percent medium light to medium gray siltstone and very fine to fine grained sandstone. Some crossbedding and ripple marks. Shows of gas at Oumalik. Pyritic Lithocampe? sp. and a few arenaceous Foraminifera. 0 - 1,600 feet.
					"PEBBLE SHALE"	Lithology as below. Thin, basal conglomerate in the Barrow area. Astarte ignekensis, Foraminifera. 310 - 850 feet.
			APTIAN			
			BARREMIAN			
			HAUTERIVIAN			
			VALANGINIAN		"PEBBLE SHALE"	Lithology as below, plus a few very thin beds of medium dark olive gray siliceous siltstone. Buchia sublaevis. 0 - 500 feet plus or minus.
			BERRIASIAN			
	JURASSIC	UPPER	PORTLANDIAN			
			KIMMERIDGIAN		"PEBBLE SHALE"	Grayish black pyritic claystone, very well rounded clear quartz and dark chert grains of fine sand to granule size embedded individually or in small groups in the claystone. Abundant Foraminifera. 910 feet.
			OXFORDIAN			
			CALLOVIAN			
		MIDDLE	BATHONIAN			
			BAJOCIAN			Medium dark gray pyritic micaceous clay shale. Tmetoceras sp.
		LOWER	TOARCIAN			Medium dark gray claystone and some siltstone. Dactylioceras sp.
			PLIENSBACHIAN		KINGAK?	Medium to medium dark gray silty claystone, micaceous, slightly carbonaceous, abundant nodules and vermicular streaks of pyrite. Amaltheus sp., Foraminifera. 0 - 990 feet.
			SINEMURIAN			Olive gray, silty sandstone mottled by medium dark gray clay shale, glauconite common. "Arietites" sp.
			HETTANGIAN			Reddish brown clay shale, thin beds of bentonite, Foraminifera.
	TRIASSIC	UPPER	RHAETIC			
			NORIAN		SHUBLIK?	Glauconitic clay shale and siltstone with some limestone. Limonite oolite beds and thin coquina at Barrow. Halobia, Monotis common. Foraminifera abundant except at Barrow. 189 - 550 (740?) feet.
			KARNIAN			
		MIDDLE				
		LOWER				
PALEOZOIC	PERMIAN					Light gray siliceous sandstone, some siltstone and claystone, 15-foot chert conglomerate near middle of section. Rare Lingula and coelocanth fish teeth. 390 feet.
	?				"RED BEDS"	Red claystone, siltstone, sandstone and rare conglomerate, unfossiliferous. 270 feet.
	DEVONIAN	MIDDLE OR LOWER				Alternating chert conglomerate and black shale. Psilophyton and other land plants. 300 feet penetrated.
?					"ARGILLITES"	Black argillite interbedded with siliceous dolomite in the Barrow area, fossiliferous (?), 1,000 feet penetrated. Green and red argillite in the Simpson area, unfossiliferous, 100 feet penetrated.

Figure 3. Stratigraphic chart giving a brief description of all formations found in the subsurface of Naval Petroleum Reserve No. 4 and their European stage equivalents.

Note: Thicknesses are those found in test wells or core tests.

PLATE 10B

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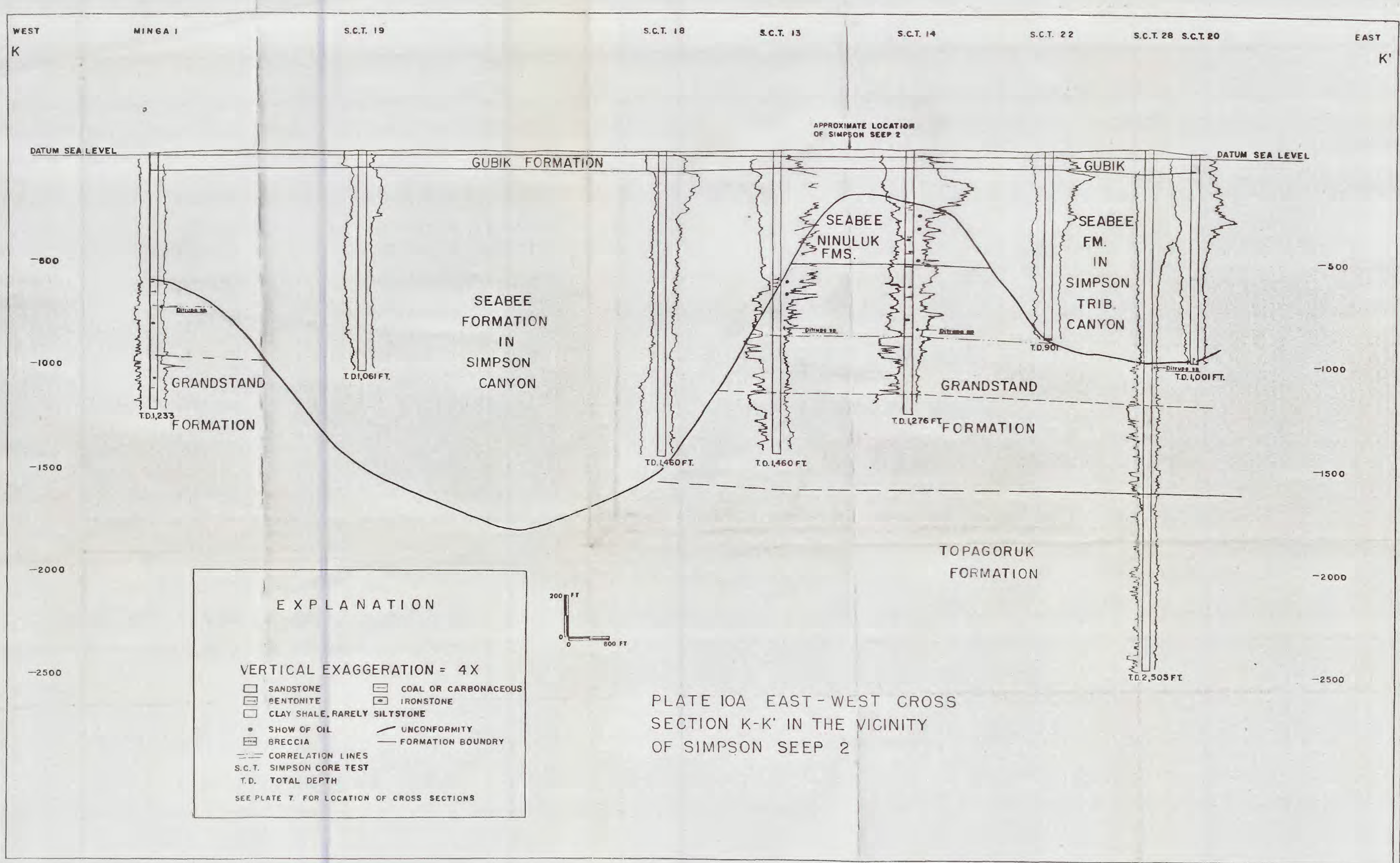

PLATE 10A EAST-WEST CROSS SECTION K-K' IN THE VICINITY OF SIMPSON SEEP 2

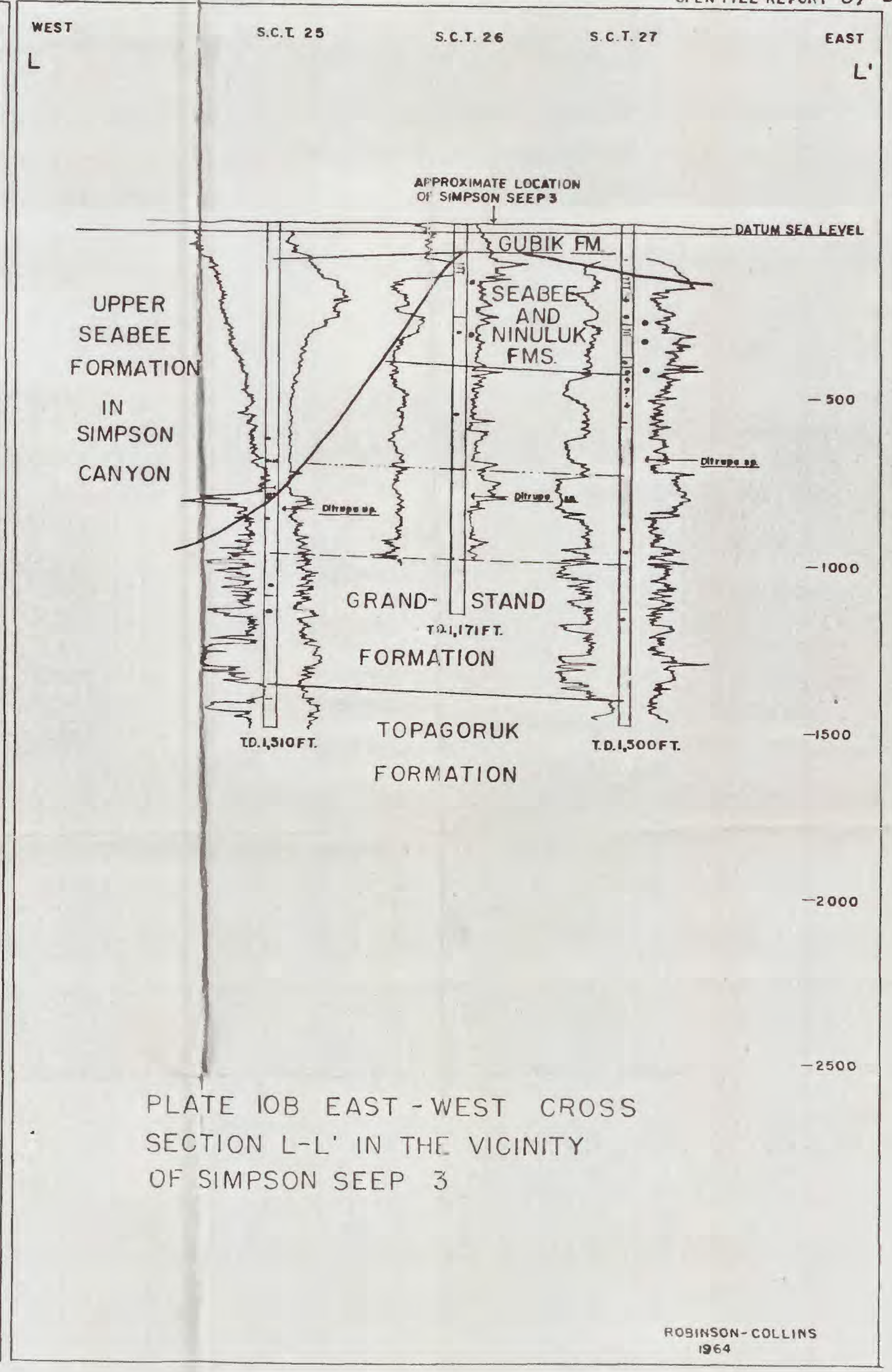

PLATE 10B EAST-WEST CROSS SECTION L-L' IN THE VICINITY OF SIMPSON SEEP 3

ROBINSON-COLLINS
1964

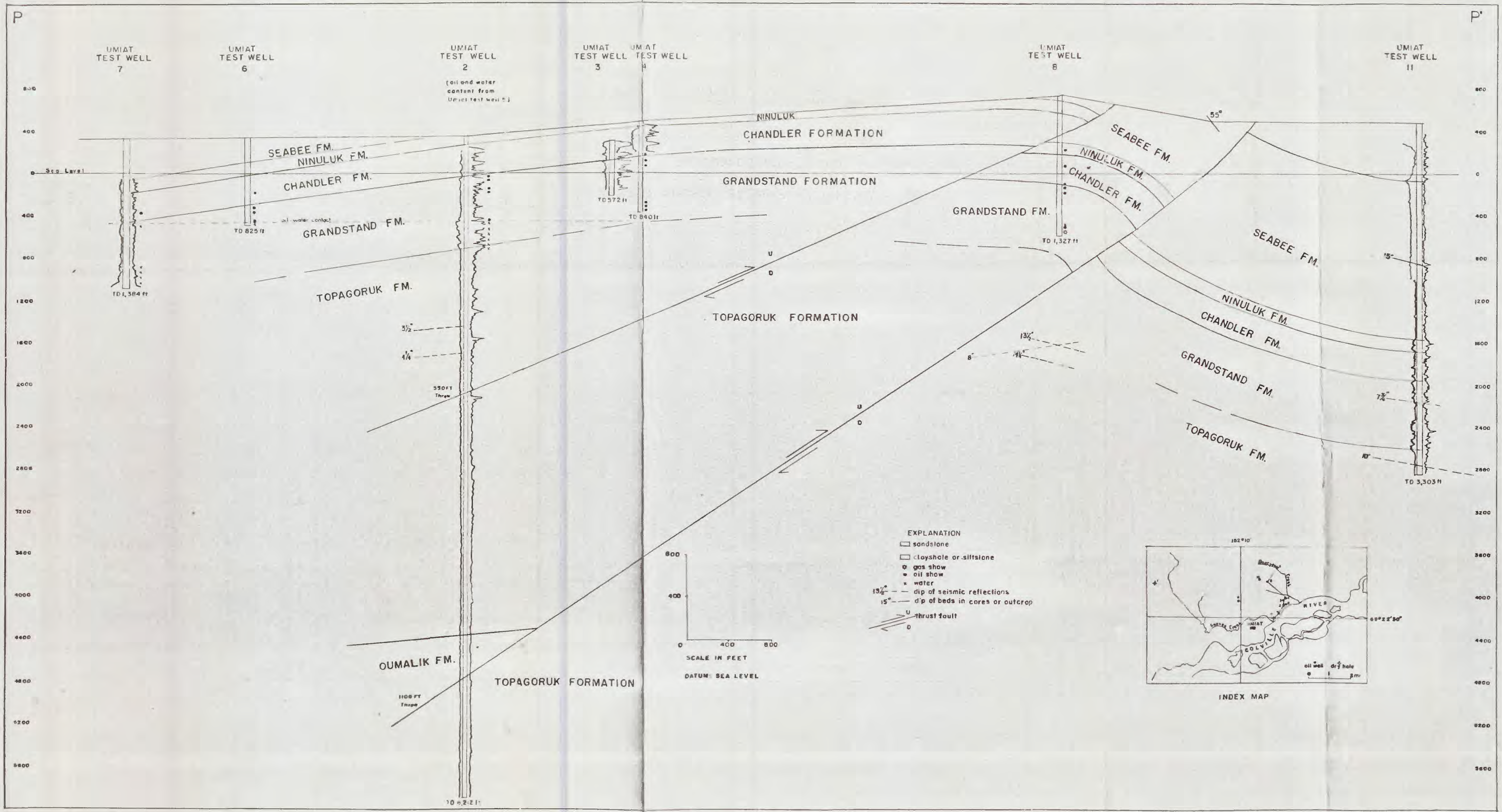

PLATE II. North-south cross section P-P' of the Umiat anticline

Robinson–Collins

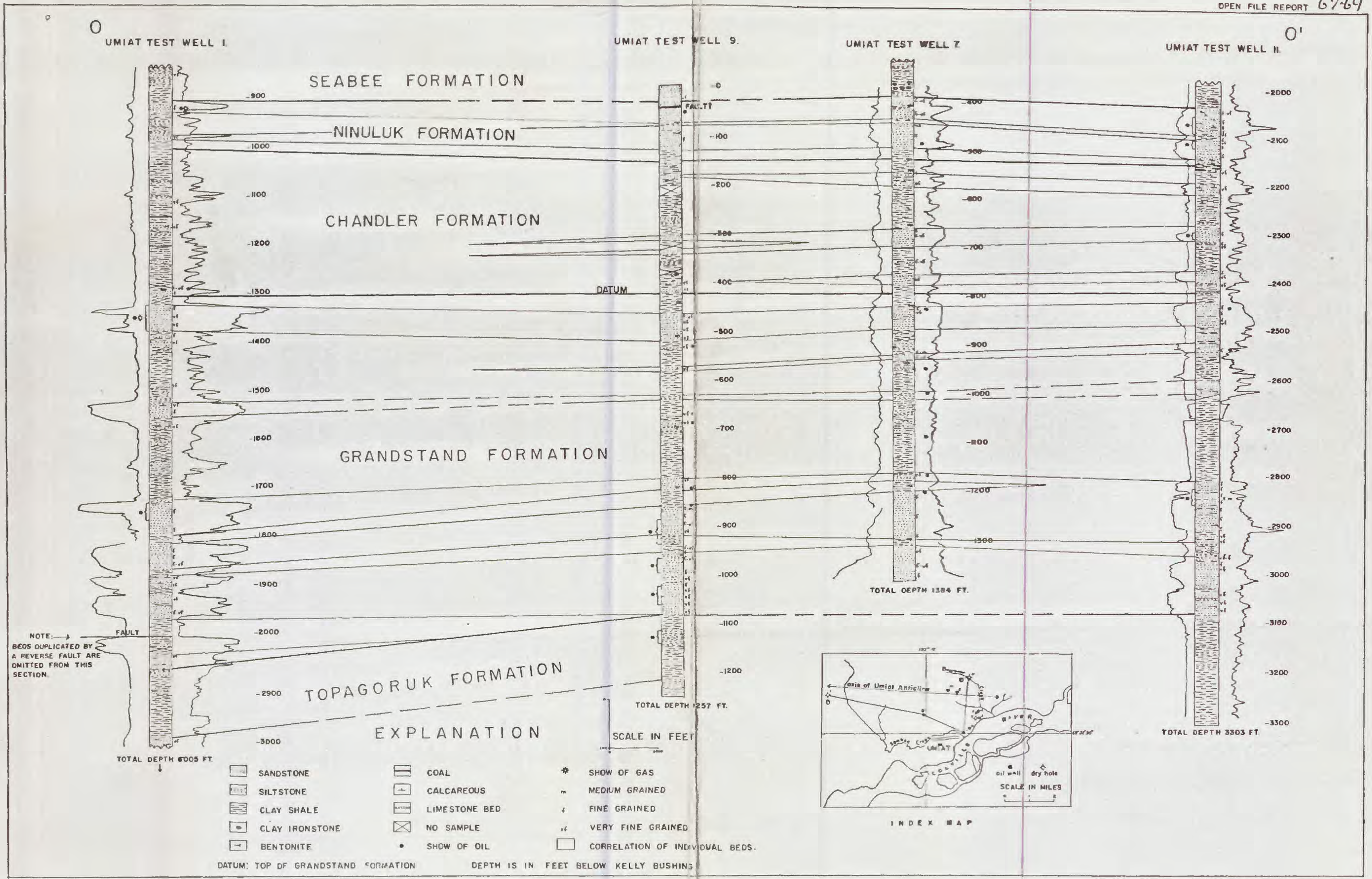

PLATE 12. LITHOLOGIC AND ELECTRIC LOG CORRELATION ALONG O-O' SHOWING CHANGES IN SANDSTONE AND SHALE BEDS IN NANUSHUK GROUP ROCKS, UMIAT OIL FIELD.

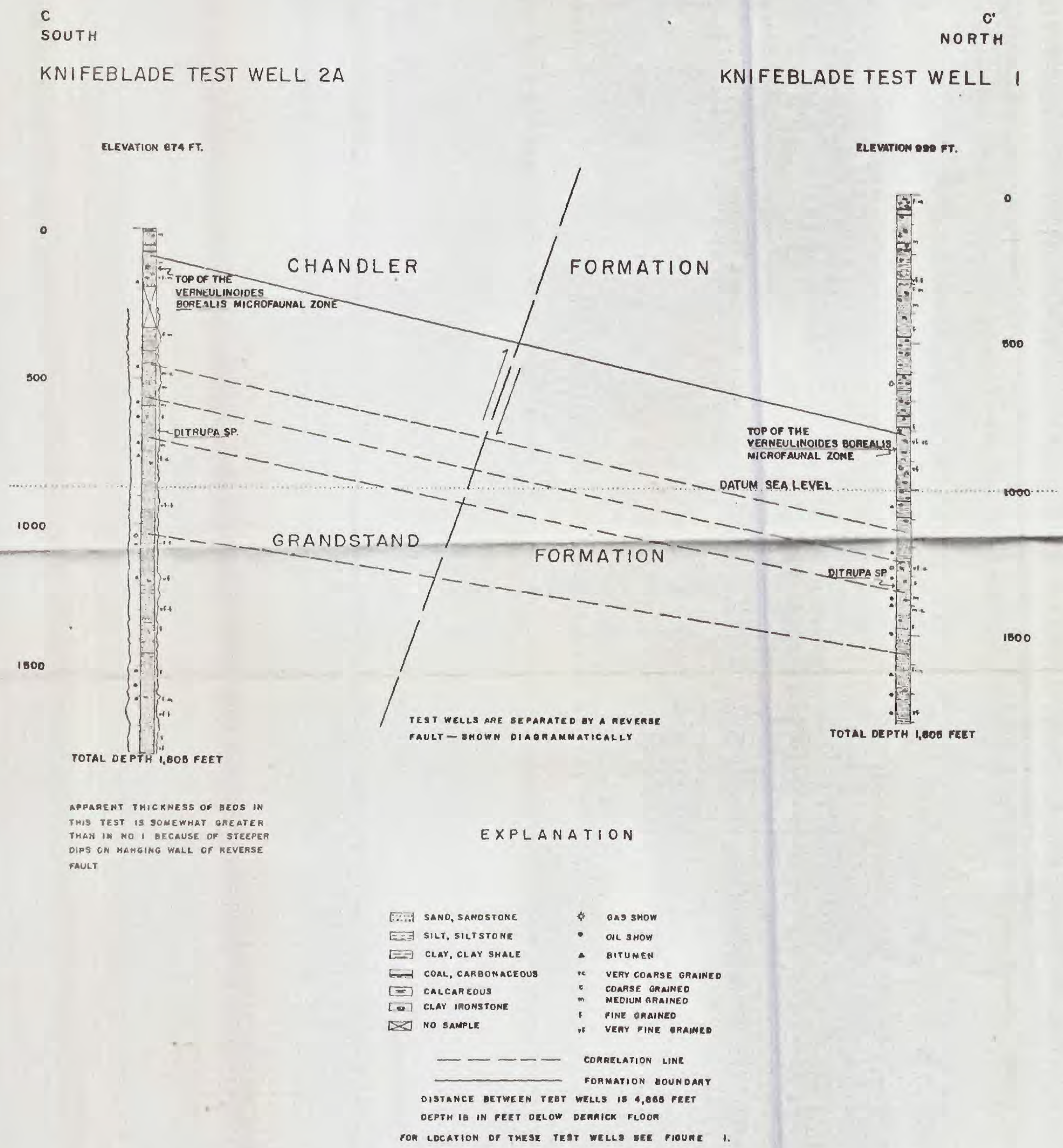

PLATE 13. Lithologic and paleontologic correlation of Knifeblade test well 1 and 2A.

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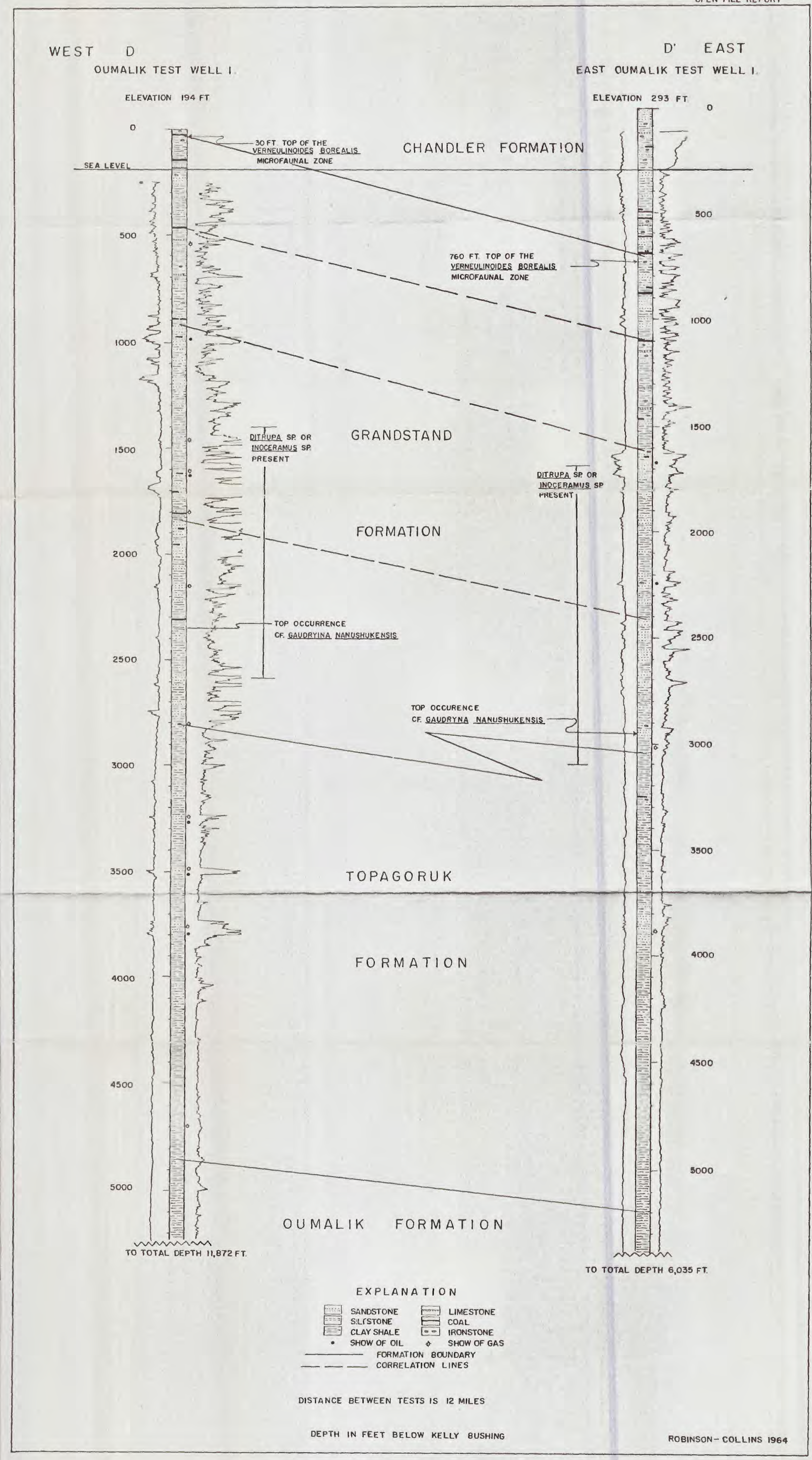

PLATE 14. ELECTRIC LOG, LITHOLOGIC AND PALEONTOLOGIC CORRELATION OF OUMALIK TEST WELL I. WITH EAST OUMALIK TEST WELL I.

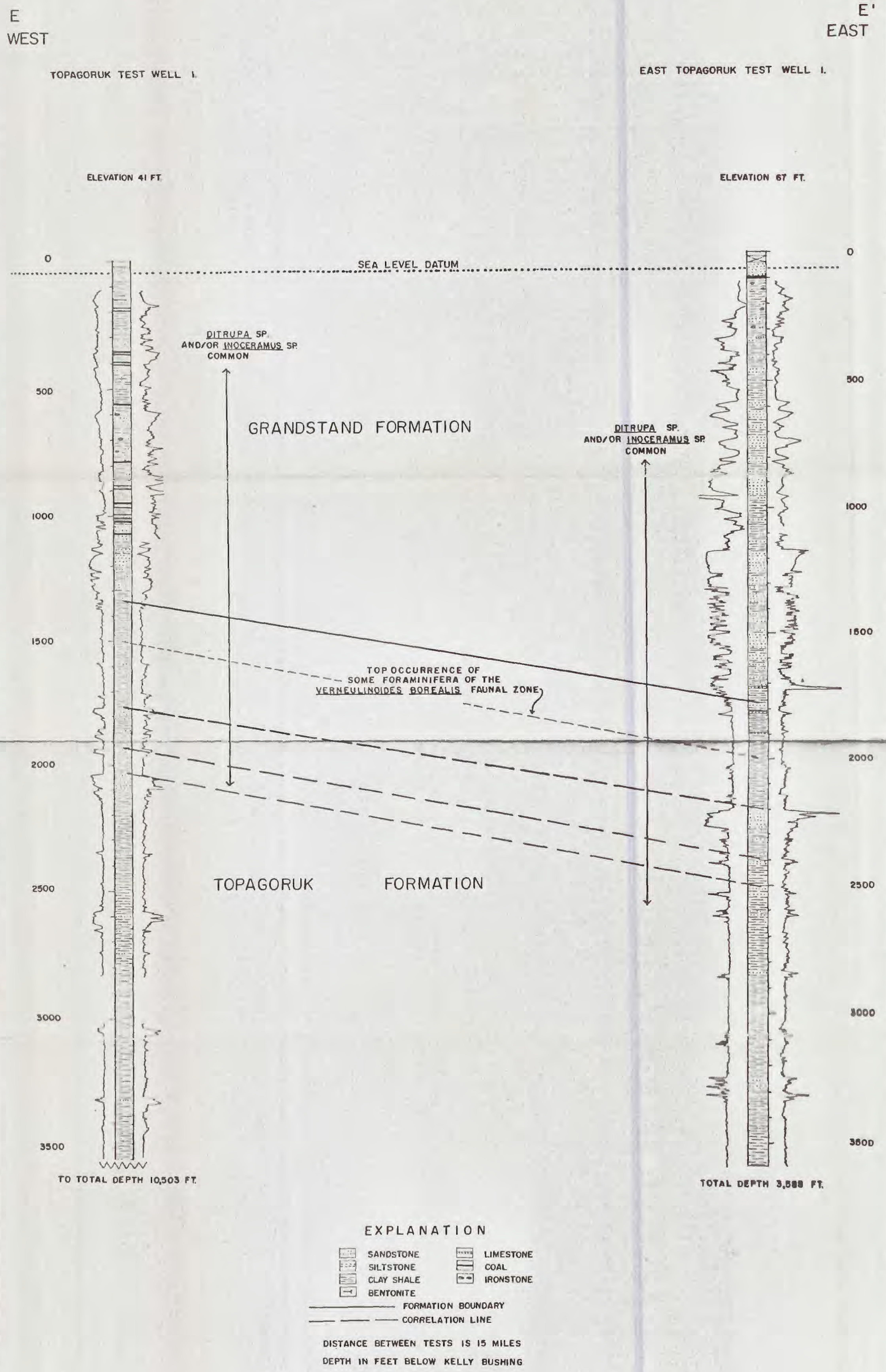

PLATE 15. ELECTRIC LOG, LITHOLOGIC, AND PALEONTOLIC CORRELATION OF TOPAGORUK AND EAST TOPAGORUK TEST WELLS.

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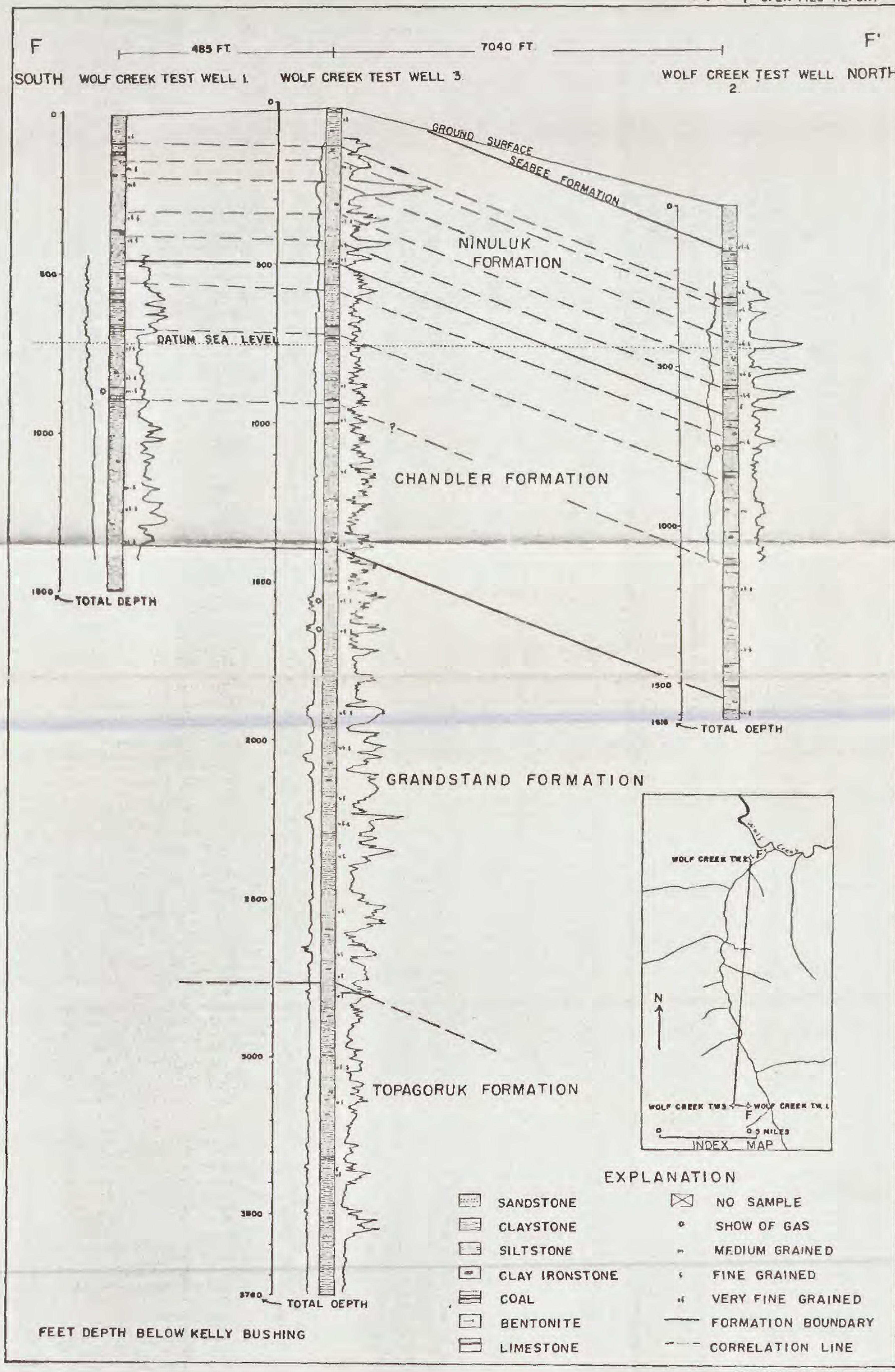

PLATE 16 LITHOLOGIC AND ELECTRIC LOG CORRELATION OF WOLF CREEK TEST WELLS

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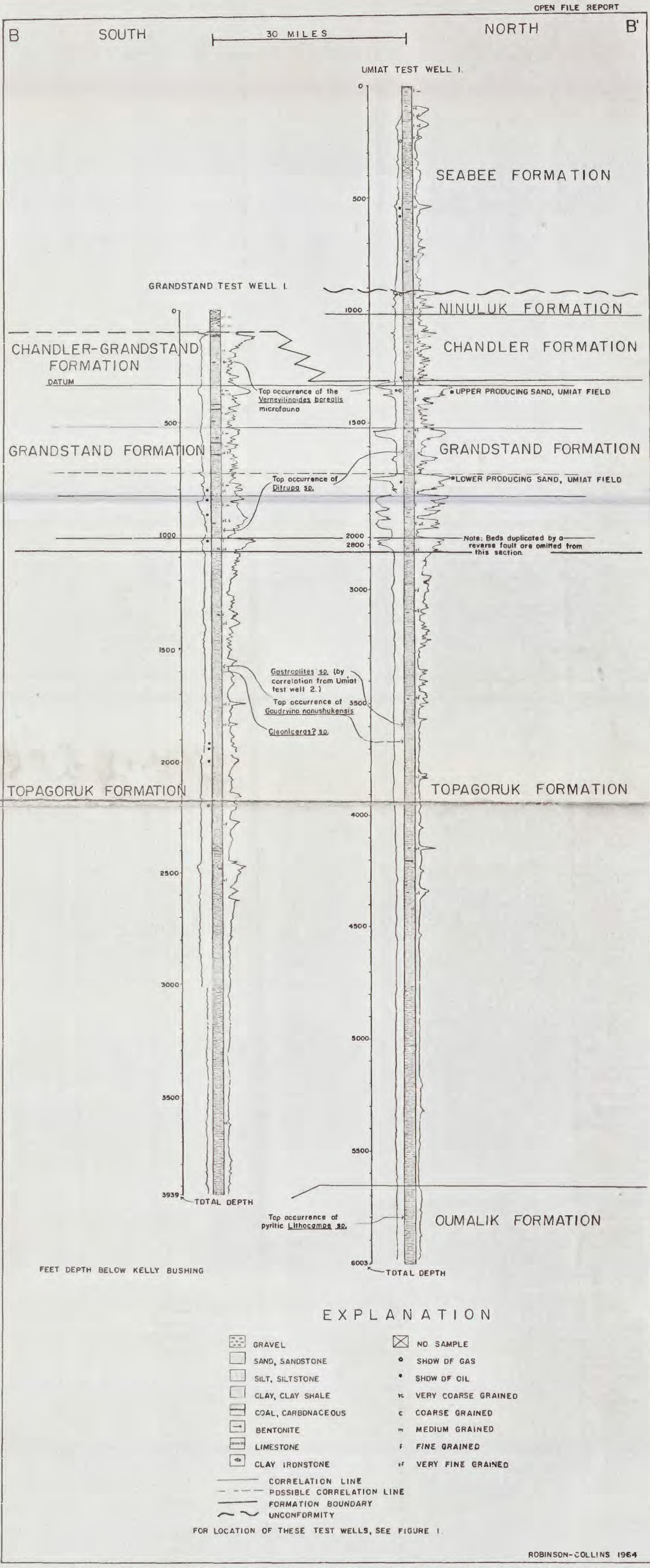

PLATE 2. COMPARISON OF THE SUBSURFACE STRATIGRAPHY IN THE GRANDSTAND AND UMIAT AREAS. ELECTRIC LOG, LITHOLOGIC AND PALEONTOLOGIC CORRELATION OF GRANDSTAND TEST WELL 1. AND UMIAT TEST WELL 1.

Pl 4

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PLATE 4. NORTHEAST-SOUTHWEST CROSS SECTION H-H', SHOWING SUBSURFACE CORRELATIONS AND REGIONAL STRUCTURE IN NAVAL PETROLEUM RESERVE NO. 4.

Note: Shape of basin northeast of Square Lake test well I based on seismic data.

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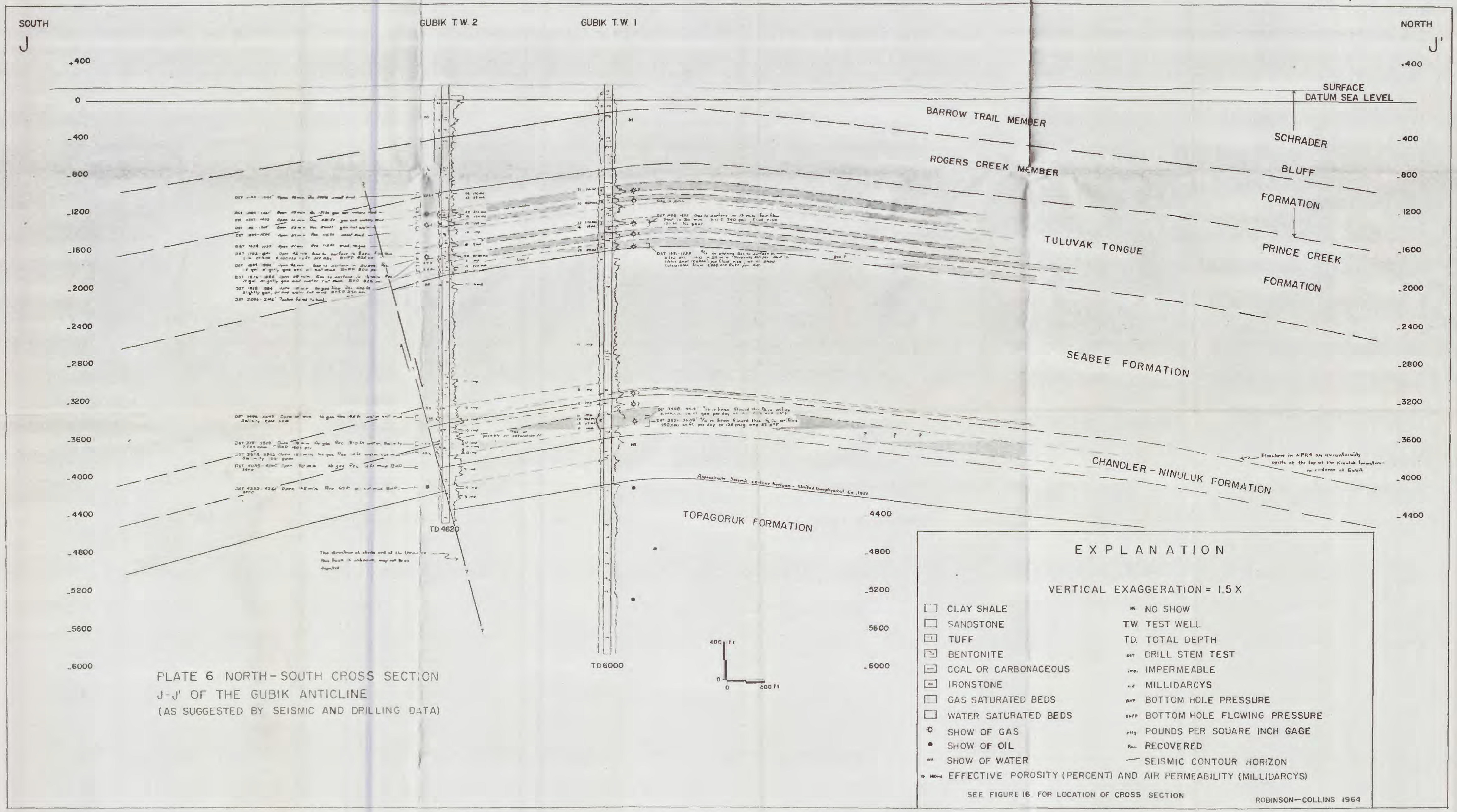
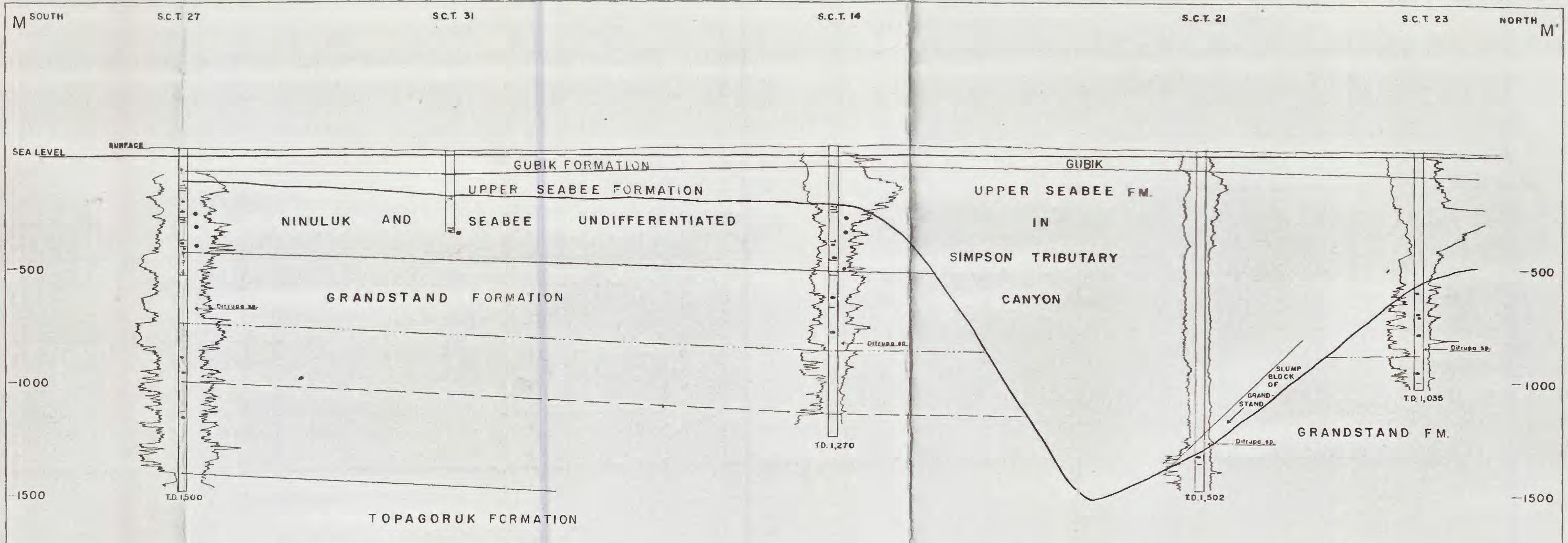


PLATE 6 NORTH-SOUTH CROSS SECTION J-J' OF THE GUBIK ANTICLINE (AS SUGGESTED BY SEISMIC AND DRILLING DATA)

PLATE 8. NORTH-SOUTH CROSS SECTION N-N' WEST SIMPSON AREA



EXPLANATION

VERTICAL EXAGGERATION = 6.6X

- SANDSTONE
- BENTONITE
- COAL OR CARBONACEOUS
- IRONSTONE
- • SHOW OF OIL
- CLAY SHALE, RARELY SILTSTONE
- FORMATION BOUNDRY
- UNCONFORMITY
- CORRELATION LINES
- SCT SIMPSON CORE TEST
- T.D. TOTAL DEPTH

SEE PLATE 7. FOR LOCATION OF CROSS SECTION

PLATE 9. NORTH-SOUTH CROSS SECTION M-M' SHOWING STRUCTURAL AND STRATIGRAPHIC FEATURES OF THE SIMPSON SEEPS AREA

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Table 2. Summary of porosity, permeability, and production data from the Umiat test wells

Well	Stratigraphic unit	Depth relative to sea level (in feet)	Porosity (percent)	Permeability (millidarcys)	Production data	Remarks
Umiat test well 1 elev. 810 ft. rotary rig water base mud	Ninuluk	-105 to -200	20	87.5	Trace of oil near top	Hole left open between +125 and -1,006 ft. from Sept. 19, 1945 to June 2, 1946. Ice filled hole from +35 to -110 ft., and 44 gallons of oil were bailed from the top of the ice. Hole abandoned at -5,195 ft.
	Killik	-200 to -499 -1,200 to -1,275 1/	8.6	<5	--	
	Grandstand 2/ upper sandstone	-508 to -570	9.5-20	0.09-27.8	Gas odor; good oil saturation in some cores	
		-1,290 to -1,340	--	--	--	
	middle sandstone 3/	-715 to -750	--	--	--	
		-1,490 to -1,545	10.3-19.6	>1-5.2	Oil and gas odor, good saturation in some cores	
	lower sandstone	-926 to -1,163	7.7-21.9	>4-62.6	Oil odor, fair saturation in some cores	
		-1,690 to -2,030	6.2-23.8	>1-12.3	Oil odor, streaky saturation in some cores	
Umiat test well 2 elev. 342 ft. rotary rig water base mud	Killik	+262 to -23	13.3-17	20-72	Bailed very slight show oil and gas	
	Grandstand upper sandstone	-50 to -160	8.2-18.4	10-270	Bailed and swabbed mud and fresh and brackish water with a skim of oil	Casing set at -663 ft. after bailing and swabbing; hole abandoned at -5,840 ft.
	lower sandstone	-455 to -720	9.1-19.3	3.5-187		
Umiat test well 3 elev. 360 ft. rotary rig water base mud	Killik	+300 to +135	--	--	--	
	Grandstand upper sandstone	+110 to -60	7.1-17.0	7.4-48	Bailed 49 bbl. oil in 24 hrs.; pumped intermittently for 12 days, recovered average 14 bbl. oil per day. Shot hole with dynamite, then pumped estimated 34 bbl. oil per day	Hole open below +288 ft. Hole frozen below -100 ft. after bailing tests. Shut in at total depth of -212 ft.
Umiat test well 4 elev. 483 ft. cable tool rig	Killik	+440 to +163	10.3	0	Strong odor, good show oil	Hole open below +440 ft. Ice in hole during bailing test; base permafrost est. -400 ft. from thermistor data. Well shut in; total depth -357 ft.
	Grandstand upper sandstone	+130 to +10	--	--	15-min. bailing test, +450 to +129.5 ft. produced slightly gas cut oil at rate of 200 bbl. per day	
	lower sandstone	-230 to -390	0.8-10.3	0	Pumping test +450 to -357 ft. indicated production rate 90-100 bbl. per day with no decline	
Umiat test well 5 elev. 335 ft. cable tool rig	Killik	+275 to 0	9.25-16.6	2.0-95	Slight show oil and gas	
	Grandstand upper sandstone	-30 to -175	12.2-12.4	13-44	Pumping test, +303 to -180 ft., average 70 bbl. oil per day	
	lower sandstone	-400 to -725	17.64	78	Water first encountered at -465 ft. 93 day pumping test, +303 to -742 ft., pumped over 400 bbl. per day, declining to 150 bbl. per day. Water content decreased from 1.35 to 0.4 percent in first 1 1/2 weeks. Pump too small to handle full capacity of well: decline result of icing (?)	Ice caused pump to stick at least once. Flow line temperature 27-28°F. Casing set to -733 ft. just before shutting well in with total depth of -742 ft.
Umiat test well 6 elev. 337 ft. cable tool rig	Killik	-13 to -293	3.35-14.35	0	Bailed 25 gal. oil every 2 hrs for 6 hrs.	
	Grandstand upper sandstone	-320 to -467	8.5-9.45	0	Oil in all sandstone beds; water first noted in hole at total depth (-488 ft.); plug to -463 ft. did not shut it off, as 28.5 bbl. oil and 11 bbl. water were pumped from above it in 13 hrs. Tubing was filled with mushy ice after test. Small amount gas to well head during tests. Plug to -446 ft. did not completely shut off water	Base of permafrost about -430 ft. Unusual temperatures in Killik and Grandstand Formations, measured with thermistors, suggest fluid flow from Umiat test well 5 toward Umiat test well 6 and imply presence of unfrozen beds with temperatures below 0°C. within the permafrost zone in Umiat test well 6. Fish in the hole, and caving, cause abandonment at -488 ft., before reaching lower sandstone bed.
Umiat test well 7 elev. 330 ft. cable tool rig	Ninuluk	-60 to -185	--	--	Slight show of oil	
	Killik	-185 to -465	--	--	At -200 ft., bailed very little oil. At -320 ft., bailed 20 gal. oil; 2 hrs. later, bailed 8 gal. water	
	Grandstand upper sandstone	-493 to -620	13.8	1	Slight oil shows in cores; at -503 ft., 70 gal. water and oil entered hole in 1 3/4 hrs. Water with a trace of oil entered hole below -508 ft.	Casing set at -865 ft., (bottom of hole, -905 ft.), did not shut off water, which continued to enter until the hole was abandoned at -1,054 ft. Ice formed intermittently in the hole between +230 and -500 ft., most commonly in the upper part.
	lower sandstone	-870 to -1,051	9.7-11.2	0-19.2	Brackish water entered hole while drilling and bailing, in spite of attempts to plug the hole and shut it off; flow of water increased at -920 ft.	
Umiat test well 8 elev. 740 ft. cable tool rig	Ninuluk	+680 to +570	9.74	18.85	Slight show oil	
		+295 to +185	--	--	Slight show oil	
	Killik	+570 to +390	--	--	Slight odor oil	
		+185 to -100	--	--	--	
	Grandstand upper sandstone	-125 to -195	--	--	Pumped est. 60 bbl. oil, no water, per day	Icing, wax, and mechanical trouble reduced flow of fluids; production capacity possibly greater than these figures indicate. Gas, with no oil or water, was produced after casing was set at -491 ft. Well shut in with total depth -587 ft.
	lower sandstone	-503 to -587	--	--	Flowed 5,858,700 cu. ft. gas per day, 1 1/2-in. orifice	
Umiat test well 9 elev. 424 ft. rotary rig oil base mud	Ninuluk	+418 to +260	--	--	Slight oil odor	
	Killik	+260 to 0	--	--	--	
	Grandstand upper sandstone	-50 to -168	2.61-20	0-130	Shows of gas noted in sandstone beds. Swabbing test while drilling recovered no oil; oil was first produced when the total depth (-833 ft.) was reached and hole was swabbed through tubing. Pumping test recovered average 217 bbl. gas-cut oil	After pumping test, well was plugged back by stages to -555 ft. but oil continued to enter hole. The plug was drilled out and casing set to total depth, -833 ft. Perforations at intervals between -42? and -833 ft. produced no oil. Thin ice lenses formed in the hole after perforating.
	middle sandstone	-255 to -285	--	--		
	lower sandstone	-385 to -677	7.59-18.8	0.13-320		
Umiat test well 10 elev. 746 ft. cable tool rig	Ninuluk	+101 to -19	--	--	Bailed 4 bbl. oil per hr. for 22 hrs.	Hole was open below +676 ft. Hole produced a show of oil after casing was set at -593 ft. Hole abandoned at -827 ft. because of caving shale.
	Killik	-19 to -279	--	--	At -234 ft. bailed 183 bbl. oil in 34 hrs.	
	Grandstand upper sandstone	-308 to -390	--	--	Bailed estimated rate 153 bbl. oil per day	
Umiat test well 11 elev. 481 rotary rig oil emulsion mud	Ninuluk	-1,559 to -1,679	7.39-15.65	0-56	Formation tests recovered brackish water and drilling mud	Hole was open below -5 ft.
	Killik	-1,679 to -1,939	5.76-19.80	0-550	Formation test recovered brackish water	
	Grandstand upper sandstone	-1,960 to -2,145	14.83-17.60	18-235	Formation test recovered brackish water	
	lower sandstone	-2,320 to -2,594	10.2-19.25	0-400	Formation tests recovered brackish water	

1/ Two intervals representing one stratigraphic unit are the result of thrust faults which duplicate beds.

2/ Each interval includes shale beds between sandstone layers, and some thin sandstone beds just above or below the strata defined as the upper and lower sandstone beds (see p. 212).

3/ The middle sandstone is present only in Umiat test well 1; in Umiat test well 9, it is represented by thin, silty beds, and is completely absent elsewhere.