Geology of Possible Petroleum Provinces in Alaska

GEOLOGICAL SURVEY BULLETIN 1094

Geology of Possible Petroleum Provinces in Alaska

By DON J. MILLER, THOMAS G. PAYNE, *and* GEORGE GRYC
With an annotated bibliography by EDWARD H. COBB

GEOLOGICAL SURVEY BULLETIN 1094

A summary of possible sources of petroleum in Alaska, with an annotated bibliography on petroleum and oil shale in Alaska and a map of Mesozoic and Cenozoic tectonic elements

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

Miller, Don John, 1919–

Geology of possible petroleum provinces in Alaska, by Don J. Miller, Thomas G. Payne, and George Gryc, with an annotated bibliography by Edward H. Cobb. Washington, U. S. Govt. Print. Off., 1959.

v, 132, p. illus., maps (part col.) diagrs., tables. 25 cm. (U. S. Geological Survey. Bulletin 1094)

Part of illustrative matter in pocket.

A summary of possible sources of petroleum in Alaska, with an annotated bibliography on petroleum and oil shale in Alaska and a map of Mesozoic and Cenozoic tectonic elements.

Bibliography: p. 113–127.

1. Geology — Alaska. 2. Petroleum — Alaska. 3. Petroleum — Alaska—Bibl. (Series)

[QE75.B9 no. 1094] G S 59–239

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. - Price $2 (paper cover)

CONTENTS

ILLUSTRATIONS

[Plates in map volume]

TABLES

GEOLOGY OF POSSIBLE PETROLEUM PROVINCES IN ALASKA

By Don J. Miller, Thomas G. Payne, and George Gryc

ABSTRACT

Alaska is divided into southern, central, and northern major geologic-physiographic regions for the purpose of appraising its petroleum possibilities.

Southern Alaska, an area of 185,000 square miles, includes the arcuate mountain chain formed by the Alaska and Aleutian Ranges and the Mentasta-Nutzotin Mountains, the coastal range-and-valley area to the south, and the southeastern Alaska "panhandle."

Oil seeps on the west shore of Cook Inlet in southern Alaska were known as early as 1853, and claims were staked in this region in 1882. Drilling began near the oil seeps in the Katalla district about 1901, and this started Alaska's first oil "boom." From 1902 to 1933 the Katalla field produced 154,000 barrels of oil from fractured shale and sandstone of Tertiary age—the first and only commercial production in Alaska.

On the basis of geology, surficial indications of petroleum, and test wells drilled, six possible petroleum provinces are indicated in southern Alaska. They are the Heceta Island area, Keku Islands area, Cook Inlet Mesozoic province, Gulf of Alaska Tertiary province, Cook Inlet Tertiary province, and the Copper River basin.

The exposed rocks in the Heceta Island area include early Paleozoic graywacke-type sandstone, sandstone, conglomerate, and massive limestone with reeflike structures; igneous rocks are rare or lacking in much of the area. The Kosciusko-Tuxekan-Heceta synclinorium, the main structural feature, is modified by minor folds and faults. Some of the minor folds are reported to be broad and open, with flanks dipping 20°–45°. As far as is known, the Heceta Island area has not heretofore been seriously considered as a possible petroleum province.

Rocks of Silurian to Cretaceous age are exposed in the Keku Island area and include moderately folded and relatively unaltered limestone and other marine sedimentary rocks.

The Cook Inlet Mesozoic province, a land area of approximately 18,500 square miles, includes a great thickness of unmetamorphosed marine sedimentary rocks of Jurassic and Cretaceous age. At least 23 test wells were drilled or started in this province by the end of 1955. Shows of oil and gas were found in many of these wells. During 1955 at least 10 oil companies were active in this area and by the end of 1955 about 1½ million acres was included in oil and gas leases applied for or granted.

The Gulf of Alaska Tertiary province includes about 5,200 square miles in which rocks of Tertiary age are exposed or are believed to underlie Quaternary deposits. Between 1901 and the end of 1955 about 47 wells were drilled or started in this province.

The Cook Inlet Tertiary embraces an area of about 9,500 square miles, of which about 4,100 is covered by the shallow water of Cook Inlet. Petroleum

exploration has been in that part of the area which overlaps the Cook Inlet Mesozoic province. Eocene or younger Tertiary nonmarine sedimentary rocks are believed to underlie much of the province, and marine rocks of Tertiary age may also be present.

The Copper River basin is a topographic basin underlain by unconsolidated deposits of Quaternary age. Tertiary rocks favorable for the accumulation of petroleum may underlie part of the basin but this is not believed likely. Except for some leasing activity no petroleum exploration had been recorded in the Copper River Basin to the end of 1955.

Central Alaska is a region of about 275,000 square miles and consists of an irregular assemblage of intricately dissected uplands and alluvium-floored lowland basins. Scattered peaks of resistant intrusive igneous rocks surmount most of the upland areas.

In the vast region of central Alaska only six test wells are known to have been drilled for the purpose of finding oil and gas. The maximum depth reached was 350 feet and the holes were mostly or entirely in Quaternary deposits. In recent years several oil companies have investigated some parts of the region, and large areas in the Yukon-Koyukuk province are now under lease. Oil seeps, gas seeps, and other indications of petroleum have been reported from many localities; samples from two localities have been analyzed and reported to be petroliferous.

The geology of central Alaska is similar in a general way to that of the area between the Rocky Mountains and Sierra-Cascade belts of the United States. Sedimentary rocks, probably equivalent to the Precambrian Belt series, and rocks of the Cambrian and all younger geologic systems have been recognized in central Alaska. The structure of the region is known to be complex, but except in local mineral districts it has not been mapped in detail. On the basis of the limited amounts of available information, the region cannot be regarded as distinctly favorable for significant accumulations of petroleum. However, three pre-Cenozoic provinces, the Yukon-Koyukuk, the Kobuk, and the Kandik, and several large Cenozoic basin provinces may be worthy of further investigation.

Northern Alaska includes the Brooks Range and all the treeless tundra north to the Arctic coast, an area of about 125,000 square miles. The presence of oil seeps along the Arctic coast has been known at least since 1900, and a description of the Cape Simpson oil seeps was published in 1909. Since then, oil and gas seeps have been described from nine localities, and oil shale and oil-bearing sandstone are known from many localities in the Arctic foothills province. Geologic conditions are favorable for oil and gas accumulations in approximately half the region.

In 1923 approximately 37,000 square miles in northern Alaska was reserved by Executive order as Naval Petroleum Reserve No. 4 (NPR–4). In 1944 the U.S. Navy Department began a vast petroleum exploration program, which was suspended in 1953. In the years 1945 through 1955, 37 test wells and 45 core tests were drilled on 18 structures. Three oil fields, Umiat, Simpson, and Fish Creek, and two gas fields, South Barrow and Gubik, were discovered. Total reserve estimates for all discoveries of oil to 1955 range from 30 to 100 million barrels, and for gas, from 370 billion to 900 billion cubic feet.

All northern Alaska, with the exception of the Brooks Range, can be considered a possible petroleum province, but the region can be subdivided into provinces of somewhat different potentialities. These subdivisions roughly correspond with the geomorphic provinces and sections, which in turn reflect differences in geology. The known oil-bearing beds are of Mesozoic age, primarily Cretaceous, and thus the possible petroleum provinces could be designated as Mesozoic. However, Paleozoic and Cenozoic rocks with favorable reservoir characteristics are exposed in the region and possibly underlie, in favorable structural situations, some of the areas as yet not tested.

The Arctic coastal plain province includes gently folded and flat-lying Mesozoic strata that overlie a basement complex of Paleozoic and early Mesozoic age. Near the southern edge of this province the basement rocks are at depths of at least 20,000 feet, and to the north these rocks rise to within 2,500 feet of the surface.

The Teshukpuk Lake section of the Arctic coastal plain includes many of the known oil seeps; it is the most accessible to sea transportation, and lies almost completely within NPR-4. Thirteen test wells and 35 core tests have been drilled here; one gas field and two oil fields (at present, noncommercial) have been discovered. The possibility of further discoveries may depend largely on locating porous sandstone in stratigraphic rather than anticlinal traps.

The White Hills section is distinguished topographically from the Teshukpuk section by its white-gravel-covered hills and fewer lakes, and geologically by the presence of Tertiary rocks, including 2,000 feet of nonmarine beds in the west and at least 7,000 feet of marine beds to the east, in the vicinity of Carter Creek. This section appears to be more complex structurally. No test wells have been drilled in the White Hills section.

The northern foothills section includes many closed anticlines. Twenty-four test wells and 10 core tests have been drilled on 11 structures, and 2 discoveries have been made—the Umiat oil field and the Gubik gas field. All these tests have been drilled in Cretaceous rocks.

The southern foothills section is structurally similar to the Alberta foothills and to the northern part of the Brooks Range. Great thicknesses of marine shale of Early Cretaceous, Jurassic, and Triassic age are exposed. The outcropping Mesozoic sandstone is generally poorly sorted, nonporous, and impermeable. To the south the section is bordered by mountainous exposures of Mississippian limestone, which probably underlies at least part of this section.

The rocks that underlie the deeply eroded complex structures of the Brooks Range include schist, slate, argillite, and limestone. Some exposed limestone has a strong petroleumlike odor and contains traces of petroleum residues.

INTRODUCTION

In 1941 and again in 1951 the American Association of Petroleum Geologists sponsored symposia on possible future petroleum provinces of North America, to which members of the U.S. Geological Survey were invited to contribute appraisals of the potential petroleum resources of Alaska (Smith, 1941; Gryc, Miller, Payne, 1951). This report is an outgrowth of the paper contributed by the writers to the second symposium and of other papers presented orally at scientific meetings and published only in abstract (Payne and Gryc, 1951; Gryc and Jensen, 1953; Miller, 1953c). The current lively interest in petroleum in Alaska and the significant developments that have taken place in this field recently have made it desirable to revise and expand the symposium paper written in 1950 and to publish the data in a form more readily available to those interested specifically in the petroleum possibilities of Alaska.

This report was completed in essentially the present form early in 1957. An arbitrary cutoff date of January 1, 1956, was adopted for information included on petroleum developments and indications of petroleum, and for references included in the annotated bibliography. Minor revisions of the text and the tectonic map were made on the basis of geologic information obtained during the 1956 field season. The manuscript for this report was made available to the public in open file on July 31, 1957.

Petroleum was among the first of the useful minerals to be discovered in Alaska, but sporadic attempts to develop these resources have, at least until recently, been relatively unrewarding in value of petroleum produced or reserves indicated. Oil seeps on the west shore of Cook Inlet are said to have been known to the Russians as early as 1853. The seeps in the Katalla and Yakataga districts bordering the Gulf of Alaska became known to white explorers or prospectors about 1896, and those on the Arctic coast have been known at least since early 1900. Reports of the natives first drew the attention of the early explorers to the seeps at Cape Simpson and other localities on the Arctic slope, and it is likely that some of the conspicuous oil and gas seeps of the Pacific region also were known to the natives long before the discovery and settlement of Alaska by white men.

The earliest known effort to develop the petroleum resources of Alaska was the staking of claims in the vicinity of oil and gas seeps in the Chinitna district on Cook Inlet in 1892 by a man named Edelman. These claims were abandoned, but other claims were staked in the Chinitna and Katalla districts about 1896, and drilling was started in both districts during Alaska's first oil "boom" at the turn of the century. Interest collapsed in 1904 for a variety of reasons, chief among them being failure to obtain oil in large quantity, high cost of exploration, difficulty of obtaining title to oil lands under the placer mining laws then in effect, and increasing supply of oil on the west coast due to rapid development of fields in California. Activity continued on a small scale at a few localities, mainly in the Katalla field. Withdrawal by the Government of the oil lands for oil and gas leasing in November 1910 halted all exploration, except on a few claims previously patented or staked, until passage of the oil and gas leasing in February 1920. This started a new "boom" involving all the more accessible areas on the south coast where indications of petroleum were known, and in other areas where no indications had been found.

In 1923 a tract approximately 37,000 square miles in area, embracing the then known oil seeps in northern Alaska, was set aside as

Naval Petroleum Reserve No. 4 (NPR–4). On the south coast drilling was carried on sporadically through the twenties and early thirties, mainly in the Katalla field and in the Kanatak district on the Alaska Peninsula. The Katalla field, which has provided the only commercial production in Alaska up to 1955, was closed down in 1933 when part of the refinery installation at the field was destroyed by fire. In the late thirties and early in 1940 two deep test wells, the first in Alaska to be drilled with modern rotary equipment and to depths greater than 5,100 feet, were put down in the Kanatak and Chinitna districts.

The critical situation with regard to oil in the Pacific area early in World War II again focused attention on Alaska's petroleum possibilities. The public lands in three large tracts embracing the known petroliferous areas in Alaska were withdrawn from leasing in 1943 under the oil and gas leasing laws, as one phase of the U.S. Government program for the development of possible petroleum supplies for the Armed Forces. Steady improvement of both petroleum supply and the military situation in the Pacific made it unnecessary to carry out the proposed program of drilling to obtain oil immediately for military use. Other longer range phases of the program were continued through initiation in 1944 of U.S. Navy Department exploration in Naval Petroleum Reserve No. 4 (NPR–4) and Geological Survey petroleum investigations in both southern and northern Alaska (Reed, 1946). The war-imposed restrictions on potentially petroliferous areas in southern Alaska were lifted in August 1946, again opening public lands in these areas to leasing for petroleum exploration. The Navy Department program for exploration of NPR–4 from 1944 to 1953, which marked the first systematic exploration of a large area in Alaska through coordinated geologic and geophysical methods and exploratory drilling, resulted in the discovery of several prospective oil fields and gas fields. The recent upsurge in volume of applications for federal oil and gas leases, in geologic investigations undertaken by major oil companies, and in drilling—all indicate that Alaska in 1955 is in the midst of its third "boom" in petroleum exploration.

ROLE OF THE GEOLOGICAL SURVEY IN PETROLEUM EXPLORATION IN ALASKA

For more than half a century the Geological Survey has been collecting geologic information bearing on the mineral resources of Alaska. This has been done by detailed examination of mining camps or other limited areas in which valuable mineral deposits already were known and by reconnaissance or detailed areal mapping to determine the presence of geologic conditions favorable for the occurrence of undiscovered mineral deposits. The first Geological Survey investigation aimed specifically at petroleum deposits was G. C. Martin's reconnaissance of the Katalla, Chinitna, and Kanatak districts in 1903 (Martin, 1904). Investigations of known or potentially petroliferous areas in southern Alaska were continued intermittently by Martin and other members of the Geological Survey until 1924. The results of these investigations were published as separate areal reports by the Geological Survey, and Martin (1921) also summarized in a single report the status of knowledge on petroleum in Alaska up to 1920. Results of the Geological Survey reconnaissance of northwestern Alaska in the period 1923–26, made largely to obtain adequate geographic and geologic knowledge for administration of the newly created Naval Petroleum Reserve No. 4, also were published in a single report (Smith and Mertie, 1930). From 1927 to 1943 the investigations of the Geological Survey in Alaska were concerned to a large extent with the study of deposits of metallic minerals or coal, or with regional studies in areas where the geologic conditions appeared to be favorable for such mineral deposits. No investigations made primarily of petroleum resources were undertaken during this period, but many studies, nevertheless, contributed directly or indirectly to the fund of geologic knowledge bearing on petroleum in Alaska.

In 1944 the Geological Survey initiated detailed examinations of known petroliferous areas in both southern and northern Alaska under its program of war-minerals investigations. Geologic studies have been continued from year to year since then in southern Alaska and in 1954 were started in central Alaska, as part of a long-range program of petroleum investigations. Since 1945 the Geological Survey has participated in the Navy Department exploration of NPR–4 and adjacent areas in northern Alaska. Although the drilling and geophysical phases of this program were suspended by the Navy Department early in 1953, provision was made for assembling and publishing in Geological Survey professional papers much of the technical data already accumulated, and for carrying out additional fieldwork on special problems as needed to complete these reports.

An annotated bibliography of references relating to petroleum and oil shale in Alaska in publications of the Geological Survey is given in the last chapter of this report.

POSSIBLE PETROLEUM PROVINCES IN ALASKA

On the basis of our present knowledge all northern Alaska, north of the Brooks Range, and several areas in central and southern Alaska may be designated as possible petroleum provinces (pl. 1). Within these provinces geologic conditions are believed to be locally favorable or at least possibly favorable for the occurrence of commercially significant accumulations of petroleum. The areas outlined as possible petroleum provinces necessarily are generalized; some include small areas known definitely to be geologically unfavorable, as for example, areas in which small bodies of intrusive igneous rock are exposed, and some are wholly or in part alluvium-covered areas in which the extent or even the presence of favorable bedrock is problematical. The part of Alaska not included in the basin areas and petroleum provinces (pl. 1) includes large areas known definitely to be unfavorable or impossible for petroleum in commercial quantity, as for example, the large area of schist and other unfavorable metamorphic rocks north and east of Fairbanks. Unfavorable areas also include some small areas that are as yet too little known geologically to be classed as either favorable or unfavorable.

Confirmed and reported indications of petroleum in Alaska are shown on plate 1. Many oil and gas seeps and shows in wells are known in three provinces: northern Alaska, north of the Brooks Range; the Cook Inlet Mesozoic province in southern Alaska; and the Gulf of Alaska Tertiary province. Oil shale is exposed in the Kandik province of central Alaska. Gas has been found in wells drilled in coal-bearing deposits of the Cook Inlet Tertiary province. Many reported indications of petroleum that either have not been checked by field examination or are regarded as disproved or doubtful also are shown on plate 1. On the basis of field examination by the Geological Survey some reported oil and gas seeps are regarded as disproved or doubtful because no indication of oil or gas was found or because the oily-appearing substance at the localities described was not petroleum oil. A few reported indications are classed as doubtful because the locations are in areas where the geology is known to be unfavorable for petroleum. Inflammable gas found in seeps and wells in association with unconsolidated surficial deposits at some localities is believed to be marsh gas.

The substance most frequently mistaken in Alaska as an indication of petroleum is the iridescent film of iron oxide found on the surface of pools or sluggish streams in swampy areas or tidal flats, or found in association with iron-rich springs. Such an iron oxide film is easily distinguished from petroleum because it will break up into angular rafts when stirred, it is not inflammable, and it lacks the characteristic odor of petroleum. Oil films and gas derived from decaying vegetation, common in swampy areas, around the margin of lakes and in association with peat deposits, as well as oily distillation products of burned coal beds (Martin, 1922) also have been mistaken for petroleum indications.

For the purpose of appraising its petroleum possibilities Alaska may be divided conveniently into three major geologic-physiographic regions, the southern, central, and northern regions. These three regions are described in separate sections of this report, and references cited in each are listed together at the end of the report. Many of the references cited are included also in the annotated bibliography of U. S. Geological Survey publications on petroleum and oil shale in Alaska, which constitutes the last section of this report. The writers are indebted to many geologists in the Geological Survey for heretofore unpublished information bearing on petroleum in Alaska, and also for many helpful suggestions and editorial comments received during preparation of this report.

SOUTHERN ALASKA

By Don J. Miller

Southern Alaska, as here defined, includes the arcuate mountain chain formed by the Alaska and Aleutian Ranges and the Mentasta-Nutzotin Mountains, the coastal range-and-valley area to the south, and the southeastern Alaska "panhandle." This region, having an area of 185,000 square miles, is the most rugged and predominantly mountainous physiographic province of Alaska and is designated the Pacific Mountain System. Mount McKinley in the Alaska Range, rising to an altitude of 20,330 feet, is the highest peak of the North American continent. Large areas in the Alaska Range and the Chugach, Wrangell and St. Elias Mountains lie above 10,000 feet. The only extensive areas of relatively low relief are (a) the Cook Inlet-Susitna-Matanuska lowland area and Copper River basin-Chitina Valley area, between the arcuate mountain chains of the Alaska-Aleutian Ranges and the Chugach-Kenai Mountains; and (b) the coastal lowland that borders the Gulf of Alaska from the Copper River southeastward to Icy Point, near Cross Sound. Rivers draining the southern Alaska region flow into the Pacific Ocean, into Bristol Bay, and into the Bering Sea by way of the Yukon and Kuskokwim Rivers. The region has some of the largest remaining icefields of the North American continent.

The coastal ranges and valleys bordering the Gulf of Alaska, the southeastern margin of the Alaska Peninsula, and a narrow coastal strip extending into southeastern Alaska comprise a geologic belt that is comparable in many aspects of its geologic history to the coast-range-and-valley province of Western United States. This belt includes two geologic provinces, the Cook Inlet Mesozoic province and the Gulf of Alaska Tertiary province, parts of which are considered to be favorable for the occurrence of petroleum and to offer the most promising possibilities for the development of oil and gas fields in southern Alaska.

The Alaska Range and the adjacent Talkeetna, Wrangell, and Mentasta-Nutzotin Mountains, the Aleutian Range, the interior part of the St. Elias Mountains, and the Coast Ranges in southeastern Alaska constitute a second belt that is geologically analogous in some ways to the Sierra-Cascade belt of Western United States. Because of its complicated structure and large areas of metamorphic and igneous rocks much of this belt is unfavorable for the occurrence of petroleum in commercial quantity. This belt does, however, include four areas that may be classed as geologically possible for petroleum.

This section includes a review of the history of petroleum exploration in southern Alaska, a summary of the depositional and tectonic history of the southern Alaska region, a brief description of the geology of the principal tectonic elements, and a more detailed description of areas that are regarded as possible petroleum provinces. Information on petroleum exploration through 1920 was taken mainly from the preliminary report on petroleum in Alaska by G. C. Martin (1921). The discussion of the history of sedimentation and deformation in southern Alaska is based largely on a preliminary draft prepared by Payne and on his chart summarizing the Mesozoic and Cenozoic tectonic history of Alaska (Payne, 1955). Acknowledgment is due for information contributed by G. D. Eberlein on the Heceta Island area, by Arthur Grantz on the Nelchina area, and by A. S. Keller on the Kamishak and Chignik districts.

PETROLEUM EXPLORATION

The effort to explore and develop the petroleum resources of Alaska began in the southern region. Surface indications of petroleum were found first, and proved to be most abundant and widespread, in the Chinitna, Kanatak, Katalla, and Yakataga districts on the south coast. These districts, being more easily accessible and more favorably located with respect to potential markets than other known or possibly petroliferous areas of Alaska, were naturally the most attractive for exploration. Until 1945 exploration by drilling was confined almost entirely to the south coast of Alaska.

Oil and gas seeps in the Iniskin Peninsula area of the Chinitna district (pl. 1), on the west shore of Cook Inlet, were discovered by the Russians about 1853, and samples of the oil were collected in 1882. A description published in 1869 of oil seeps "near Katmai" probably referred to the belt of oil and gas seeps in the Kanatak district on the Alaska Peninsula. Oil and gas seeps in two belts bordering the Gulf of Alaska, one in the Katalla district and one in the Yakataga district, were discovered about 1896. Staking of claims in the vicinity of the oil and gas seeps on the Iniskin Peninsula in 1882 by a prospector named Edelman is the earliest known effort to develop the petroleum resources of Alaska. These claims were abandoned but in 1896 claims were staked again on the Iniskin Peninsula and many claims were staked also in the Katalla and Yakataga districts. Drilling began near the discovery oil seeps in the Katalla district in 1901, and was continued intermittently in this district until 1932. Several shallow wells were drilled also on the Iniskin Peninsula and in the Kanatak district during Alaska's first period of oil activity, which ended in 1904.

Passage of the oil and gas leasing act in February 1920 resulted in renewed activity in all the known petroliferous districts of southern Alaska (Martin, 1921). Some attention was given also to other areas where indications of petroleum were not known or, if reported, had not been confirmed, notably the Chignik district on the Alaska Peninsula, in the vicinity of Anchorage and at other localities in the Cook Inlet-Susitna valley area, and in the vicinity of Killisnoo on Admiralty Island in southeastern Alaska. Several wells were drilled in the Kanatak district between 1923 and 1926, the first such exploration undertaken in Alaska by major oil companies. The first test well in the Yakataga district was drilled during 1926 and 1927. A well reportedly drilled to shallow depth in search of oil on the outskirts of Anchorage in 1920–21 is recorded in the name "Oil Well Road." During the period 1926–30 a test well was drilled near Chickaloon in the Matanuska Valley.

Exploration activity in southern Alaska dwindled gradually during the late twenties and early thirties, and was at a standstill when the Katalla field was closed down as the result of a fire late in 1933. This event may appropriately be taken as marking the end of the first phase of exploration for oil in southern Alaska, during which about 63 wells with an aggregate footage of about 63,000 feet were drilled by the cable-tool method. Most of these wells were located on or near surface indications of petroleum; the deepest was 5,034 feet and only one other well was deeper than 2,400 feet.

Field geologic investigations were resumed in coastal areas of southern Alaska by oil companies during the middle and late thirties. Between 1938 and 1940 two deep test wells, one on the Iniskin Peninsula and one in the Kanatak district, were drilled with rotary equipment at sites selected on the basis of surface geologic mapping. Failure of these wells to obtain oil in commercial amount, coupled with the war-imposed restrictions and the withdrawal from leasing of public land in the known petroliferous areas of southern Alaska from 1943 to 1946, again resulted in cessation of exploration activity by private companies or individuals.

Interest in the petroleum possibilities was heightened by the enormously increased consumption of petroleum products in Alaska during and after the war. Geologic field studies of southern Alaskan areas were resumed by major oil companies in 1948, and from 1951 to 1955 increased steadily in scope and in the number of companies involved. In 1954 the seismograph was employed for the first time in the search for petroleum in southern Alaska. Leasing activity was resumed on a small scale after the withdrawn lands were restored late in 1946, and increased markedly in 1951. During that year more than 450 individuals, cooperating as the Northern Development Company, applied for leases covering a tract of nearly a million acres in the Katalla and Yakataga districts. By the end of 1955 oil and gas leases or prospecting permits in effect or in the stage of application covered a nearly continuous belt along the Gulf of Alaska between the Copper River and Cape Fairweather, nearly one-half of the lowland area on the Kenai Peninsula, and other widely scattered areas on Cook Inlet and in the valleys of the Susitna and Matanuska Rivers, in the Nelchina district, and on the Alaska Peninsula.

In 1953 one well was started in the Nelchina district. In 1954 drilling was continued at this site, a well was started on the Iniskin Peninsula, and one well was completed and abandoned and a second well started in the Yakataga district. A well also was started late in 1954 near Houston on the eastern margin of the Susitna valley, where flows of gas and saline water were found in two diamond-drill holes put down in 1951 and 1952 by the U. S. Bureau of Mines in the course of exploration for coal deposits. During 1955 drilling continued on wells in the Nelchina district, on the Iniskin Peninsula and near Houston. The second well in the Yakataga district was completed and abandoned, and one well was drilled on the west shore of Knik Arm.

During the second phase of petroleum exploration in southern Alaska, beginning in the midthirties, five wells were drilled and drilling was suspended at the end of 1955 but possibly not completed on three other wells. Rotary equipment was used to drill all but one of these wells. The total footage drilled from 1936 through 1955 was 50,026 feet. The deepest well was 10,013 feet.

HISTORY OF SEDIMENTATION AND DEFORMATION

Sedimentary rocks representing the Ordovician and all younger geologic systems have been identified in southern Alaska. Highly metamorphosed rocks that underlie Paleozoic and younger sedimentary rocks in the eastern Alaska Range are correlated with the Birch Creek schist of Precambrian age, exposed in the area between the Yukon and Tanana Rivers in central Alaska. Precambrian sedimentary rocks may also be represented in the highly metamorphosed basal part of the stratigraphic sequence in southeastern Alaska.

Major orogenies that affected the southern Alaska region occurred in Late Ordovician, Late Silurian or Early Devonian, Jurassic, Early Cretaceous, early Tertiary, and late Tertiary and Quaternary times. The Jurassic, Early Cretaceous, and early Tertiary orogenies were accompanied by extensive igneous intrusion and mineralization.

The tectonic elements discussed below are shown on plate 2.

PALEOZOIC HISTORY

The rocks of all systems of the Paleozoic era, excepting the Cambrian, are known in southern Alaska, and include rocks of marine sedimentary origin. This Paleozoic sequence constitutes a great thickness of rocks representing deposition in a broad magmatic geosynclinal belt, the history of which is not known in detail. Rocks of Paleozoic age are extensively exposed in southeastern Alaska, principally in the area of the Prince of Wales geanticline. In the rest of southern Alaska much of the Paleozoic sequence has been obliterated by Mesozoic and Cenozoic sedimentation, orogenies, and intrusions. Paleozoic rocks are exposed locally in anticlinoria and upfaulted blocks in the Alaska Range; in the northern part of the Aleutian Range and in the Talkeetna and Wrangell Mountains of the Talkeetna geanticline, where they have been extensively covered by Cenozoic lavas and intruded by Mesozoic and Cenozoic igneous rocks; and in the part of the Seldovia geanticline lying south of the Chitina Valley.

Lower and Middle Ordovician rocks, including marine graywacke, slate, chert and volcanic rocks, are exposed on Kuiu Island and on Prince of Wales Island and neighboring islands in southeastern Alaska. They are at least 3,000 feet thick in the area of El Capitan Passage (between Prince of Wales and Kosciusko Islands) and may be much thicker elsewhere. Deposits of limestone and shale of Middle Ordovician age occur locally in the western part of the Alaska Range and are at least 2,000 feet thick. Despite the restricted outcrop areas that have been reported, Ordovician rocks probably were deposited widely in southern Alaska. A Late Ordovician orogeny is known to have occurred in southeastern Alaska, but there is no record of intrusive activity.

Although rocks of Silurian age are known only in southeastern Alaska, they probably were deposited and may be represented at depth elsewhere in southern Alaska. They are known to be exposed on Prince of Wales Island and adjacent islands and to the north in the area of Glacier Bay. These occurrences may be part of a belt of Silurian sedimentary rocks extending throughout much of the area of the Prince of Wales geanticline. The Silurian sequence, possibly 16,000 feet thick locally, includes three parts. The lower part consists of marine graywacke (after Pettijohn, 1949, p. 244–245), conglomerate, volcanic rocks, and some limestone. The middle part, locally as much as 8,000 feet thick, is predominantly pure limestone which contains thick lenses of conglomerate, breccia, and graywacke derived in part from the limestone. The upper part consists of red beds, graywacke, and limestone. Limestone of the middle part and sandstone of the upper part locally are impregnated with a black organic substance.

In southeastern Alaska there is evidence of a second Paleozoic orogeny, in Late Silurian or Early Devonian time. The nonmarine red beds of the upper part of the Silurian may reflect the beginning of movement. Although the Silurian strata in the area of Heceta Island were affected by this orogeny, they are anomalous in that they are not as strongly deformed as rocks of Silurian to Cretaceous age in adjacent areas in southeastern Alaska.

In southeastern Alaska Middle and Upper Devonian rocks, having a maximum thickness of at least 10,000 feet, comprise marine volcanic rocks, limestone, chert, slate, and some graywacke and conglomerate. Middle Devonian limestone, marble, calcareous schist, and graywacke, as well as volcanic rocks in the form of greenstone schist, occur locally in thicknesses of at least 5,000 feet in the Alaska and Aleutian Ranges and in the eastern part of the Wrangell Mountains.

Rocks of Mississippian and Permian age are exposed extensively in a broad belt in the Chitina Valley and adjacent area, in the Wrangell, Nutzotin, and Mentasta Mountains and westward in the Alaska Range, and in scattered small areas in southeastern Alaska. In the Chitina Valley-Wrangell Mountain area the Mississippian sequence includes not less than 6,500 feet of slate and schist locally associated with minor amounts of altered limestone and volcanic rocks, and the Permian sequence includes several thousand feet of volcanic rocks interbedded with limestone and clastic sedimentary rocks, succeeded by 5,000 to 6,000 feet of lava flows at least in large part of Permian age. Mississippian rocks in southeastern Alaska include limestone, chert, quartzite, sandstone, and some conglomerate. The Permian sequence in this area consists of volcanic rocks interbedded with limestone, chert, conglomerate, sandstone, and shale. Rocks of Pennsylvanian age are known in southeastern Alaska by fossil-bearing marine limestone on one small island, but rocks of this age have not been positively identified anywhere else in southern Alaska.

Definite evidence for strong orogenic movement is lacking in the Middle Devonian to early Mesozoic rocks of southern Alaska. The apparent absence of sedimentary rocks representing most of Pennsylvanian and all of Early and Middle Triassic time, as well as other local stratigraphic discontinuities, do suggest, however, uplift and erosion.

MESOZOIC AND PALEOCENE HISTORY

SEDIMENTATION

Upper Triassic and Lower Jurassic rocks probably were deposited over much of southern Alaska. Known outcrop areas of Upper Triassic rocks are small but widely distributed. The Upper Triassic rocks are a few thousand feet thick and include marine volcanic rocks, thick units of limestone, chert, shale and argillite, and lesser amounts of sandstone and conglomerate. Lower Jurassic rocks, consisting of several thousand feet of marine and nonmarine volcanic rocks with interbedded shale, sandstone and limestone, are extensively exposed around the margin of the Cook Inlet basin and in the Matanuska Valley-Nelchina area. The Lower Jurassic series may also be represented in the undifferentiated sequences of greenstone, slate, and graywacke on Kodiak Island, Prince William Sound, and in southeastern Alaska. Upper Triassic limestone exposed on the Alaska Peninsula reportedly is petroliferous.

Beginning in Middle Jurassic time southern Alaska became differentiated into geanticlinal and geosynclinal belts that persisted throughout the remainder of Mesozoic time (pl. 2) and are reflected in the present distribution of mountain chains and of rocks of similar age and lithology in arcuate belts about the Gulf of Alaska. Middle and Upper Jurassic marine clastic sedimentary rocks totaling 15,000 to 20,000 feet were deposited in the Matanuska geosyncline. Many indications of petroleum are known in these rocks in the Kanatak and Chinitna districts. Middle Jurassic marine sedimentation in the Alaska Range geosyncline is represented by 3,000 feet or more of sandstone, conglomerate, slate, and a few beds of limestone, exposed in the valleys of the Skwentna and Yentna Rivers. Fossils of Late Jurassic age have been identified in shaly or slaty rocks at localities on Admiralty, Kupreanof, and Gravina Islands in southeastern Alaska. Middle and Late Jurassic deposition may be represented elsewhere in southeastern Alaska, and also in the belt of greenstone-graywacke-slate bordering the Gulf of Alaska.

Deposition in the Alaska Range geosyncline during the early part of the Cretaceous (Neocomian) is represented by several thousand feet of marine slate and graywacke in the central and western part of the Alaska Range, and by similar rocks in the Nutzotin Mountains. Deposits of this age but of quite different lithology in the Matanuska geosyncline include 800 feet of arenaceous limestone in the Herendeen Bay area of the Alaska Peninsula and 780 to 1,175 feet of marine limestone, sandstone, shale, and conglomerate in the Nelchina area on the southeast flank of the Talkeetna Mountains. Rocks of Neocomian age have been identified in the Seymour geosyncline and in the coastal belt of Mesozoic rocks in southeastern Alaska, and may be present elsewhere in the greenstone-graywacke-slate belt bordering the Gulf of Alaska.

The middle part of the Cretaceous (Albian and Cenomanian) probably is represented in the Alaska Range geosyncline by several thousand feet of nonmarine sandstone, conglomerate, shale, and some lava. The age assignment of these rocks is based on fossil plants and stratigraphic relationships. Several thousand feet of marine clastic sedimentary rocks in the eastern part of the Chitina Valley are of Albian age, and deposition farther west in the area of the Matanuska geosyncline during Albian time is indicated by fossils of early Albian age found in reworked concretions in the basal Upper Cretaceous beds of the Nelchina area (Arthur Grantz, oral communication, 1955). Two coarse clastic units in the Matanuska geosyncline—the marine Kotsina conglomerate in the western part of the Chitina Valley and the nonmarine Arkose Ridge formation in the Matanuska Valley—are tentatively assigned to the Albian and Cenomanian stages of sedimentation by Payne (1955). Imlay and Reeside (1954, p. 231), on indirect paleontologic evidence, have correlated the Kotsina conglomerate with the basal Upper Cretaceous (Coniacian) beds of the Nelchina area and eastern Chitina Valley. Conglomerate and graywacke unconformably overlying greenstone in Prince William Sound may be of Albian and Cenomanian age.

Sedimentary rocks of the upper part of the Cretaceous system (Coniacian through Campanian or younger) are widespread in the Matanuska geosyncline. They are represented in the area of the Chitina Valley westward to the eastern part of the Matanuska Valley by a lower unit of marine sandstone and conglomerate a few hundred to possibly as much as 2,500 feet thick, and by an upper unit of marine shale with minor sandstone as much as 8,000 feet thick. In the northern part of the Alaska Peninsula they comprise 2,000 feet or more of marine siltstone and sandstone, and in the southwestern part of the Alaska Peninsula, 800 to 1,600 feet or more of marine and nonmarine sandstone, shale, conglomerate, and coal. The bulk of the marine slate and graywacke in the Chugach Mountain geosyncline probably is of Coniacian or younger Cretaceous age. Deposits of this age may be represented in the Alaska Range geosyncline by nonmarine tuff and clastic sedimentary rocks that lie unconformably on nonmarine sedimentary rocks tentatively assigned to the middle part of the Cretaceous.

In the Matanuska Valley the earliest Tertiary deposits appear to be more closely related structurally to Mesozoic rocks than to younger Tertiary strata. Here the Upper Cretaceous rocks are overlain with approximate structural conformity by a nonmarine sequence that contains a flora of early Tertiary age. These rocks, which consist of shale, sandstone, conglomerate, and coal and have a maximum thickness of nearly 7,000 feet, are tentatively assigned to the Paleocene epoch and are considered by Payne (1955) to represent the closing phase of sedimentation in the Matanuska geosyncline. The Paleocene may be represented also in several areas marginal to the Gulf of Alaska by unfossiliferous marine and nonmarine sequences that are similar in lithologic characteristics to, but are more highly deformed than, sequences known to be of Tertiary age.

DEFORMATION

Differentiation of the southern Alaska region into geanticlinal and geosynclinal belts was initiated by an orogeny that began in latest Early Jurassic or earliest Middle Jurassic time and may have continued into earliest Cretaceous time. Four phases of the Jurassic and Cretaceous orogeny—latest Toarcian and earliest Bajocian, late Bathonian and early Callovian, late Callovian, and Portlandian and Berriasian—are indicated by unconformities in the Jurassic and Lower Cretaceous sequence in the area of the Matanuska geosyncline. Widespread intrusive activity beginning in Middle Jurassic time and continuing into Late Jurassic time resulted in extensive mineralization and emplacement of igneous bodies of batholithic size, notably in southeastern Alaska and in the area of the Talkeetna geanticline.

Another major orogeny in Early Cretaceous time (late Neocomian and Aptian) resulted in intense deformation, further batholithic intrusion and mineralization, and erosion of the sedimentary rocks in the Alaska Range and Seymour geosynclines, and in minor deformation and erosion in the area of the Matanuska geosyncline. An unconformity between greenstone and overlying conglomerate and graywacke in the Prince William Sound area possibly represents uplift during this orogeny of a geanticlinal belt bordering the present Gulf of Alaska. Sedimentary rocks of Aptian age have not been identified anywhere in southern Alaska.

A late Cenomanian orogeny recognized in northern Alaska may be represented by an unconformity in nonmarine deposits of the Alaska Range geosyncline. Moderate deformation in the area of the Matanuska geosyncline in Cenomanian and Turonian time is indicated by the apparent absence of beds of this age and by unconformable overlap of beds of Coniacian age onto Lower Cretaceous, Jurassic, and Upper Triassic beds. Deformation in the major geosynclinal belts of southern Alaska in later Cretaceous time probably was minor, but uplift and erosion are indicated by the apparent lack of sedimentary rocks of later Maestrichtian or Danian age.

A third major orogeny, representing the first phase of the Laramide orogeny, resulted in strong regional deformation and further intrusive activity over much of southern Alaska. Deformation of the Chugach Mountain belt of geosynclinal sedimentary deposits is believed to have taken place largely during this orogeny. Deformation was gentle in the southwestern part of the Matanuska geosyncline, the orogeny being marked there mainly by uplift and by the initiation of volcanic activity. Payne (1955) has tentatively placed this orogeny at the close of Paleocene time, mainly on the basis of structural relationships observed in the late Mesozoic and early Tertiary rocks in the lower Matanuska Valley area of the Matanuska geosyncline. In this area the earliest Tertiary sedimentary deposits, inferred to be Paleocene in age, rest with approximate structural conformity on Upper Cretaceous rocks but are overlain with marked angular discordance by less deformed sedimentary deposits of Eocene or later Tertiary age. Other geologists have dated this orogeny as latest Cretaceous or earliest Tertiary because at many places in southern Alaska the earliest Tertiary deposits, either known to be, or generally considered to be, of Eocene age, rest unconformably on more highly deformed rocks of Late Cretaceous age.

POST-PALEOCENE CENOZOIC HISTORY

Nonmarine coal-bearing sedimentary rocks of known or probable Eocene age, totaling a few thousand feet, are exposed in the area of the Shelikof trough and its extensions northward and northeastward into the present area of the Susitna and Matanuska Valleys. Lava flows, tuff, and agglomerate interbedded with these sedimentary rocks in the southern part of the Shelikof trough record the earliest phase of volcanic activity, which has continued intermittently to the present time in the Aleutian Range and the Wrangell Mountains. Fossiliferous marine strata of Eocene and late Tertiary age are exposed in small areas near the southwestern end of the Alaska Peninsula, but definite evidence that marine deposition extended farther northeast in the Shelikof trough during Tertiary time has not been found. Nonmarine sedimentary rocks of probable Eocene age, in part coal bearing and at some localities interbedded with or overlain by volcanic rocks, are exposed in and near the margin of the Copper River basin, in the eastern Wrangell Mountains, and in the area of the Admiralty trough in southeastern Alaska.

Deposition in the Yakataga geosyncline during the last important marine invasion of the present land area of southern Alaska is represented by Eocene marine and nonmarine strata succeeded by Oligocene, Miocene, and Pliocene marine strata, totaling at least 25,000 feet. Many oil and gas seeps are known in this belt of sedimentary rocks, which constitutes the Gulf of Alaska Tertiary province. The presence of early Tertiary nonmarine sedimentary rocks on Kodiak

Island, and of late Tertiary or early Quaternary marine rocks on Kodiak and Trinity Islands and on Middleton Island indicates probable continuity of the Tertiary belt in the Middleton shelf and at least the northern part of the Shumagin shelf.

Eocene deposits in the area of the Shelikof trough were gently, and locally strongly, deformed during Oligocene or Miocene time. Much of southern Alaska probably was reduced to an area of low relief during or following this late phase of the Laramide orogeny. The orogeny beginning in Pliocene time, and continuing to the present, resulted in strong differential uplift and faulting throughout southern Alaska. Folding was strong locally in the area of the Yakataga geosyncline, but gentle elsewhere in the southern Alaska region, except adjacent to major faults.

A subtropical to temperate climate in the present area of southern Alaska during early Tertiary time is indicated by the Paleocene(?) and Eocene fossil flora in the widely distributed nonmarine deposits, and by the Eocene to early Miocene invertebrate fauna in marine deposits of the Yakataga geosyncline and southwestern part of the Shelikof trough. Colder climate and accompanying local glaciation beginning in middle or late Miocene time is indicated by the marine invertebrate fauna and by marine glacial deposits in the area of the Yakataga geosyncline. At the time of maximum glaciation during the Pleistocene most of the southern Alaska region probably was covered by ice. In part of the coastal region bordering the Gulf of Alaska on the northeast, however, the glaciers may have been little more extensive than they were during the past few centuries.

GEOLOGY OF TECTONIC ELEMENTS

COAST RANGES GEANTICLINE

Igneous rocks of the Jurassic and Cretaceous batholithic intrusions predominate in the Alaskan part of the Coast Ranges geanticline (pl. 2). Bedded rocks are restricted almost entirely to a narrow belt along the southwest flank of the geanticlinal trend. They consist of intensely metamorphosed volcanic rocks, clastic sedimentary rocks, and some limestone, mostly of Paleozoic age. The area of this geanticline is unfavorable for petroleum.

ALASKA RANGE GEOSYNCLINE

Sedimentary rocks of Paleozoic and Mesozoic age in considerable thickness are exposed in the Alaska Range geosyncline, including the Nutzotin segment. These rocks are generally unfavorable for petroleum, however, because they are intensely deformed, are intruded by igneous bodies, and are thermally and dynamically metamorphosed.

The youngest deposits of this geosyncline, the Cantwell formation in the Alaska Range and equivalent strata of latest Early Cretaceous age and Late Cretaceous age in the Nutzotin segment, although locally only moderately deformed and little altered, are nonmarine. No indications of petroleum in these rocks have been reported.

SEYMOUR GEOSYNCLINE

In the area of the Seymour geosyncline are exposed Triassic and Jurassic slate, graywacke and other marine sedimentary rocks interbedded with volcanic rocks, and also Lower Cretaceous marine slate and graywacke with minor amounts of conglomerate, calcareous sandstone, and impure limestone. Sedimentary rocks of this geosyncline have undergone metamorphism and deformation to the extent that they are believed to be unfavorable for petroleum.

TALKEETNA GEANTICLINE

Igneous rocks predominate in the Talkeetna geanticlinal belt. Batholiths emplaced during the Jurassic and Cretaceous orogenies form much of the Talkeetna Mountain mass and the central and northern part of the Aleutian Range. The western and central part of the Wrangell Mountains, and also the highest peaks in the northern part of the Aleutian Range have been built up by Cenozoic volcanic activity. Volcanic rocks of Paleozoic age are exposed along the trend of the Talkeetna geanticline in isolated hills that protrude from the alluvium in the northern part of the Copper River basin. Mississippian and Permian rocks exposed in the eastern Wrangell Mountains contain much volcanic material and are likewise unfavorable for petroleum.

PRINCE OF WALES GEANTICLINE

Sedimentary rocks which are exposed in the area of the Prince of Wales geanticline represent all periods of the Paleozoic era except the Cambrian and are intruded by large bodies of igneous rock. Each of the Paleozoic systems includes limestone, sandstone, and other marine sedimentary rocks, and all except the Pennsylvanian include volcanic rocks. Over much of the geanticline these rocks are intensely deformed and metamorphosed. The only areas of possible interest for petroleum exploration are structural basins in the vicinity of Heceta Island and in the vicinity of the Keku Islands in southeastern Alaska (pl. 1), where limestone and other marine sedimentary rocks of Silurian and younger age are anomalously only gently to moderately deformed and where indications of petroleum have been reported. These areas are described under the section on possible petroleum provinces.

MATANUSKA GEOSYNCLINE

In a belt 750 miles or more in length the Mesozoic deposits of the Matanuska geosyncline may be favorable for the development of oil or gas fields. Oil and gas seeps and other indications of petroleum are known to be present in these rocks in the Chinitna, Kanatak, and Chignik districts, and have been reported also at other localities in the area of the Matanuska geosyncline. This belt, designated the Cook Inlet Mesozoic province (pl. 1), is described in the section on possible petroleum provinces.

SELDOVIA GEANTICLINE

Rock consisting of slate and schist with a minor amount of volcanic material and recrystallized limestone, of Mississippian age, is exposed in the eastern part of the Seldovia geanticline. From the vicinity of Klutina Lake southwestward to Kodiak Island the bedded rock exposed in this geanticlinal belt comprises Upper Triassic and Lower Jurassic volcanic rocks interbedded with marine limestone, chert, slate, and graywacke. These sedimentary and volcanic rocks in general are intensely deformed, are metamorphosed, and are intruded by some large bodies and many small bodies of igneous rocks, and hence are unfavorable for petroleum. In a narrow belt on the east shore of Cook Inlet in the vicinity of Seldovia and Port Graham, however, Lower Jurassic interbedded sedimentary and volcanic rocks are not as intensely deformed as elsewhere in the area of the Seldovia geanticline. Some of the beds of marine limestone at this locality are fossiliferous. Although this narrow belt of Lower Jurassic rocks is shown in the area of the Seldovia geanticline on plate 2, it is more closely allied structurally (in degree of deformation and alteration) with the Matanuska geosyncline and is included in the Cook Inlet Mesozoic province.

CHUGACH MOUNTAINS GEOSYNCLINE

In a belt extending through the Chugach and Kenai Mountains and the central part of Kodiak Island the exposed rocks have remarkably uniform lithologic characteristics. They consist of a monotonous sequence of thousands, possibly tens of thousands of feet of dark argillite or slate interbedded with massive poorly sorted sandstone of graywacke type. These deposits of the Chugach Mountains geosyncline are marine but are almost lacking in organic remains. Although the rocks are excellently exposed in a mountain belt and have been studied at many localities, determinative fossils have been found at only three widely separated localities. These indicate a Late Cretaceous (late Coniacian or early Santonian) age, according to Imlay and Reeside (1954, p. 227–228).

Because of the complex folding and lack of distinctive beds it has not been possible to determine the structure of the slate and graywacke in detail, but from the prevalence of steep dips and zones of shearing, it is obvious that the rocks are intensely folded and faulted. Slaty cleavage has developed in the argillaceous rocks at many places. Igneous bodies of small to moderate size are common, and the sedimentary rocks are characteristically shot through with a network of quartz veinlets. In spite of these unfavorable aspects, the area of the Chugach Mountains geosyncline has been given some attention as a possible petroleum province in the past, largely because of reported indications of petroleum. None of these has been confirmed. Gas seeps found in lakes and marshes in the Cordova area and along The Alaska Railroad between Seward and Kenai Lake are believed to be marsh gas formed from decay of vegetation in the Recent lake bottom and swamp sediments (Martin, 1921, p. 71).

GREENSTONE, GRAYWACKE, AND SLATE OF MESOZOIC AGE BORDERING GULF OF ALASKA

A narrow belt of Mesozoic rocks bordering the Gulf of Alaska from Kodiak Island on the west to Baranof Island in southeastern Alaska is similar in lithologic characteristics, structure, and possibly in its tectonic and sedimentational history to the Seldovia geanticline. Exposed rocks in this belt are largely slate, graywacke, and marine volcanic rocks altered to greenstone. Rocks of Late Cretaceous age may be included as synclinal or downfaulted masses, but the sequence is believed to be mostly older and to underlie the Late Cretaceous rocks of the Chugach Mountains geosyncline. Fossils indicating an Early Cretaceous (Valanginian) age have been found in slate and graywacke at two localities in this belt in southeastern Alaska. Other parts of these rocks are referred tentatively, on the basis of lithologic characteristics and other evidence, to the Lower Jurassic. The Cretaceous and older rocks in this belt are regarded as unfavorable for petroleum because of their complex structure and alteration due to dynamic and thermal metamorphism.

SHELIKOF TROUGH

The known deposits of the Shelikof trough include the Eocene coal-bearing sedimentary rocks exposed in and around the margin of the Cook Inlet basin. Also included are scattered small areas of similar nonmarine sedimentary rocks and volcanic rocks, presumably also Eocene, along the eastern margin of the Alaska Peninsula between Kamishak and Katmai Bays; the thick sequence of Tertiary nonmarine rocks, largely of volcanic origin, in the southwestern part of the Alaska Peninsula; and small areas of Eocene and late Tertiary marine strata near the southwestern end of the Alaska Peninsula.

Inasmuch as the area of the Shelikof trough is largely coincident with the area of the Cook Inlet basin and the southwestern part of the Matanuska geosyncline, the possibilities for petroleum in the Cenozoic deposits of this trough are discussed in the sections on the Cook Inlet Mesozoic and Tertiary provinces.

ADMIRALTY TROUGH

Deposits of the Admiralty trough of early Tertiary age are exposed in several separate areas, most of which are on Admiralty, Kupreanof, and Kuiu Islands. They consist of at least 1,350 feet of coarse sandstone and conglomerate with some coal beds, succeeded by about 2,500 feet of volcanic rocks associated with a minor amount of nonmarine sediments, also including some coal. Flora associated with the coal beds includes elements of the so-called Kenai flora which is regarded as of Eocene age. The beds are gently deformed.

In the early part of this century a large number of oil claims were staked in one of the areas of coal-bearing sediments, near Angoon on Admiralty Island (Martin, 1921, p. 73). No indications of petroleum are known to have been reported in this area. Because of their nonmarine and predominantly volcanic nature, the Tertiary deposits of the Admiralty trough are not considered to be favorable for petroleum. In the southern part of Admiralty Island, the eastern part of Kuiu Island, and the central and southern part of Kupreanof Island, however, the Tertiary rocks may be underlain by more favorable Mesozoic and Paleozoic rocks whose petroleum possibilities are discussed under the section on the Keku Islands area.

YAKATAGA GEOSYNCLINE

Predominantly marine sedimentary rocks exceeding 25,000 feet in maximum thickness and representing a substantial part of the Tertiary period are exposed in the area of the Yakataga geosyncline. These rocks contain numerous indications of oil in the Katalla, Yakataga, and Malaspina districts, and have yielded the small amount of oil produced from the Katalla field. The belt of sedimentary rocks deposited in this geosyncline is described as the Gulf of Alaska Tertiary province (pl. 1) in the section on possible petroleum provinces.

COOK INLET AND COPPER RIVER CENOZOIC BASINS

The Cook Inlet and Copper River Cenozoic basins are topographically analogous to the Cenozoic basins of central Alaska and their petroleum possibilities to some extent are dependent on factors which are discussed in detail by Payne on pages 72–75 of this report. In the area including the Cook Inlet basin and adjoining outcrops of early Tertiary deposits of the Shelikof trough, Eocene or young Tertiary rocks may have possibilities as a reservoir for petroleum derived from the underlying Mesozoic deposits of the Matanuska geosyncline, and also as a source of gas and perhaps of oil. This area, designated the Cook Inlet Tertiary province (pl. 1), is described in the section on possible petroleum provinces.

Sedimentary rocks of Tertiary age are exposed in several small areas at or near the margin of the Copper River basin, and possibly have been penetrated by one test well for water in the basin. Although the known Tertiary sequence is thin and entirely nonmarine, the possibility that a thicker and more favorable Tertiary sequence is present beneath the Quaternary unconsolidated deposits somewhere in the basin cannot be definitely ruled out. The Copper River basin (pl. 1), therefore, is also included among the possible petroleum provinces of southern Alaska.

MIDDLETON SHELF

The Middleton shelf is an area of probable Tertiary sediments built southward from the margin of the Yakataga geosyncline to form a shelflike feature in the Gulf of Alaska. Deposits are probably continuous with, but most likely thinner than, Tertiary deposits in the Yakataga geosyncline.

SHUMAGIN SHELF

The Shumagin shelf is probably of Tertiary age and appears to be comparable in origin to the Middleton shelf. The two shelves are separated by a depression extending southward from Shelikof Strait.

ALEUTIAN TRENCH

The segment of the Aleutian trench adjacent to the Middleton shelf is believed to be an area of accumulation of thick deposits of Quaternary age. Subsidence and accumulation may have begun in Tertiary time.

POSSIBLE PETROLEUM PROVINCES

HECETA ISLAND AREA

In the Heceta Island area of the Prince of Wales geanticline Silurian rocks that may be favorable for petroleum are exposed in a synclinorium about 30 miles long and 10 to 25 miles wide. Included in this area are Heceta and Tuxekan Islands, the western part of Kosciusko Island, a small part of Prince of Wales Island, and many other small islands bordering on Davidson Inlet and Sea Otter Sound (pl. 1). These islands, part of the Alexander Archipelago of southeastern Alaska, are largely mountainous, with steep, cliffed shorelines and with peaks rising to altitudes of 2,000 to 3,000 feet.

Small portions of the islands are low-lying wave-planed surfaces. The islands are covered by dense forest up to an altitude of 2,200 feet.

The stratigraphic sequence and major structural features of the Kosciusko-Tuxekan-Heceta synclinorium are known mainly from shore traverses (Buddington and Chapin, 1929). Detailed mapping of Heceta and Tuxekan Islands from 1947 to 1949 by the Geological Survey (G. D. Eberlein, written communication) has provided additional geologic information bearing on the petroleum possibilities of the area. The geology of the part of the Heceta Island area lying south of latitude 56 degrees N. has been compiled by Condon (written communication).

The generalized sequence of Paleozoic rocks in the Heceta Island area, based on the report by Buddington and Chapin (1929) and on the written communication by Eberlein, is described in table 1.

TABLE 1.—*Stratigraphic sequence in Heceta Island area, southeastern Alaska.*

Age	Thickness (feet)	Character
Late Silurian	5,000+	Predominantly or entirely marine. Interbedded red, greenish-gray, and gray sandstone, in large part of graywacke type, with minor amounts of shale, limestone, limestone breccia, and fossiliferous white sandstone and conglomerate.
Late(?) and Middle Silurian	8,000+, locally	Marine. Massive pure limestone in beds as much as 2,000 feet thick. Local thick lenses of conglomerate, coarse breccia, and sandstone of graywacke type, in part formed on flanks of reefs.
		Unconformity?
Early Silurian	3,000±	Marine. Interbedded volcanic rocks, sandstone of graywacke type and conglomerate consisting largely of volcanic rocks or limestone. Locally underlies Middle Silurian limestone unit and rests on Ordovician rocks.
	Not known	Marine. Predominantly dark graphitic slate, with some interbedded sandstone of graywacke type, and some limestone and conglomerate. Locally underlies Middle Silurian limestone unit and rests on Ordovician rocks.
		Unconformity?
Early Silurian(?) Early and Middle Ordovician	4,000, locally	Marine. Slate, sandstone of graywacke type, and volcanic rocks.

The Middle and Upper Silurian rocks in portions of the Kosciusko-Tuxekan-Heceta synclinorium, especially on Heceta and Tuxekan Islands, are less altered than either Paleozoic or Mesozoic rocks in any other part of southeastern Alaska. Igneous intrusions are sparse or lacking in much of the synclinorium, although a large body of diorite has been mapped in the northeastern part of Kosciusko Island, and a small body of diorite is exposed in the central part of Marble Island. The two highest units of the Silurian rocks may include favorable source and reservoir beds. Reeflike structures have been found in Middle or Upper Silurian limestone units at several localities (G. D. Eberlein oral communication, 1955).

The Silurian rocks of the Heceta Island area form a major synclinal basin, modified by many minor folds and by faults. According to Buddington and Chapin (1929, p. 308), Eagle, Owl, Hoot, and White Cliff Islands on the east side of Davidson Inlet are in the core of a gentle anticlinal dome within the synclinorium. Some of the minor folds are reported to be broad and open, with flank dips of 20 degrees to 45 degrees.

So far as known the Heceta Island area has not heretofore been seriously considered as a possible petroleum province. No petroleum indications are known definitely to be present, although vague reports of oil seeps in the general area have come to the attention of the Geological Survey from time to time. Dark solid carbonaceous material has been observed in bioclastic limestone and associated limestone breccia of the Upper Silurian unit at several localities and in sandstone of the Upper Silurian unit at one locality (G. D. Eberlein, oral communication, 1955). Analyses and extraction tests of samples of the limestone breccia and the sandstone indicate, however, that the carbonaceous material is not derived from petroleum.

KEKU ISLANDS AREA

A thick sequence of rocks of Silurian to Cretaceous age in the area of the Prince of Wales geanticline may possibly be favorable for petroleum. These rocks occupy part of a synclinorium in the vicinity of the Keku Islands, at the north end of Keku Strait in southeastern Alaska. The area outlined on plate 1, about 25 miles long and 12 miles wide, embraces the known exposures of moderately deformed and relatively unaltered limestone and other marine sedimentary rocks which may, however, extend farther northwest and southeast in the Keku synclinorium, beneath volcanic rocks and other nonmarine deposits of the Admiralty trough. Much of this possible petroleum province lies beneath the waters of Frederick Sound, Saginaw Bay, and Keku Strait. The land area, including the southern tip of Admiralty Island, the Cornwallis Peninsula on Kuiu Island, and many small islands in Keku Strait, for the most part lies below 1,500 feet altitude and is heavily forested.

The geology of the Keku Islands area is described by Buddington and Chapin (1929) from reconnaissance investigations of the Geological Survey up to the midtwenties. The sequence of moderately deformed sedimentary and volcanic rocks of Silurian to Cretaceous age in this area totals at least 20,000 feet in composite thickness and includes the following marine units of possible interest for petroleum: dense limestone with intercalated beds of conglomerate, of Silurian age; coarsely crystalline limestone with thin beds of chert, of Mississippian age; conglomerate, limestone, sandstone, and black shale constituting a lower division of Permian age; limestone with intercalated layers of chert, constituting an upper division of

Permian age; conglomerate, limestone, sandstone, and black shale of Late Triassic age; and shale and sandstone of Early Cretaceous age. Limestone and calcareous conglomerate beds of the Silurian, Mississippian, Permian, and Triassic systems locally are highly fossiliferous. Much of the Mississippian limestone has a fetid odor when first broken, according to Buddington and Chapin.

Although indications of oil reportedly have been found in the Keku Islands area, no attempts are known to have been made, to the end of 1955, to explore the petroleum possibilities of this area. In 1944 a prospector told members of the Geological Survey that he had seen an oil seep near the southwest end of Admiralty Island, at a locality several miles inland from the head of Murder Cove or Herring Bay (G. M. Flint, Jr., written communication, 1956). J. C. Roehm, in an unpublished report of the Territory of Alaska Department of Mines, in 1947, referred to oil-saturated black shale and an oil seep near the southwest end of Admiralty Island, and to bituminous matter in limestone of Permian age on the Keku Islands.

COOK INLET MESOZOIC PROVINCE

The Cook Inlet Mesozoic province is a sinuous belt at least 750 miles long and 10 to 50 miles wide, and is characterized by a great thickness of unmetamorphosed marine sedimentary rocks of Jurassic and Cretaceous age. The Cook Inlet Mesozoic province [1] coincides approximately with the area of the Matanuska geosyncline as shown on plate 2, but excludes the part of this geosynclinal belt in the Chitina Valley, and includes a part of the northwest flank of the Seldovia geanticline on the Kenai Peninsula. The Cook Inlet Mesozoic province, as outlined on plate 1, has a land area of about 18,500 square miles.

The known and inferred geologic boundaries of the Cook Inlet Mesozoic province are shown on plate 3. From Kodiak Island and Becharof Lake northeastward the boundaries of the province are defined in part by exposed contacts of unmetamorphosed sedimentary rocks deposited in the Matanuska geosyncline with the volcanic rocks, intrusive igneous rocks, and metamorphosed or highly deformed sedimentary rocks of the Talkeetna and Seldovia geanticlinal belts. Inferred boundaries of the Mesozoic province beneath the Tertiary and Quaternary deposits along Cook Inlet and in the Copper River basin are rough projections of the regional geologic trends between areas in which the boundaries are defined by outcrops. On the east the boundary of the petroleum province is inferred

[1] This is a revision of the more cumbersome name "Alaska Peninsula-Cook Inlet Mesozoic province" used previously by Gryc, Miller, and Payne (1951, pp. 163–164).

to be approximately at the lower end of the Chitina Valley. Mesozoic marine sedimentary rocks deposited in the Matanuska geosyncline are exposed along the north side of the Chitina Valley, but in this area the sedimentary rocks have been invaded by igneous intrusions and mineralizing solutions to the extent that they are believed to be unfavorable for petroleum. Southwest of Kodiak Island and Becharof Lake the southeastern boundary of the Mesozoic province is concealed beneath the Pacific Ocean, and the northwestern boundary is concealed beneath Tertiary and Quaternary deposits on the Alaska Peninsula. In this area the boundaries are extended along regional geologic trends to Pavlof Bay, beyond which volcanic rocks predominate on the Alaska Peninsula.

The northeastern part of the Cook Inlet Mesozoic province is topographically a lowland belt between the high mountain chains of the Aleutian Range and the Talkeetna and Wrangell Mountains on the north, and the Kenai and Chugach Mountains on the south. Mountains rising to an altitude of 5,000 to 6,000 feet in the narrowest part of the province, between the Talkeetna and Chugach Mountains, form a divide between the Matanuska Valley-Cook Inlet lowland area draining to the southwest, and the southern Copper River basin-Chitina Valley lowland which drains southward through a deep canyon cut across the Chugach Mountains by the Copper River. From near the mouth of Cook Inlet southwest to Kamishak Bay the province includes rugged foothills of the Aleutian Range rising to altitudes of 2,000 to 4,000 feet. Southwest of Kamishak Bay in the Alaska Peninsula portion of the province, the Mesozoic rocks extend across the axis of the Aleutian Range, and, together with overlying Tertiary rocks, form mountains that rise to an average altitude of 4,000 feet. In this part of the province Cenozoic volcanic rocks extruded upon the Mesozoic and Tertiary sedimentary rocks form ridges and isolated peaks as much as 8,000 feet in altitude. From a drainage divide lying near the southeast coast on the Alaska Peninsula many small streams drain southeastward into Shelikof Strait and the Pacific Ocean, and larger rivers drain northwestward into Bristol Bay.

The major geologic features of the Cook Inlet Mesozoic province were established by reconnaissance and local, more detailed, investigations made by the Geological Survey between 1895 and 1931 (Atwood, 1911; Capps, 1922, 1935, 1940; Knappen, 1929; Martin, 1921, 1926; Martin, Johnson, and Grant, 1915; Martin and Katz, 1912; Mather, 1925; Moffit, 1927, 1938; Smith, 1925, 1926; Smith and Baker, 1924). Several of these investigations in the Alaska Peninsula and Chinitna districts had as their primary objective appraisal of the petroleum possibilities. Much geologic information resulting

506319—59——3

from field studies made by oil company geologists in connection with drilling in the Kanatak district from 1923 to 1926 and in the Chinitna district from 1938 to 1940, as well as information obtained from the drilling, has been released to the Geological Survey. The results of detailed mapping and stratigraphic studies carried out in this province since 1944 under the Geological Survey's program of petroleum investigations in southern Alaska are in part published (Imlay, 1952, 1953; Imlay and Reeside, 1954; Kirschner and Minard, 1949; Keller and Reiser, 1959; and Grantz, 1953), or are on file as War-Minerals Investigations.[2] Intensive field investigations were resumed by major oil companies in 1948, but little information resulting from these investigations or from recent drilling has been released for publication. At the end of 1955 two areas in the Cook Inlet Mesozoic province, on the Alaska Peninsula northeast of, and southwest of, the Chignik district (pl. 3), still were unmapped geologically.

STRATIGRAPHY

Marine sedimentary rocks of the Cook Inlet Mesozoic province are exposed principally in seven areas: the Herendeen Bay, Chignik-Aniakchak, and Kamishak-Kanatak areas of the Alaska Peninsula; the Chinitna and Seldovia areas at the mouth of Cook Inlet; and the Matanuska Valley-Nelchina area on the south and southeast flank of the Talkeetna Mountains (pl. 3). One or more generalized stratigraphic sections for each of these areas except the Seldovia area are shown on plate 4. The Mesozoic rocks exposed in the Chitina Valley also are shown in a composite section and are described here because of their possible bearing on the sedimentary sequence of rocks beneath the unconsolidated Quaternary deposits in the Copper River basin.

The oldest known sedimentary unit of possible interest for petroleum in the Cook Inlet Mesozoic province is limestone of Late Triassic age. Upper Triassic limestone interbedded with chert or volcanic rocks, ranging in thickness from 1,000 to 2,200 feet, is exposed in limited areas at Puale Bay in the Kanatak district, on Kamishak Bay, and in the Chinitna district and Seldovia area at the mouth of Cook Inlet. In the Chitina Valley a sequence of limestone and shale of Late Triassic age, totaling 6,000 feet, is extensively exposed. Where the basal contact relation has been observed the Upper Triassic limestone rests on a thick sequence of massive volcanic rocks of Triassic(?) or older age. At Puale Bay some limestone beds of Late Triassic age are abundantly fossiliferous, and some are re-

[2] Kellum, L. B., Davies, S. N., and Swinney, C. M., 1945, Geology and oil possibilities of the southwestern part of the Wide Bay anticline, Alaska: U. S. Geol. Survey prelim. rept. (map, charts, and text).

ported to be petroliferous. Here the overlying Lower Jurassic rocks consist of interbedded marine siltstone and tuffaceous sandstone, with some limestone near the base. The Lower Jurassic rocks exposed along Cook Inlet and in the Matanuska-Nelchina area, although predominantly volcanic, were deposited in part, and perhaps in large part, in a marine environment. In the Seldovia area it includes fossiliferous marine limestone.

The Middle and Upper Jurassic sequence of the Cook Inlet province consists of fossiliferous marine clastic sedimentary rocks with a maximum thickness of 15,000 to 20,000 feet. Similarity in fauna and lithologic characteristics in the separate areas of outcrop from the Herendeen Bay area on the southwest to the Nelchina area on the northeast give support to the inference that these are the deposits of a single geosynclinal trough—the Matanuska geosyncline—and are continuous between at least some of the areas of outcrop, though concealed by Cenozoic deposits or the shallow waters of Cook Inlet and Kamishak Bay.

Nearly all the known indications of petroleum in the Cook Inlet Mesozoic province are associated with the Middle and Upper Jurassic sequence of rocks. Sandstone beds that are potential reservoirs for petroleum are present throughout the rocks, although in outcrop and in wells drilled in the Kanatak and Chinitna districts the sandstone of Jurassic age has been found to be characteristically poorly sorted and low in porosity and permeability. Lenticularity of sandstone beds, abrupt lateral change in facies, and other features indicative of near-shore deposition, however, offer possibilities that sandstone with more favorable reservoir characteristics may be present locally. Several unconformities reflecting local uplift, folding, or faulting in Middle and Late Jurassic time (pl. 4) may also afford possibilities for reservoirs and stratigraphic traps.

Rocks of Cretaceous age are less extensive than the Middle and Upper Jurassic rocks in the Cook Inlet Mesozoic province but are believed to have possibilities for petroleum in the northern part of the province, from the Copper River basin southwest perhaps as far as Cook Inlet, and also in the southwestern part of the province, including the Herendeen Bay-Chignik area and possibly the Aniakchak area. The Lower Cretaceous series is represented by middle Neocomian (Valanginian) marine limestone consisting largely of finely comminuted shells in the Herendeen Bay area, and by similar limestone associated with sandstone, shale, and some conglomerate in the Nelchina area (pl. 4). The limestone in the Nelchina area is fetid when struck (Grantz, 1953). The Upper Cretaceous series is represented in the southwestern part of the province by 800 to 1,600 feet or more of marine and nonmarine clastic beds comprising the Chignik formation, and in the northern part of the province by about 10,000 feet of marine sandstone, siltstone, and shale of the Matanuska formation. Both the Chignik and Matanuska formations overlap onto Jurassic strata. Rocks of the Chignik formation at some localities in the Chignik district were reported by Knappen (1929, p. 110) to have a petroliferous odor when freshly broken. The Chignik formation on the northwest shore of Chignik Lagoon (southwest extension of Chignik Bay) is described by A. S. Keller and J. T. Cass (1956) as containing marine sandstones that are in part petroliferous.

The marine Upper Cretaceous sequence in the Katmai-Kamishak area, although possibly as much as 4,600 feet thick, is confined largely to areas of synclinal structure that are above drainage level (Keller and Reiser, 1959).

The Matanuska formation of Late Cretaceous age is extensively exposed in the Nelchina-Matanuska area. It may extend southwest of the Matanuska Valley, beneath Cook Inlet and the Cenozoic deposits of the adjoining lowland, and it is believed to be present beneath Cenozoic deposits in much of the southern part of the Copper River basin. The Matanuska formation is exposed at several localities in the basin, near its southwest margin, and about 700 feet of strata correlated with the Matanuska formation on lithologic characteristics and faunal evidence were penetrated by a test hole for water near Lake Louise, about 18 miles from both the west and the south margins of the basin (Arthur Grantz, oral communication, 1955). The Matanuska formation also has been identified faunally in the eastern part of the Chitina Valley, where it consists of about 8,000 feet of marine strata (Imlay and Reeside, 1954, p. 231). Favorable sedimentary rocks of Albian age may be present in the Copper River basin area of the Cook Inlet Mesozoic province, for marine beds of this age are exposed in a thickness of a few thousand feet in the Chitina Valley and are inferred to have been deposited also in or near the Nelchina area (p. 14). In the Matanuska Valley the nonmarine Arkose Ridge formation, consisting of arkosic sandstone and conglomerate possibly of Cretaceous age (Barnes and Payne, 1956, p. 10–12), may underlie the Matanuska formation.

In the southwestern part of the Alaska Peninsula, and locally farther north in the Kamishak-Katmai area, Upper Jurassic or Cretaceous rocks of the Cook Inlet Mesozoic province are overlain with generally minor structural unconformity by early Tertiary deposits of the Shelikof trough. The lower Tertiary rocks are largely nonmarine, including a widespread coal-bearing arkosic sandstone and shale formation, regarded as of Eocene age, and much fragmental volcanic material interbedded with lava flows. Marine strata of Eocene, Miocene and Pliocene(?) age are exposed in the Herendeen Bay area and the Shumagin Islands. With the possible exception of these marine strata, which appear to be of very limited extent on land, the Tertiary rocks offer little promise as a source of petroleum, but might conceivably serve as a reservoir for oil or gas derived from the underlying Mesozoic marine rocks. On the Alaska Peninsula, therefore, Tertiary deposits of the Shelikof trough are included in the Cook Inlet Mesozoic province, with regard to their petroleum possibilities. From the lower part of Cook Inlet northeastward in the Cook Inlet Mesozoic province the Mesozoic and Paleocene(?) rocks are overlain with marked angular unconformity by Eocene and younger Tertiary deposits whose petroleum possibilities are discussed separately under the Cook Inlet Tertiary province.

STRUCTURE

The Mesozoic and Paleocene(?) rocks of the Cook Inlet Mesozoic province are folded along trends which in general approximately parallel the axis of the Matanuska geosyncline, ranging from northeastward in the Alaska Peninsula to eastward in the Chitina Valley. Approximate structural conformity of the stratigraphic sequence from Upper Jurassic through upper Eocene on the Alaska Peninsula indicates that the major period of deformation in the southwestern part of the province was post-Eocene. In the northeastern part of the province, embracing the Chitina Valley and Nelchina-Matanuska areas and possibly all but the southwestern margin of the Cook Inlet area, the major period of deformation was earlier than late Eocene, possibly late Paleocene or near the beginning of the Tertiary. In this part of the province there was also locally important deformation or faulting during one or more stages in Jurassic and Cretaceous time.

In the Alaska Peninsula area and the Chinitna district the rocks of Mesozoic and early Tertiary age in general are gently folded or tilted. Several well-defined anticlines with flank dips of 5 degrees to 45 degrees, the largest 30 miles long, have been mapped in this area. From the north shore of Becharof Lake northeastward to the Chinitna district the province is bounded on the northwest by the Bruin Bay fault, a major high-angle thrust fault that dips northwestward. In the Kanatak-Kamishak area Upper Jurassic to lower Tertiary rocks locally are more tightly folded along easterly trends. An angular contact between Kialagvik and Shelikof formations of Jurassic age in the Kanatak district suggests the possibility of locally significant deformation in Bathonian or early Callovian time. Several stocklike bodies of quartz diorite, probably emplaced in Tertiary time, intrude Mesozoic and Tertiary rocks at several localities between Aniakchak Crater and Kamishak Bay. Deep-seated intrusions of this type are regarded by the writer as probably more unfavorable, insofar as petroleum possibilities are concerned, than mafic and intermediate intrusive bodies such as those associated with the Tertiary and Quaternary volcanoes of the Aleutian Range.

Rocks of Early Jurassic age in the vicinity of Seldovia form a northwestward-dipping homocline, complicated by minor folding and faulting. These rocks, although within the area of the Seldovia geanticline, are regarded as being more closely allied, structurally and stratigraphically, with the Mesozoic sequence of the Cook Inlet province, and as possibly indicative of the degree of deformation of the Mesozoic rocks inferred to underlie the adjacent part of the Kenai lowland and Cook Inlet.

In the Matanuska Valley the Cretaceous and associated earliest Tertiary rocks are moderately to tightly folded and are cut by many faults. This belt of rocks is in part bounded on the north by a zone of northward-dipping thrust faults. Along the south side of the Matanuska Valley the rocks of Mesozoic and early Tertiary age are in part in fault contact and in part in depositional contact with volcanic rocks or more highly altered sedimentary rocks of the Seldovia geanticlinal belt. In the upper part of the Matanuska Valley the Mesozoic and early Tertiary rocks are cut by many small bodies of intrusive igneous rock.

In the Nelchina area the Jurassic and Cretaceous rocks are gently to moderately folded and are cut by many high-angle faults. Faulting with attendant variable deformation, uplift, and tilting of different structural segments, at several stages during Mesozoic and early Tertiary time, afford possibilities for stratigraphic and structural traps for petroleum. These possibilities can be only partly assessed from surface data.

Moderately to gently folded and faulted Jurassic and Cretaceous rocks are inferred, from outcrops around the southwestern margin and within the Copper River basin, to underlie Cenozoic deposits in the southern part of the basin. Along the northern margin of the Chitina Valley and at the head of the Chitina Valley the Jurassic and Cretaceous rocks are much faulted and have been extensively invaded by intrusive rocks and mineralizing solutions.

INDICATIONS OF OIL AND GAS

Seeps of oil and gas on the Iniskin Peninsula in the Chinitna district reportedly were the first indications of petroleum to be discovered in Alaska. The known seeps are in the southern and central part of this peninsula (pl. 1). All the surface seeps of oil are in outcrop areas of the Tuxedni formation of Middle Jurassic age, but most or all also are on or near fault zones along which the oil could have migrated from a stratigraphically lower source. A well drilled near the northernmost of the oil seeps on the Iniskin Peninsula found shows of oil and gas from a depth of 4,600 feet to nearly the bottom of the well at 8,775 feet, in strata of Middle Jurassic and possibly Early Jurassic age. The gas seep near Dry Bay, in the southeastern part of the Iniskin Peninsula, is in alluvial deposits presumed to be underlain at shallow depth by the Chinitna formation of Late Jurassic age, and also is on or near an inferred fault.

Prospectors' reports of seeps of oil or oil with gas at two localities on Kamishak Bay, at the entrance to Bruin Bay and at the Mouth of the Douglas River, were regarded as reliable by Mather (1925, p. 176–177) but are classified as reported but not confirmed on plate 1. These seeps were not seen either by G. C. Martin or by Mather during their traverses on Kamishak Bay, nor were any oil seeps reported by oil company geologists who made a reconnaissance investigation of the Kamishak district in 1948 (Hazzard and others, 1950). The Naknek formation of Late Jurassic age is exposed at the localities of these reported seeps. A prospector also reported an oil seep associated with fossiliferous sandstone "on the west shore of Shelikof Strait about 20 miles southwest of Cape Douglas" (G. A. Parks, 1920, written communication). Fossiliferous marine sandstone of Jurassic and Cretaceous age is exposed in sea cliffs near Kaguyak, 25 to 30 miles southwest of Cape Douglas, but no seeps have been reported by several geological parties that have visited the area.

In the Kanatak district, active oil seeps and oil residues are found principally in two areas: southwest of Puale Bay in the vicinity of Oil Creek and on the Bear Creek-Salmon Creek anticline, and south of Becharof Lake on the Ugashik anticline. The flow of oil at the largest of these seeps was estimated in 1921 to be about half a barrel per day (Capps, 1922, p. 107). At some localities a paraffin residue covers areas as much as two or more acres in extent (Capps, 1922, p. 107–109; Smith, 1926, p. 86–87). In the seep area southwest of Puale Bay the oil and associated gas are issuing from the predominantly sandy upper part of the Shelikof formation. Sandy or conglomeratic beds of the lower part of the Naknek formation comprise the surface rocks at the oil seeps and residues on the Ugashik anticline. Wells drilled in the Kanatak district found shows of oil and gas, or oil residues, from the surface to a maximum depth of about 7,300 feet in the Naknek and Shelikof formations and in beds tentatively assigned to the Middle and Lower Jurassic.

At Wide Bay in the Kanatak district a small oil seep was found in 1924 in sandstone of the Kialagvik formation exposed at low tide in a reef on the northwest flank of the Wide Bay anticline (Smith, 1926, p. 84–85). Smith also observed thin veinlets of a solid hydrocarbon residue resembling gilsonite in the Kialagvik formation at several localities on Wide Bay. Seeps of an inflammable gas, presumably petroleum gas, have been observed near the head of the East Fork of the Kejulik River (Smith and Baker, 1924, p. 206) and on Gas Creek (Smith, 1925, p. 206), also a tributary of the Kejulik River. The gas seeps in the northern part of the Kanatak district are in the area of outcrop of the Naknek formation. According to Smith (1925, p. 206), the seeps on Gas Creek are on the surface trace of a minor eastward-trending fault. Small oil seeps reportedly seen in the Kejulik River valley were not found by a Geological Survey field party (Smith, 1925, p. 206). Some limestone beds of Late Triassic age exposed in the vicinity of Cape Kekurnoi on the northeast side of Puale Bay are petroliferous, according to G. D. Hanna (oral communication, 1955). No seeps or other indications of oil have been observed in the Upper Triassic sequence at this locality by members of the Geological Survey, although Kellum, Davies, and Swinney [2] described a "tar(?) sand" in overlying strata assigned to the Lower Jurassic.

Knappen (1929, p. 210) reported that rocks of the Naknek and Chignik formations have a distinct petroliferous odor at a few places in the Chignik district, particularly on the west side of Chignik Bay at the mouth of Dago Frank Creek and along the shore of Chignik Lagoon. In the course of a reconnaissance investigation of Chignik Lagoon in 1955 A. S. Keller and J. T. Cass (1956) found petroliferous sandstone in exposures of the Chignik formation on the northwest shore. Oil seeps reported at other localities in the northeastern part of the Chignik district and in the Aniakchak area (Smith and Baker, 1924, p. 209–210) have not been verified.

A U. S. Coast and Geodetic Survey party reported seeing an oil seep on the east shore of Andronica Island in 1913 (J. B. Miller, written communication, 1914, and Martin, 1921, p. 73). Only volcanic rocks of Cenozoic age have been mapped on this small island of the Shumagin group (Atwood, 1911, pl. 6).

To the end of 1955 no definite indications of oil were known that could be attributed to the Mesozoic and Paleocene(?) rocks in the Cook Inlet Mesozoic province north of the Chinitna district. In 1921 A. H. Brooks of the Geological Survey examined and sampled a supposed oil seep near the mouth of Chester Creek on the outskirts of Anchorage (Brooks, 1922). Although an analysis of the oil was said to be indicative of a natural crude oil, no further mention of

[2] Kellum, L. B., Davies, S. N., and Swinney, C. M., 1945, Geology and oil possibilities of the southwestern part of the Wide Bay anticline, Alaska: U. S. Geol. Survey prelim. rept. (map, charts, and text).

the seep can be found and several attempts in recent years to find a seep at the reported locality have failed. Unconsolidated Quaternary deposits at the locality of the reported seep probably are immediately underlain by early Tertiary nonmarine sedimentary rocks, similar to those that are exposed below high tide line on Knik Arm about 3 miles to the west. The Tertiary deposits have been found about 175 feet below sea level in a test well for water about 5½ miles to the northeast (Cedarstrom and Trainer, 1953). Prior to 1920, oil seeps had been reported at the mouth of the Little Susitna River and near Tyonek, presumably by prospectors (Martin, 1921, p. 72), but these seeps were not observed by several geologic parties that visited the localities before 1920 nor, so far as is known, have any seeps been reported there in recent years. Oil seeps reported recently at Goose Bay on Knik Arm and on Crooked Creek in the eastern part of the Nelchina area have not been verified.

A well drilled near Chickaloon in the Matanuska Valley is reported to have struck gas in association with coal (Smith, 1929, p. 60). The coal-bearing sedimentary rocks penetrated by this well are referred to the Paleocene(?) part of the sedimentary sequence in the Cook Inlet Mesozoic province. Other indications of gas shown in the northern part of the Cook Inlet Mesozoic province on plate 1 are believed to be associated with the Eocene or young Tertiary coal-bearing rocks and are described in the sections on the Cook Inlet Tertiary province and the Copper River basin.

EXPLORATION ACTIVITY

Claims were first staked in 1892 in the vicinity of Oil Bay and Dry Bay in the Chinitna district, but these were soon abandoned without any serious attempt to explore their petroleum possibilities. Claims were staked again at Oil Bay in 1896, at Dry Bay about 1901, and in the Kanatak district about 1902. Drilling was under way at Oil Bay at least by 1902 and possibly as early as 1898. Drilling began in 1903 in the vicinity of Oil Creek near Puale Bay (formerly Cold Bay) in the Kanatak district. More detailed information on the early exploration for petroleum in these districts is given in the report by Martin (1921, p. 52–54, 65–68).

Presence of surface indications of petroleum undoubtedly was the principal basis for selecting the locations of 11 wells drilled or started in the Chinitna and Kanatak districts between 1902 and 1906. Wells drilled in the Chinitna district during this period are on the southeast flank of the Fitz Creek anticline at locations ranging from a little less than 1 mile to a little less than 4 miles from the surface trace of the axis. Wells drilled at this time in the Kanatak district are in an area of gentle homoclinal dip, several miles northeast, but approximately along the projected trend, of the Bear Creek-Salmon Creek anticline.

Exploration activity in the Cook Inlet Mesozoic province fell off sharply after 1904 and was virtually at a standstill from 1906 through 1919. A few prospectors retained previously established title to claims in the Kanatak district after Alaskan oil lands were withdrawn from entry in 1910. Passage of the oil and gas leasing act of 1920 brought a new rush to obtain title to the known petroliferous areas of the province, particularly in the Kanatak district. Geologists of several different oil companies investigated this district in 1920 and 1921, with the result that drilling was begun by two companies in 1923 on the Pearl Creek dome, the more northerly of two structural highs on the Ugashik anticline. From 1923 to 1926 five wells were drilled to depths ranging from a few hundred feet to 5,034 feet on the Pearl Creek dome, without finding oil or gas in commercial quantity. These wells started in the lower part of the Naknek formation, and two reportedly bottomed in the upper part of the Shelikof formation. During the twenties some attention was given also to other parts of the Cook Inlet Mesozoic province where no definite indications of petroleum were known. Leases were taken near Anchorage, near the head of Cook Inlet, near Chickaloon, and at several localities on the Alaska Peninsula. A well drilled near Anchorage in 1920–1921 reportedly was abandoned before reaching bedrock. Between 1926 and 1930 drilling was carried on intermittently at a site about 2 miles west of Chickaloon in the Matanuska Valley (Smith, 1931, p. 77–78).

Leasing activity was revived in the Chinitna and Kanatak districts in 1933 and 1934. In 1936 a company was organized for the purpose of exploring a unitized group of oil and gas leases on the Fitz Creek anticline in the Chinitna district. A test well drilled on this structure in 1938 and 1939 was abandoned at a depth of 8,775 feet. An intensive geologic investigation of the Kanatak district in 1938, supported jointly by three major oil companies, resulted in selection of a test site on the Bear Creek-Salmon Creek anticline. The well started at this site in 1938 was abandoned in 1940 at a depth of 7,596 feet. These two test wells were the first in Alaska to be drilled with rotary equipment. Both wells found many shows of oil and gas, but suitable reservoir beds apparently were lacking.

No exploration was undertaken in the Cook Inlet Mesozoic province by private interests from 1941 through 1947, although some lease rights were retained during this period. In 1948 and 1949 a geological party supported jointly by two major oil companies investigated several areas in the province. Oil and gas leases covering part of the Kamishak district were taken in conjunction with this exploration, but were released following the 1948 field season. In

1952, oil company geologic investigations were resumed; brisk leasing activity during that year involved, for the first time, the Nelchina area. In each year from 1953 through 1955 exploration activity in the province increased over the previous year. Drilling started in 1953 at a site in the Nelchina area was suspended for the winter late in 1955 at a depth of 3,060 feet. In 1954 a test well was started in the Chinitna district, at a location on the Fitz Creek anticline about 3,000 feet south of the deep test drilled in 1938–39. Drilling at this location was suspended at a depth of 9,745 feet late in 1955. The seismograph was employed as an exploration tool for the first time in the Cook Inlet Mesozoic province in 1954. During 1955 exploration by drilling, geologic studies, or seismograph operations in the province was carried out by at least ten oil companies. At the end of 1955 about 1½ million acres within the known or inferred boundaries of the province were included in oil and gas leases granted or applied for.

Available information on wells drilled in search of petroleum in the Cook Inlet Mesozoic province through 1955 is summarized in table 2. This table includes one well, near Houston in the Susitna-Matanuska area, which is in the Cook Inlet Tertiary province outside the area inferred to be underlain by possibly favorable Mesozoic rocks, and two other wells, near Anchorage and near Goose Bay in the Susitna-Matanuska area, which are regarded as attempts to test the petroleum possibilities of both provinces. To the end of 1955 at least 23 test wells with an aggregate footage of about 53,000 were drilled or started in the Cook Inlet Mesozoic province. The deepest well was the Beal No. 1 in the Chinitna district, in which drilling was suspended at a depth of 9,745 feet in 1955. Shows of oil and gas were found in many of the wells, but none had attained commercial production to the end of 1955.

GULF OF ALASKA TERTIARY PROVINCE

The Gulf of Alaska Tertiary province (pl. 1) is an arcuate lowland-and-foothills belt in which sedimentary rocks of Tertiary age, representing the marine and nonmarine deposits of the Yakataga geosyncline, are exposed or are inferred to underlie lowland areas covered by Quaternary unconsolidated deposits or ice (pl. 5). The province borders the Gulf of Alaska from the Copper River delta 300 miles southeastward to Icy Point, and extends inland 2 to 40 miles to the southern front of the Chugach and St. Elias Mountains. The area of the province, excluding the known exposures of pre-Tertiary basement rocks within it, is about 5,200 square miles.

The Gulf of Alaska Tertiary province is characterized topographically by its relatively straight coastline, and by extensive coastal lowlands. Elsewhere about the Gulf of Alaska, in contrast, the coastline

TABLE 2.—*Wells drilled for petroleum in the Cook Inlet Mesozoic and Tertiary provinces, southern Alaska, through 1955*

Location No. (pl. 3)	Company and name of well	Location	Year	Total depth (feet)	Formation or deposit penetrated	Results
			Kanatak district			
1	J. H. Costello 1	Oil Creek area	1903	728	Upper Jurassic Shelikof formation.	Abandoned, crooked hole. Shows of oil.
2	J. H. Costello 2	do	1904		do	Not known; probably abandoned at shallow depth.
3	Pacific Oil & Commercial Co. 1	Trail Creek-Becharof Creek divide.	1903–4	1,421	do	Abandoned; strong flow of fresh water. Oil residue, shows of oil and gas.
4	Pacific Oil & Commercial Co. 2	Trail Creek	1904	1,542	do	Abandoned; *tools lost.* Shows of oil and gas.
5	Pacific Oil & Commerical Co. 3	Becharof Creek?	1902–4?		do	Not known; probably abandoned at shallow depth.
6	Associated Oil Co. Alaska 1	Barabara Creek area, Pearl Creek dome.	1923–6	3,033	Upper Jurassic; Naknek formation, upper part of Shelikof(?) formation.	Abandoned. Oil residue, shows of oil and gas.
7	Associated Oil Co. Finnegan 1	Ugashik Creek, Pearl Creek dome.	1923	560	Upper Jurassic Naknek formation.	Abandoned. Trace of oil.
8	Standard Oil Co. of California Lee 1.	Barabara Creek area, Pearl Creek dome.	1923–26	5,034	Upper Jurassic, Naknek and Shelikof formations.	Abandoned. Shows of oil and gas.
9	Standard Oil Co. of California Lathrop 1.	Pearl Creek, Pearl Creek dome	1923		Upper Jurassic Naknek(?) formation.	Not known; probably abandoned at shallow depth.
10	Standard Oil Co. of California McNally 1.	Ugashik Creek, Pearl Creek dome.	1925	510	Upper Jurassic Naknek formation.	Abandoned.
11	Standard Oil Co. of California Grammer 1 (drilled jointly with Tide Water Associated Oil Co. and Union Oil Co. of California).	Salmon Creek, Bear Creek-Salmon Creek anticline.	1938–40	7,596	Upper Jurassic Shelikof formation; Middle Jurassic Kialagvik formation. Lower Jurassic(?), Triassic(?).	Abandoned. Oil residue; shows of oil and gas.
			Chinitna district			
12	Alaska Petroleum Co. 1	Bowser Creek, southeast flank of Fitz Creek anticline.	1900?; 1902–3	1,000–?	Middle Jurassic Tuxedni formation.	Abandoned; strong flow of salt water. Strong shows of oil and gas.
13	Alaska Petroleum Co. 2	do	1904	450	do	Abandoned, caving. Shows of oil and gas.
14	Alaska Petroleum Co. 3	do	1904	900	do	Abandoned. Initial production of 10 barrels per day reported; shows of gas.
15	Alaska Petroleum Co. 4	do	1906?		do	Not known; probably abandoned at shallow depth.

16	Alaska Oil Co. 1	Brown Creek, southeast flank of Fitz Creek anticline.	1902	320	Upper Jurassic Chinitna formation.	Abandoned, tools lost.
17	Alaska Oil Co. 2	do	1903		do	Abandoned at shallow depth, accident to drilling equipment.
18	Iniskin Drilling Co. I.B.A. 1	Fitz Creek, Fitz Creek anticline	1938–9	8,775	Middle Jurassic Tuxedni formation, Lower Jurassic(?).	Abandoned near limit of drilling equipment. Produced small amount of oil; shows of gas.
19	Iniskin Unit Operator Inc. Beal 1	Head of Brown Creek, Fitz Creek anticline.	1954–55		do	Drilling suspended October 1955 at 9,745 ft.
			Susitna-Matanuska area			
20	Anchorage Oil & Development Co.	Oil Well Road, Anchorage	1920–21	300±	Quaternary unconsolidated deposits.	Abandoned.
21	Peterson Oil Association Chickaloon 1.	Drill Lake 2 miles west of Chickaloon.	1926–30	1,465	Lower Tertiary coal-bearing rocks; intrusive(?) igneous rocks.	Abandoned. Shows of gas.
22	Anchorage Gas & Oil Development Co., Inc. Houston 1.	Alaska Railroad, 1 mile northwest of Houston.	1954–55		Lower Tertiary(?) coal-bearing rocks.	Drilling suspended October 1955 at 2,145 ft.
23	Alaska Gulf Oil & Gas Co	Near Goose Bay, west shore of Knik Arm.	1955	3,855	Quaternary unconsolidated deposits, Tertiary coal-bearing rocks.	Abandoned.
			Nelchina area			
24	Aledo Oil Co. and Alaska Oil & Gas Development Co. Eureka 1.	Glenn Highway, 3 miles southwest of Eureka Roadhouse.	1953–55		Upper Cretaceous, Matanuska formation.	Drilling suspended October 1955 at 3,060 ft.

is extremely irregular and the mountains rise abruptly from the shore. The bedrock uplands developed in the Tertiary sedimentary sequence include (a) isolated groups of hills and unnamed mountains with summit altitudes ranging from 2,000 to 5,000 feet in the Katalla district; (b) the Robinson Mountains rising to a maximum altitude of 9,000 feet in the Yakataga district; (c) the Chaix and Samovar Hills and other hills rising to 4,000–6,000 feet along the northern margin of the Malaspina Glacier; and (d) the seaward, partly wave terraced portion of a narrow ridge extending up to an altitude of 3,500 feet in the Lituya district. Despite the relatively mild climate at sea level, about one-fifth of the province is covered by glaciers or by permanent ice and snow fields. Most of the drainage is by short swift streams originating in glaciers. Well-drained lowland areas and lower slopes up to an altitude of about 1,500 feet are covered by a dense growth of forest and underbrush.

The principal published sources of information on the geology of the Gulf of Alaska Tertiary province, all based on investigations prior to 1921, are reports on the Katalla and Yakataga districts by Martin (1908, 1921), Maddren (1914), and Taliaferro (1932); on the Malaspina and Dry Bay districts by Russell (1891, 1893), Tarr and Butler (1909), and Blackwelder (1907); and on the Lituya district by Mertie (1933). Geologic studies carried out intermittently in the province from 1944 to 1954 under the Geological Survey's program of petroleum investigations in southern Alaska are described in several reports published (Miller, 1951a, 1951b, 1953a, 1957; Plafker and Miller, 1957) or released as War-Minerals Investigations.[3]

STRATIGRAPHY

Marine and nonmarine sedimentary rocks of Tertiary age exceeding 25,000 feet in maximum thickness and resting with angular unconformity on metamorphosed sedimentary and volcanic rocks of presumed Mesozoic and older age make up the bedrock in the Gulf of Alaska Tertiary province. The Tertiary rocks include deposits formed during each of the epochs from Eocene to Pliocene and undoubtedly form a continuous belt, in part concealed by large glaciers and ice fields, that extends from the Katalla district through the Yakataga and Malaspina districts to the west shore of Yakutat Bay. Rocks of Tertiary age also are exposed in a narrow belt between Lituya Bay and Icy Point in the southeastern part of the Lituya district, and are present in a small outlier near Cape Fairweather in the northwestern part of the Lituya district. In the Yakutat district, between Yakutat Bay and Cape Fairweather, the mountains

[3] Miller, D. J., Rossman, D. L., and Hickcox, C. A., 1945, Geologic and topographic map and sections of the Katalla area, Alaska: U. S. Geol. Survey prelim. rept. (map and text).

at the inner margin of the coastal plain so far as known are composed of metamorphic rocks of pre-Tertiary age. It is probable, however, that Tertiary rocks are continuous between the exposures on Yakutat and Lituya Bays, at least offshore and possibly also beneath the coastal plain.

Plate 6 shows one or more generalized stratigraphic sections in each of the districts where Tertiary rocks are exposed. Three major subdivisions of Tertiary rocks are recognized on the basis of gross lithologic characteristics and fossil evidence. These units are believed to correspond to major changes in the depositional environment of the Yakataga geosyncline. The oldest unit, of Eocene and possibly early Oligocene age, consists predominantly of interbedded or intertonguing nonmarine coal-bearing strata and shallow marine or brackish water strata. Fossil plants and marine invertebrates in this unit are regarded as indicating subtropical to temperate climate on land and tropical to warm-temperate marine environment. This unit includes the Kushtaka, Stillwater, and Tokun formations in the Katalla district, and the Kulthieth formation in the Yakataga and Malaspina districts. It is not represented in the exposed Tertiary sequence of the Lituya district.

The middle unit, formed in middle Oligocene to approximately middle Miocene time, is characterized by massive concretionary mudstone and siltstone, believed to have been deposited in moderately deep water, in part in a reducing environment. Local volcanic activity is indicated by interbedded marine tuff and agglomerate. This unit is highly organic at some places, and many of the known indications of petroleum in the Katalla and Yakataga districts are associated with it. The unit includes the lower and middle parts of the Katalla formation in the Katalla district, the Poul Creek formation in the Yakataga district, and the basal part of the exposed Tertiary sequence in the Lituya district. It is absent in the exposed Tertiary sequence in the Malaspina district, where the early and late Tertiary units are in unconformable contact.

The youngest unit, deposited during the time interval from middle or late Miocene to late Pliocene or possibly earliest Pleistocene, consists of shallow marine sandstone and siltstone interbedded with marine tillite ("conglomeratic" sandy mudstone). The marine invertebrate fauna, on the whole, indicates considerably colder water than in earlier Tertiary time, and the marine glacial deposits indicate rigorous glaciation of adjacent land areas. This unit is represented by the upper part of the Katalla formation in the Katalla district, by the Yakataga formation in the Yakataga and Malaspina districts, by the upper part of the unnamed sequence in the Lituya district, and by strata exposed on Middleton Island, a small island in the Gulf of Alaska 80 miles southwest of Cordova (Miller, 1953).

STRUCTURE

In late Tertiary or early Pleistocene time the Chugach-St. Elias Mountain chain was uplifted along an arcuate northward-dipping fault system, and the bordering belt of Tertiary sedimentary rocks was folded and displaced along many high-angle thrust faults. The largest of these faults, the Chugach-St. Elias fault, has been traced along the southern front of the Chugach and St. Elias mountains from the delta of the Copper River to Yakutat Bay, a distance of 180 miles. This fault, which dips 30°–60° N., is estimated to have a stratigraphic throw of not less than 10,000 feet. In the Lituya district the Fairweather fault, lying in a great trench at the base of the Fairweather Range, bounds the Tertiary province.

The major thrust faults and grain of folding in the Tertiary rocks in general parallel the trend of the bordering fault system along the Chugach-St. Elias front; the intensity of folding and magnitude of displacement along faults increases toward the mountain front. Transverse trends in the western part of the Katalla district apparently are related to the northward-trending Ragged Mountain fault that exposes the pre-Tertiary basement rocks. In the Katalla district the folds are typically of small amplitude, tightly compressed, and asymmetric, the axial planes being inclined to the west or north.

In the Yakataga district three belts of differing structural pattern are recognized: In the belt nearest the Chugach-St. Elias fault the Tertiary rocks show intense minor folding with much overturning, and are displaced along many northward-dipping high-angle thrust faults, which in general are subparallel to the axial planes of the folds. In the intermediate belt the folds are of small amplitude but relatively long, and are less tightly compressed and more widely spaced. The belt nearest the coast is characterized by broad synclines and narrow, tightly pinched, asymmetric, longitudinally faulted anticlines.

In the Malaspina district, faulting and uplift predominated over folding during the late Cenozoic orogeny, for the youngest Tertiary strata are only broadly folded or gently tilted. At least two earlier stages of deformation and uplift within the Tertiary period are recorded by angular unconformities within the Kulthieth and Yakataga formations, and by overlap of the upper part of the Yakataga formation on early Tertiary and pre-Tertiary rocks.

Near Lituya Bay in the Lituya district the narrow belt of Tertiary rocks is folded into a shallow syncline and a strongly asymmetric anticline. These folds pass to the southeast into a seaward-facing homocline which, at Icy Point, is overturned. Upper Tertiary rocks in the outlier in the northern part of the Lituya district form a broad syncline trending northwest.

INDICATIONS OF OIL AND GAS

The abundant oil and gas seeps in the Katalla and Yakataga districts, which were discovered about 1896, first attracted attention to the petroleum possibilities in the Gulf of Alaska Tertiary province, and undoubtedly have been the most important factor in encouraging exploration. The stratigraphic occurrence of most of the oil seeps and other indications of petroleum points to probable sources in the lower and middle part of the Tertiary sequence. Pre-Tertiary rocks exposed in and adjacent to the province, including rocks possibly as young as Late Cretaceous, are believed to be unfavorable for petroleum.

In the Katalla district the known oil seeps, as well as indications of oil in wells, are confined to a narrow eastward-trending belt near the coast. Martin (1921, p. 29–30) inferred that the oil is coming from relatively undisturbed Mesozoic rocks lying beneath complexly deformed and overthrust Tertiary rocks, citing as evidence the occurrence of seeps in a belt diagonal to structural trends in Tertiary rocks, and the similarity of the oil to that from seeps in the Jurassic rocks of the Alaska Peninsula-Cook Inlet area. More recent investigations have shown that most of the oil seeps actually are in the outcrop area of the middle part of the Katalla formation, which locally includes a petroliferous, highly organic shale. On the west flank of Ragged Mountain in the western part of the Katalla district, however, oil resembling that found elsewhere in the district seeps from hard siltstone and sandstone of probable early Tertiary age, and also from pre-Tertiary metamorphic rocks near the contact with the early Tertiary(?) strata.

In the Yakataga district the known oil seeps are in the area of outcrop of the Poul Creek formation and lower part of the Yakataga formation. Nearly all the oil seeps are on or near the faulted crest of the Sullivan anticline, which lies near the coast. A well that was drilled in 1954–55 on this structure found shows of oil and gas in strata tentatively correlated with the lower part of the Poul Creek formation and the Kulthieth formation.

In the course of the Geological Survey's investigation of the Malaspina district in 1953 and 1954, many large oil seeps were found in the Samovar Hills at the north margin of the Malaspina Glacier. The oil issues from the Kulthieth formation, which at this locality consists of interbedded marine and nonmarine strata, and from interbedded argillite and graywacke of the Yakutat group of Late(?) Cretaceous age near the contact with the Kulthieth formation. Reports of oil seeps near the east shore of Icy Bay (Maddren, 1914, p. 114; M. M. Miller, written communication, 1947) have not been verified.

The writer in 1952 noted an oily film and petroliferous odor in Tertiary sandstone exposed at the crest of an anticline on Topsy Creek, about 5 miles southeast of Lituya Bay in the Lituya district. No other indications of petroleum are known definitely in the Gulf of Alaska Tertiary province southeast of Yakutat Bay, although oil films have been reported on Yakutat Bay (Tarr and Butler, 1909, p. 169–170) and near Cape Spencer (Martin, 1921, p. 72), and northwest of Lituya Bay.

EXPLORATION ACTIVITY

Prospectors looking for gold are reported to have discovered the oil and gas seeps in the Katalla and Yakataga districts about 1896. By 1900 large tracts in both districts were staked for petroleum exploration under the placer mining laws, and the first well was drilled in the Katalla district in 1901. In 1902 the second well drilled near the discovery oil seeps at the head of Katalla Slough struck oil at shallow depth. The early history of the development of the Katalla field, as well as exploration elsewhere in the Katalla district and in the Yakataga district up to 1920, is described by Martin (1921, p. 11–15, 39–40). Drilling was continued intermittently in the Katalla district until 1932, and one well was drilled in the Yakataga district during the period 1926–27. Production ceased at the Katalla field when part of the refinery was destroyed by fire in December 1933. Interest in the petroleum possibilities of the Gulf of Alaska Tertiary province was revived briefly in the late thirties, when new applications for oil and gas leases were filed, and geologic investigations of the Katalla and Yakataga districts were made jointly by three major oil companies.

New impetus was given to the search for petroleum in this province in 1951, when applications for oil and gas leases covering nearly a million acres in the Katalla and Yakataga districts were filed by a large group cooperating as the Northern Development Company. In 1953 the Phillips Petroleum Company and Kerr-McGee Oil Industries, Inc., entered into a development contract with the U. S. Department of the Interior for exploration of the Northern Development Co. lease tract and other adjoining leases in the Yakataga district. Under this exploration prorgam one well located on Big River in the Yakataga district was drilled and abandoned in 1954, and a second well located on Little River was drilled during 1954–55 and abandoned late in 1955. At the end of 1955 oil and gas leases covering about 2 million acres in the Gulf of Alaska Tertiary province, or more than half of the total area of the province, were in effect or applied for.

Between 1901 and the end of 1955 about 47 wells were drilled or started in search of oil in the Gulf of Alaska Tertiary province. These wells are listed in table 3, which incorporates information

TABLE 3.—*Wells drilled for petroleum in the Gulf of Alaska Tertiary province, southern Alaska*

Location No. (pl. 5)	Company and name or number of well[1]	Location	Year	Total depth (feet)	Formation or deposit penetrated	Results
			Katalla district			
1	Alaska Steam Coal & Petroleum Syndicate (ASC&PS) (A).	Head of Katalla Slough	1901	270	Miocene and (or) Oligocene. Katalla formation.	Abandoned; tools lost. Show of oil.
2	ASC&PS (1)	Katalla field	1902–3	550	do	Discovery well of Katalla field; struck flow of oil at 366 ft in 1902. Produced intermittently, 1902–33.
3	ASC&PS (2)	do	1903	1,000±	do	Oil at 700 ft. Produced intermittently 1912–33.
4	Alaska Petroleum & Coal Co. 1 (110).	Near head of Katalla Slough	1903	1,710	do	Abandoned at limit of drilling equipment. Small shows of oil reported.
5	Alaska Petroleum & Coal Co. 2 (111).	Katalla River	1903	280	Quaternary unconsolidated deposits.	Abandoned.
6	Company not known (102)	East shore of Bering River	1903	580	do	Abandoned.
7	ASC&PS (3)	Katalla field	1904	900±	Miocene and (or) Oligocene, Katalla formation.	Produced 1912–33.
8	ASC&PS (B)	do	1904		do	Not known; probably abandoned at shallow depth.
9	ASC&PS (C)	do	1904		do	Not known; probably abandoned at shallow depth.
10	ASC&PS (103)	Chilkat Creek	1904	400±	do	Abandoned; tools lost.
11	ASC&PS (104)	Near mouth of Chilkat Creek	1904	650±	do	Abandoned; tools lost? Shows of oil and gas.
12	ASC&PS (105)	do	1904	800±	do	Shows of oil and gas; not tested for production?
13	ASC&PS (108)	Mitcher Creek	1904	1,000±	do	Show of oil; not tested for production.
14	Alaska Petroleum & Coal Co. 3 (112).	Near Katalla	1904	1,500±	do	Abandoned.
15	Clarence Cunningham 1 (106)	Near Point Hey	1904		Quaternary unconsolidated deposits.	Abandoned at shallow depth.
16	Clarence Cunningham 2 (107)	do	1904		Miocene and (or) Oligocene, Katalla formation.	Abandoned at depth of several hundred feet.
17	Alaska Petroleum & Coal Co. 4 (113).	Near Katalla	1905–6		do	Abandoned at depth probably exceeding 1,500 ft.
18	Rathbun well (101)	West shore of Bering Lake	1905–6	1,700±	Eocene, Tokun(?) formation	Abandoned; small flow of gas in 1945.
19	Alaska Petroleum & Coal Co. 5 (114).	Near Katalla Slough	1907	1,600	Miocene and (or) Oligocene, Katalla formation.	Abandoned.
20	Alaska Coal Oil Co. 1 (115)	Mirror Slough	1911–17	1,040	Lower Tertiary(?)	Abandoned. Shows of oil and gas at 700 ft.
21	Alaska Coil Oil Co. 2 (116)	do		272	do	Abandoned.
22	Alaska Coil Oil Co. 3 (117)	do		250±	do	
23	Amalgamated Development Co. (4).	Katalla field	1912	690	Miocene and (or) Oligocene, Katalla formation.	Oil between 400 and 500 ft; produced 1912–33.
24	Amalgamated Development Co. (5).	do	1912	1,000±	do	Oil at 650 and 800 ft; produced 1912–33.
25	Amalgamated Development Co. (6).	do	1912	100±	do	Abandoned, tools lost.

TABLE 3.—*Wells drilled for petroleum in the Gulf of Alaska Tertiary province, southern Alaska*—Continued

Location No. (pl. 5)	Company and name or number of well[1]	Location	Year	Total depth (feet)	Formation or deposit penetrated	Results
			Katalla district—Continued			
26	Amalgamated Development Co. (7).	Katalla field	1912	645	Miocene and (or) Oligocene, Katalla formation.	Oil at 300–450 ft; produced 1912–33.
27	Amalgamated Development Co. (8).	do	1913	1,100±	do	Small amount of oil between 700 and 800 ft; produced briefly in 1917.
28	St. Elias Oil Co. (9)	do	1917	1,810	do	Abandoned; small amounts of oil at 650 and 1,000 ft; gas at 350 ft.
29	St. Elias Oil Co. (109)	Near Katalla field	1917	1,613	do	Abandoned, caving. Small amounts of oil at 1,050, 1,230, and 1,613 ft, gas at 260, 290, 460, and 1,520 ft.
30	St. Elias Oil Co. (11)	Katalla field	1918	1,130	do	Oil at 490 and 590–1,000 ft, gas at 380 and 475 ft; produced 1918–33.
31	St. Elias Oil Co. (12)	do	1918	903	do	Oil at 330, 430, and 590 ft; produced 1918–33.
32	St. Elias Oil Co. (13)	do	1918–19	900	do	Oil at 635 and 770 ft, gas at 637 ft; produced 1919–33.
33	St. Elias Oil Co. (14)	do	1919–20	2,265	do	Abandoned; shows of oil and gas.
34	Chilkat Oil Co. (16)	do	1920	740?	do	Oil at 365, 510 and 740 ft; produced 1920–33.
35	Chilkat Oil Co. (17)	do	1920	903	do	Produced 1920–33.
36	Chilkat Oil Co. (18)	do	1921	1,000	do	Produced 1921–33.
37	Chilkat Oil Co. (19)	do	1921–22	1,465	do	Produced 1922–33.
38	Chilkat Oil Co. (20)	do	1922	1,202	do	Produced 1922–33.
39	Chilkat Oil Co. (21)	do	1922	1,751	do	Produced 1922–33.
40	Chilkat Oil Co. (22)	do	1923?	1,280	do	Produced 1923?–33.
41	Chilkat Oil Co. (23)	do	1925	1,160	do	Produced 1925–33.
42	Chilkat Oil Co. (24)	do	1925–26	2,350	do	Abandoned.
43	Chilkat Oil Co. (25)	do	1931–32	2,005	do	Abandoned. Show of gas.
44	Alaskan Gulf Syndicate Johnson 1 (118).	Nichawak Mountain	1930	190	do	Abandoned.
			Yakataga district			
45	General Petroleum Corp. Sullivan 1.	Johnston Creek; south flank of Sullivan anticline.	1926–27	2,005	Miocene and (or) Oligocene, Poul Creek formation.	Abandoned. Shows of oil and gas.
46	Phillips Petroleum Co. and Kerr-McGee Oil Industries, Inc. Sullivan Strat. 1.	Head of Big River; Sullivan anticline?	1954	4,837	do	Abandoned, strong flow of slightly saline water.
47	Phillips Petroleum Co. and Kerr-McGee Oil Industries Inc. Sullivan 1.	Near head of Little River	1954–55	10,013	Miocene(?) and Oligocene, Poul Creek formation, Eocene(?), Kulthieth(?) formation.	Abandoned; shows of oil and gas reported.

[1] Numbers and letters in parentheses are well designations adopted by Martin (1921) and extended in later reports on the Katalla district (Miller, 1951b, and Miller, D. J., Rossman, D. L., and Hickcox, C. A., 1945, Geologic and topographic map and sections of the Katalla area, Alaska: U.S. Geol. Survey prelim. rept.

assembled by G. C. Martin (1921, p. 21–25) on drilling up to 1920. The total footage drilled is about 60,000 feet, and the greatest depth reached is 10,013 feet.

During the 32-year period from 1902 to 1933 the Katalla field produced about 154,000 barrels of paraffin-base oil having a gravity of 41°–45° Bé. Of the 28 wells drilled in the Katalla field, 18 in an area of about 60 acres produced oil from fractured sandstone and siltstone of the Katalla formation, at depths ranging from 360 to 1,750 feet. The field is believed to be in a fault zone. Most of the productive wells are on a claim patented under the placer mining law prior to enactment of the oil and gas leasing law.

COOK INLET TERTIARY PROVINCE

The Cook Inlet Tertiary province (pl. 1) includes the Cook Inlet basin, a topographic basin floored by Quaternary unconsolidated deposits; and also bordering low-lying areas in which early Tertiary deposits of the Shelikof trough are exposed. Nonmarine sedimentary rocks of Eocene or younger Tertiary age are believed to underlie much of the Cook Inlet Tertiary province. Marine rocks of Tertiary age conceivably may be present also. The province is bounded on the southeast by the Kenai and Chugach Mountains, on the north and northeast by the Talkeetna Mountains, and on the northwest by the Alaska and Aleutian Ranges. The boundary on the southwest is an arbitrarily chosen line drawn across lower Cook Inlet from Chinitna Bay to Kachemak Bay. The province embraces an area of about 9,500 square miles, of which about 4,100 square miles is covered by the shallow waters of Cook Inlet, Turnagain Arm, and Knik Arm. In the southeastern part of the Cook Inlet Tertiary province, the Eocene or younger Tertiary rocks are inferred to be underlain by the predominantly marine deposits of the Matanuska geosyncline. The possibilities for petroleum in these older rocks were discussed in the section on the Cook Inlet Mesozoic province.

Most of the land area of the Cook Inlet Tertiary province ranges from sea level to about 400 feet in altitude and is in part poorly drained and dotted with lakes and swamps. Early Tertiary sedimentary rocks form hills with a maximum altitude of 3,000 feet on the Kenai Peninsula north of Kachemak Bay, and also are exposed in, or are inferred to underlie, the piedmont slopes and foothills of the bordering mountains up to about the same altitude. In the Susitna valley some isolated hills of pre-Tertiary rocks rise to a maximum altitude of about 4,500 feet. The province is drained by the Susitna and Matanuska Rivers, and by many other small streams that are tributary to Cook Inlet or its extensions in Knik Arm, Turnagain Arm, and Kachemak Bay.

The principal sources of information on the geology of the area included in the Cook Inlet Tertiary province are regional reports based on reconnaissance mapping (Martin, Johnson, and Grant, 1915; Capps, 1913, 1935, 1940) and reports describing more detailed local investigations of coal deposits, including reports published (Barnes and Payne, 1956; Barnes and Cobb, 1959; and Barnes and Sokol, 1959) or placed in open file (Barnes, 1955; Cobb, 1950, 1951, and 1952). Seismic investigations and drilling undertaken in this province by oil companies in 1954 and 1955 undoubtedly have yielded critically needed information on the subsurface geology, but because of its potential economic value this information had not been made public at the end of 1955.

STRATIGRAPHY

Unconsolidated to moderately well indurated coal-bearing sedimentary rocks of known or probable Eocene or younger Tertiary age are exposed in many discontinuous areas in the Cook Inlet Tertiary province. The principal areas of outcrop are shown on plate 3. These rocks also have been penetrated by a well drilled for water through the unconsolidated deposits near Anchorage (p. 35) and by a test well for petroleum drilled in 1955 near the west shore of Knik Arm. The Eocene or younger Tertiary coal-bearing rocks have been studied in greatest detail in the Homer district, which includes the southern half of the Kenai lowland. In this district Tertiary rocks, which have been named the Kenai formation, consist of partly indurated sand, silt, and clay with thin conglomerate lenses and many thin beds of subbituminous coal or lignite (Barnes and Cobb, 1959). Nearly continuous exposures of the formation in the beach bluffs on the north shore of Kachemak Bay have a composite thickness of 4,700 feet. The total thickness, according to Barnes and Cobb, may be much more than this. Neither the base nor the top of the Kenai formation has been identified in the Homer district. On the south side of Kachemak Bay, horizontal leaf-bearing beds that have been correlated with the Kenai formation (Martin, Johnson, and Grant, 1915, p. 83, 87), rest with angular contact on Lower Jurassic beds.

In the Little Susitna district, on the north side of the western extremity of the Matanuska Valley, coal-bearing rocks of Tertiary age resembling the Kenai formation are exposed in a thickness of a few tens of feet in scattered small outcrops and in strip-mine cuts (Barnes and Sokol, 1959). At least 1,200 feet of these coal-bearing rocks was penetrated by diamond-drill holes near Houston, at the west end of the Little Susitna district. In the eastern part of the Little Susitna district, according to the report by Barnes and Sokol, 600 feet of moderately indurated pebble conglomerate and sandstone exposed in the southern part of the Little Susitna canyon appears to dip beneath the nearest outcrop of the coal-bearing rocks. The two sequences of rock were not observed in contact, however, and their relationship is not definitely established. In the Wishbone Hill district, which is farther east in the Matanuska Valley and just beyond the boundary of the Cook Inlet Tertiary province as shown on plate 1, only the uppermost part of the Tertiary rocks, the Tsadaka formation (Barnes and Payne, 1956, p. 19–20), is regarded as the equivalent of the relatively undeformed Eocene or younger Tertiary rocks that characterizes the Cook Inlet Tertiary province. In this district the Tsadaka formation, including 700 feet or more of conglomerate, sandstone and siltstone, rests with angular contact on the more highly deformed Wishbone and Chickaloon formations, which are regarded as probably of Paleocene or possibly early Eocene age (Barnes and Payne, 1956, p. 13) and as the youngest deposits of the Matanuska geosyncline.

In the Skwentna-Chulitna area, at the northwest margin of the Cook Inlet Tertiary province, lignite-bearing unconsolidated to loosely consolidated clay, sand, and gravel is exposed in a maximum thickness of 900 feet (Capps, 1913, p. 28–36). This sequence of rock, presumed to be Eocene in age, rests with angular contact on highly deformed slate and graywacke of Mesozoic age and is overlain with apparent structural conformity by 500 to 1,100 feet or more of coarse gravel possibly of Oligocene or younger Tertiary age. Farther south along the northwest margin of the province, in the vicinity of Straight Creek, the exposed thickness of the early Tertiary coal-bearing rocks, including some interbedded volcanic deposits, may be as much as 2,000 feet (Capps, 1935, p. 60–65).

About 1,000 feet of friable sandstone, conglomerate and shale, with beds of lignite as much as 15 feet thick, is exposed in the beach cliffs on the west shore of Cook Inlet at Tyonek (Atwood, 1909, Brooks, 1911, p. 94–103). Similar beds exposed along the Beluga River north of Tyonek, according to Atwood (1909, p. 120–121), may be divisible into two units separated by an unconformity. A coal bed 20 to 30 feet thick is exposed on the Beluga River about 9 miles above the mouth (Barnes, 1955). In 1949 the writer observed coal-bearing sandstone and shale exposed in a thickness of at least a few hundred feet in beach cliffs on the west shore of Cook Inlet at Redoubt Bay and south of Point Harriet (west of Kalgin Island). Coal is reported to have been mined on Kalgin Island (Eric Fribrock, written communication, 1949). No exposures of Tertiary bedrock were seen during the writer's traverse around this island in 1949, but the many large blocks of friable coal in glacial deposits near the south end indicate that Tertiary rocks lie near the surface there, if they are not exposed. Tertiary conglomerate, sandstone and siltstone a few hundred feet thick are exposed north of the entrance to Chinitna Bay in the Chinitna district (Martin and Katz, 1912, p. 77–78; Arthur Grantz, oral communication, 1955). At this locality Tertiary rocks rest with a small angle of discordance on the Naknek formation of Late Jurassic age.

STRUCTURE

The Eocene or younger Tertiary sedimentary rocks at most of the areas of outcrop in the Cook Inlet Tertiary province are nearly flat lying or only gently tilted or folded. At most localities along the northwestern margin of the province the Tertiary beds dip eastward at an angle ranging from a few degrees to 15 degrees. In the Little Susitna district the dominant structure of the Tertiary beds, based on widely scattered outcrops, is a moderate to gentle southerly dip (Barnes and Sokol, 1959). Outcrops around the southern margin of the Kenai lowland and at a few scattered localities inland indicate a broad basin or trough modified by small folds (Barnes and Cobb, 1959). At Tyonek and on the Beluga River the regional strike is approximately north and the dip is easterly at angles ranging from 10 degrees to 60 degrees (Atwood, 1909, p. 120; Brooks, 1911, p. 95). On the west shore of Cook Inlet opposite Kalgin Island the regional dip is easterly or southeasterly at a low angle. A major fault along which there has been recent displacement is inferred to extend from the Little Susitna district southwestward across the Cook Inlet Tertiary province (pl. 3).

INDICATIONS OF OIL AND GAS

No indications of oil are known definitely to be associated with the Eocene or younger Tertiary rocks of the Cook Inlet Tertiary province, but these rocks may be the source of gas found at two or more localities. Diamond-drill holes put down in 1951 and 1952 by the U. S. Bureau of Mines in the course of exploration for coal deposits near Houston encountered flows of inflammable gas and saline water in the Tertiary coal-bearing rocks at depths ranging from 555 to 775 feet. A mass-spectrometer analysis of air- and water-free gas collected at diamond-drill hole 2 in 1952 was analyzed by the National Bureau of Standards, with the following results:

Component	*Mole percent*
Methane	72. 8
Nitrogen	27. 2
Argon	Trace
	100. 0

Small gas seeps are visible between the high-tide and low-tide shorelines at two localities on the southern margin of the Kenai lowland.

These seeps are on or near outcrops of the Kenai formation. Gas reported at a test well drilled in 1955 to a depth of 3,855 feet near the west shore of Knik Arm [4] possibly is derived from the Tertiary coal-bearing rocks which underlie the area.

EXPLORATION ACTIVITY

Many of the petroleum exploration activities undertaken up to the end of 1955 within the area here included in the Cook Inlet Tertiary province are also within the inferred boundaries of the Cook Inlet Mesozoic province, and hence are regarded as intended or potential attempts to find petroleum in both the Mesozoic and Tertiary strata. Included in this category are leasing near the head of Cook Inlet and drilling near Anchorage in the early twenties, the surface geologic studies undertaken in the Kenai lowland by oil companies during the periods 1947–48 and 1953–55, seismograph operations in the Kenai lowland and Cook Inlet in 1954 and 1955, a part of the leasing activity in the Cook Inlet-lower Matanuska Valley area during the period 1952–55, and the drilling at a site near Goose Bay on Knik Arm in 1955. The discovery of gas and saline water in test borings for coal near Houston aroused new interest in the possibility that the Tertiary rocks might be both a source and reservoir for commercial accumulations of gas, and perhaps also of oil. This discovery is believed to be at least partly, and perhaps largely responsible for the recent leasing activity in the area between Houston and Knik Arm. Drilling started at a test site near Houston in 1954 and was suspended for the winter late in 1955 at a depth of 2,145 feet. It was reported that this hole found shows of gas and saline water at 580 feet, shows of gas at 750 feet, and petroliferous sand at 1,974 feet.

COPPER RIVER BASIN

The Copper River basin is a topographic basin underlain by unconsolidated deposits of Quaternary age. It is bounded on the east by the Wrangell Mountains, on the south by the Chugach Mountains, on the west by the Talkeetna Mountains, and on the north by low hills on the south flank of the Alaska Range. Over an area of about 5,700 square miles, shown on plate 1, it is considered possible, although not likely, that favorable sedimentary rocks of Tertiary age may be present beneath Quaternary deposits. The possibilities for petroleum in Mesozoic marine rocks that are inferred to underlie the southern part of the Copper River basin were discussed in the section on the Cook Inlet Mesozoic province.

The Copper River basin is a plain of low relief, ranging from 2,000 feet to 3,000 feet altitude, and dotted with many lakes. The

[4] The Anchorage Times, Nov. 14, 1955.

Copper River drains all but the northwestern part of the basin, which is drained by the headwaters of the Susitna River. In the southeastern part of the basin the Copper River and its major tributaries are incised as much as 400 feet into unconsolidated deposits of Quaternary age.

The geologic setting of the Copper River basin is shown on plate 3. Sedimentary rocks of known or probable Tertiary age are exposed at several places in and around the margin of the basin, and have been penetrated by one well drilled for water in the basin. Nonmarine sedimentary beds underlying the Cenozoic volcanic rocks of the Wrangell Mountains are exposed in several small areas at the eastern margin of the basin (Mendenhall, 1905, p. 54). No fossils have been found in these beds, which include soft feldspathic sandstone, conglomerate, and as much as 200 feet of soft sandstone interbedded with shale containing black limestone concretions. Similar beds underlying and interbedded with basal beds of Cenozoic volcanic rocks in the eastern Wrangell Mountains are considered to be early Tertiary and probably Eocene on the basis of fossil leaves found in them (Moffit, 1938, p. 97). In the course of recent field investigations Arthur Grantz (oral communication, 1955) has mapped exposures of continental gravel totaling at least a few hundred feet in thickness in the Nelchina area and at three localities in the southwestern part of the Copper River basin (see pl. 3). Fossil plants obtained from the gravels in the western part of the Nelchina area are at least in part of Eocene age, according to R. W. Brown. Based on his examination of the driller's logs and the spoil mound, Grantz believes that a test hole for water in the Copper River basin about 6 miles south of Lake Louise may have penetrated about 100 feet of Tertiary gravel beneath about 100 feet of Quaternary gravel and above the Matanuska formation of Cretaceous age.

Nonmarine sedimentary rocks of early Tertiary age, comprising the Gakona formation of Mendenhall (1905, p. 52–53), are exposed east of the Gakona Glacier on the south flank of the Alaska Range. This locality is about 35 miles north of the northern boundary of the Copper River basin as outlined on plate 1. The Gakona formation here includes at least 500 feet of conglomerate overlain by 1,500 feet or more of soft shale with beds of gravel, sand, and lignite.

No definite indications of petroleum are known that can be attributed to sedimentary rocks of Tertiary age in the Copper River basin. Seeps of inflammable gas associated with saline springs have been found at two localities in the south-central part of the basin (pl. 1). At the more easterly of the two localities, gas and muddy saline water issue from craters in small mounds or cones of mud. A mass-spectrometer analysis of gas collected in 1952 at the more westerly seep locality was analyzed by the U. S. Bureau of Mines, with the following results:

Component	Mole percent
Methane	48. 6
Ethane	. 2
Propane	. 0
Normal butane	. 0
Isobutane	Trace
Pentanes	. 0
Nitrogen	50. 6
Oxygen	. 1
Argon	. 1
Helium	. 1
Hydrogen	. 0
Carbon dioxide	. 2
	99. 9+

Calculated heating value—496 B.t.u. per cu. ft.

A small part of a recently acquired block of oil and gas leases in the eastern part of the Nelchina area lies in the area here included in the Copper River basin. With this exception, no exploration activity had been recorded to the end of 1955 in the Copper River basin and, so far as known, no consideration has yet been given to the possibility of finding petroleum in rocks of Tertiary age in this basin.

CENTRAL ALASKA

By Thomas G. Payne

Central Alaska is bounded on the north by the Brooks Range and on the south by the Alaska and Aleutian Ranges and extends from the Canadian boundary to the Bering Sea. This region, having an area of about 275,000 square miles, is in general of lower altitude than the bounding ranges to the north and south and is drained almost entirely by the two great river systems of Alaska, the Yukon and Kuskokwim. It consists of an irregular assemblage of intricately dissected uplands and broad alluvium-floored lowland basins. The floors of most of the basins average less than 600 feet in altitude. The hill and ridge tops of uplands in the western part of the region average 2,000 to 3,000 feet in altitude, and those of uplands to the east in the Yukon-Tanana region average 4,000 to 5,000 feet. Surmounting most of the upland areas are scattered mountains that rise 1,000 to 2,000 feet above the surrounding hilltops and commonly are composed of resistant intrusive igneous bodies.

The Brooks Range on the north is the Alaskan counterpart of the Rocky Mountains and is unattractive for petroleum exploration because of its complicated structure and large areas of metamorphic rocks. Similarly unfavorable terrain lies south of the central region, in the form of the Alaska and Aleutian Ranges and the Talkeetna, Wrangell, and Nutzotin Mountains that constitute a belt geologically analogous in some respects to the Sierra-Cascade belt of the United States.

PETROLEUM INVESTIGATIONS

In the vast region of central Alaska, through 1955 only six holes are known to have been drilled for the purpose of finding oil or gas. The maximum depth reached was 350 feet, and the holes were mostly or entirely in Quaternary deposits. Oil seeps, gas seeps, and other indications of petroleum have been reported at many localities in central Alaska (pl. 1), and samples from two localities not visited by the U. S. Geological Survey have been analyzed and reported to contain petroleum. Some of the reported seeps have been investigated by the Geological Survey and found to be iron oxide films on water, in places associated with springs. In all cases either no indications of petroleum were detected or the report was found to be based on what is probably "marsh gas" from decaying vegetation in alluvial deposits. One oil slick examined by oil company geologists is reported to be a doubtful indication of petroleum. Details of the reported seeps and drill holes are given in the discussion of the provinces in which they are located.

In recent years some of the major oil companies have investigated certain areas in central Alaska, and residents of the Territory have shown a lively interest in oil exploration.

Work by the Geological Survey, except for local detailed studies of mineral deposits, thus far has been mostly reconnaissance, and large areas of central Alaska have not been covered even in this manner. In general, structures and stratigraphic sections have not been mapped and studied in detail. In 1953 a program of semidetailed surface geologic studies by means of river traverses and a program of photogeologic mapping were started. Preliminary results of this work are available in reports published in the miscellaneous investigations series or placed in the open-file report series of the Geological Survey.

Much of central Alaska represents a type of geologic condition in which significant accumulations of petroleum are not likely to occur. Careful review of available information indicates that three pre-Cenozoic provinces—the Yukon-Koyukuk, the Kobuk, and the Kandik—and several large Cenozoic basin provinces may be worthy of investigation. Descriptions of these provinces, here referred to as possible petroleum provinces (pl. 1), follow the presentation of background information, including a review of the history of sedimentation and deformation and an evaluation of the geology of the various tectonic provinces.

HISTORY OF SEDIMENTATION AND DEFORMATION

Rocks of the Cambrian and all younger geologic systems have been reported in central Alaska. In the area between the Yukon and Porcupine Rivers and probably elsewhere they are underlain by a very thick Precambrian sedimentary sequence that probably is equivalent to the Belt series. In some areas the Paleozoic and younger rocks rest on a basement of highly metamorphosed older rocks of Precambrian age that are extensively exposed in the Yukon-Tanana region and are known as the Birch Creek schist.

The region has been affected by several orogenies, some of which were attended by extensive igneous intrusion and mineralization. Major tectonic elements that originated in Mesozoic and Cenozoic time are shown on plate 2.

PRE-DEVONIAN HISTORY

Marine sedimentary rocks of Cambrian, Ordovician, and Silurian age were deposited in a geosynclinal belt that occupied part of the area between the Alaska Range and the Yukon River. This belt may be comparable to the geosynclinal belt in Idaho, western Montana, Nevada, and western Utah that contains rocks of these ages. The early Paleozoic rock sequence, probably at least 20,000 feet thick, is as follows: Cambrian, mostly limestone, with minor black shale, identified only north of the Yukon River near Eagle; Ordovician, extensive in distribution and comprising dark gray to black slate, argillite, chert, graywacke, quartzite, limestone, and in one area basic volcanic rocks; Silurian, largely limestone and dolomite. The rock sequence is believed to thin and change lithologic characteristics northward from the geosynclinal belt toward a platform region that occupied the part of Alaska north of the Yukon River.

The pre-Devonian rocks were strongly deformed, but evidently not invaded by igneous bodies, during late Silurian or Devonian time. The deformation probably diminished in intensity northward in central Alaska.

DEVONIAN THROUGH PERMIAN HISTORY

Rocks of Middle Devonian through Permian age rest with angular discordance on Silurian or older Paleozoic rocks in the Yukon-Tanana region and probably elsewhere in central Alaska. Marine Devonian and Mississippian rocks are widespread and are several thousands of feet thick. The rock sequence comprises limestone, black shale and slate, great thicknesses of chert, quartzite, sandstone, chert conglomerate, and at many places volcanic rocks of greenstone type. The Totatlanika schist of Mississippian (?) age, exposed in the northern foothills of the Alaska Range, consists of at least 7,500 feet of rhyolitic metavolcanics, overlain by at least 2,500 feet of quartz-mica schist. Pennsylvanian(?) rocks, found only in the vicinity of the Yukon and its tributaries north of Eagle, are about 5,000 feet thick and include nonmarine shale, sandstone, and conglomerate, and one known bed of coal. Permian marine limestone, conglomerate, and volcanic rocks have been reported to occur at a few widely separated localities in central Alaska.

Other than evidence of an unconformity between Mississippian(?) and Devonian rocks in the northern part of the Alaska Range, no evidence of marked angular discordances within the thick sequence of Devonian through Permian rocks of central Alaska has been found. Although approximate structural conformity is indicated, stratigraphic discontinuities suggest periods of uplift and erosion.

MESOZOIC AND PALEOCENE HISTORY

Although rocks of Early and Middle Triassic age have not been reported in central Alaska, rocks of Late Triassic age are present and have been found to rest with structural conformity on Paleozoic beds. Marine Upper Triassic rocks are exposed in the area of the Goodnews arch where they consist of argillite, chert, dense limestone, and volcanic rocks; they probably are present at depth in the Kuskokwim geosyncline. Upper Triassic rocks, consisting of a few hundred feet of marine dark shale and limestone and beds of oil shale, are exposed at two places along the Yukon downstream from Eagle, at the mouth of the Nation River and on Trout Creek; they probably are present beneath the Cretaceous rocks elsewhere in the Kandik segment of the Kuskokwim geosyncline (pl. 2).

Oil shale of this age has been reported by prospectors to occur on the Christian River about 75 miles north of Fort Yukon.

Rocks of Jurassic age have been definitely identified in central Alaska only in the area of the Goodnews arch, where fossils of Early, Middle, and Late Jurassic age have been found in graywacke, argillite, chert, and volcanic rocks. These rocks probably underlie Cretaceous rocks in the Kuskokwim geosyncline. More detailed work in the future may reveal other Jurassic rocks in previously unmapped areas of central Alaska, and, judging from findings in northern Alaska, may indicate a Jurassic age for part of the rocks now mapped as Cretaceous.

Marine rocks of the lower part of the Cretaceous (Neocomian) occur in the area of the Hogatza arch and probably underlie younger Cretaceous rocks in the Yukon-Koyukuk geosyncline. They consist of slate, arkose, limestone, and volcanic rocks and have been named the Koyukuk group. Rocks of this age are also exposed in the Goodnews arch, where they include marine argillite, graywacke, quartzite, thin beds of limestone, and volcanic rocks; these probably underlie younger Cretaceous rocks in the Kuskokwim geosyncline. In the Yukon-Tanana region, rocks of early Cretaceous (Neocomian) age have been found in two areas referred to as the Tofty and Kandik segments of the Kuskokwim geosyncline. In the Kandik River area they consist of marine sandstone, quartzite, conglomerate, shale, and slate and are known as the Kandik formation. In the Tofty area similar rocks are present.

Marine and nonmarine strata of the middle part of the Cretaceous, of Albian and possibly of Cenomanian age, are exposed throughout much of the area of the Yukon-Koyukuk geosyncline and Kobuk trough where they are the youngest Mesozoic rocks known. They are described in the section on possible petroleum provinces. Beds of marine conglomerate, graywacke, and shale of this age are exposed locally in, and are probably present throughout the area of, the Kuskokwim geosyncline, where they are mostly buried beneath younger Cretaceous deposits. The middle part of the Cretaceous is also represented in the Tofty and Kandik segments of the Kuskokwim geosyncline, where marine and nonmarine conglomerate, graywacke, sandstone, and shale are the youngest known Cretaceous deposits. In the Eagle trough nonmarine beds believed to be of this age occur together with, and have not been differentiated in mapping from, nonmarine Eocene beds.

In central Alaska the upper part of the Cretaceous, including beds of Coniacian through Campanian age, has been found only in the area of the Kuskokwim geosyncline and in the belt extending southeastward from the Kuskokwim geosyncline to the Alaska Range geosyncline (pl. 2). The greater part of the sequence, which has been estimated to be more than 20,000 feet thick, is marine; nonmarine beds have been recognized near the top. The sequence consists of shale, argillite, and graywacke and in the upper part contains volcanic rocks.

Nonmarine rocks believed to be of Paleocene age have been found in northern Alaska and in southern Alaska, where they are related in occurrence to, and lie in approximate conformity on, Late Cretaceous beds. Such deposits have not been found in central Alaska, although some of the rocks regarded as Eocene possibly may be of this age.

The Devonian through Paleocene sedimentary rocks of Alaska have been profoundly deformed, and in many areas intruded and metamorphosed, during three major post-Paleozoic orogenies. The record of the first, which was during Jurassic time, is obscure in central Alaska, partly because of the relative lack of exposure of pre-Cretaceous Mesozoic rocks. Jurassic deformation, in more than one phase, and Jurassic intrusive bodies are known in both northern and southern Alaska, and therefore it is quite likely than an orogenic movement took place in the central region. The second major orogeny occurred in Early Cretaceous time (post-Neocomian and pre-Albian) and is indicated in several areas by greater deformation of rocks of the lower part of the Cretaceous as compared to rocks of the middle and upper parts of the Cretaceous. This orogeny was accompanied by extensive batholithic intrusion, metamorphism, and mineralization. Part of the deformation observed in pre-Cretaceous rocks and some of the intrusives that cut these rocks may be of Jurassic age. The third orogeny, also involving intrusive activity and mineralization, followed deposition of the rocks regarded as Late Cretaceous and Paleocene and represents a phase of the Laramide orogeny.

The structural grain or lineament resulting from the third, or Laramide orogeny, seems to parallel approximately the grain of the earlier orogenies in the structurally arcuate region of Alaska south of the Tanana geanticline, and also in the structurally eastward-trending region of northern Alaska, including the Kobuk trough, Brooks Range geanticline, and Colville geosyncline (pl. 2). Two structural grains are indicated, however, in the older rock areas of western Alaska between the Tanana and Brooks Range geanticlines. The older grain, striking generally eastward to southeastward and approximately paralleling the structure of the Brooks Range, is evident in the stronger folds, cleavage, and foliation of: (a) the Paleozoic rocks of the Chukotskiy-Seward uplift, (b) the Lower Cretaceous and older(?) rocks of the Hogatza arch, (c) the Lower Cretaceous, earlier Mesozoic, and Paleozoic rocks of the Goodnews arch, and (d) the rocks of similar age in the area between Marshall and Holy Cross along the lower Yukon (pl. 2). This grain probably was induced by the Early Cretaceous and Jurassic orogenies. The younger, dominant grain in this region, strikes northward to northeastward and parallels the arcuate structure of southern Alaska. It is represented by faults and broad, open folds in the Paleozoic metamorphic complex of the Chukotskiy-Seward uplift. The resistant rocks of this uplift evidently reacted to the Laramide orogeny mostly by displacements along northward to northeastward-striking faults and served as a buttress to deformation of the very thick Mesozoic rock sequence of the Yukon-Koyukuk geosyncline, the strike of which parallels the eastern border of the uplift.

POST-PALEOCENE TERTIARY HISTORY

Nonmarine early Tertiary rocks, presumably of Eocene age, occur in several areas in central Alaska and seemingly are unrelated in distribution to the Mesozoic tectonic features shown on the map (pl. 2). The Eocene deposits occur as erosional remnants in three topographic trenches (Coleen, Rampart, and Eagle troughs), in the foothills north of the Alaska Range (Healy trough), and elsewhere as small isolated remnants in or bordering some of the lowland basins. They consist of claystone, sandstone, conglomerate, and lignite and in some areas are as much as 5,000 feet thick. Sedimentary rocks of this age are believed to have been deposited extensively in what are now the alluvium-floored lowland basins (pl. 2). These bodies of Eocene sedimentary rocks were gently, and locally strongly, deformed in Oligocene or early Miocene time, during the later phase of the Laramide orogeny.

Some of the basin areas may also have been the sites of post-Eocene Tertiary sedimentation that, according to one line of evidence, may have included marine deposition. This possibility is discussed in the section on possible petroleum provinces. Numerous bodies of Cenozoic extrusive rocks, some of large size, have been found in central Alaska. They range in age from Tertiary to Recent; those of late Tertiary and Pleistocene age probably are most abundant.

Another orogeny began near the close of Tertiary time and continued into Quaternary time. Although resulting in strong faulting and folding in the Gulf of Alaska Tertiary province, this orogeny was characterized elsewhere by strong uplift that produced the present mountain ranges and upland areas. In central Alaska, broad warping, very gentle folding, and faulting, as well as uplift, occurred.

GEOLOGY OF TECTONIC ELEMENTS

TANANA GEANTICLINE

In the eastern part of the Tanana geanticline (pl. 2) the exposed rocks are Precambrian and early Paleozoic (pre-Middle Ordovician) metamorphic rocks. The part of this element extending southwestward from the Tanana River is mostly unmapped, but rocks of Ordovician, Silurian, and Devonian age, as well as older rocks, are known to be present. The bedded rocks are intensely deformed and metamorphosed and contain large intrusive igneous bodies, at least in the Yukon-Tanana region.

GOODNEWS ARCH

Rocks of Precambrian, Paleozoic, Triassic, Jurassic and Early Cretaceous age are exposed in the Goodnews arch. The sedimentary sequence contains numerous bodies of volcanic rock. This element is regarded as relatively unfavorable for petroleum exploration because of its complex structure, the presence of numerous intrusive igneous bodies, and the fact that the sandstones are dominantly poorly sorted graywackes.

506319—59——5

KUSKOKWIM GEOSYNCLINE

The main part of the Kuskokwim geosyncline, lying southwest of the headwaters of the Nowitna River, contains an estimated thickness of 40,000 feet of Cretaceous rocks, part of which are andesitic volcanic rocks. The bulk of the sandstone is marine graywacke, probably of low porosity and permeability; a few beds of sandstone associated with coal in the uppermost part of the sequence are texturally cleaner. The structure of the Cretaceous strata is complex, and the shales commonly show fracture cleavage. Numerous intrusive bodies of early Tertiary age cut the Cretaceous rocks. Because of these conditions this area has not been included in the discussion of possible petroleum provinces.

A shown in plate 2 the Kuskokwim geosynclinal belt extends northeastward to the Nenana River and thence eastward to the international boundary north of the Yukon River. In its extent northeast and east of the Cretaceous area of the Kuskokwim River region this geosynclinal belt is known to contain only two areas of Mesozoic rocks, the Tofty segment and the Kandik segment. The gross synclinal structure represented by the belt is indicated, where rocks of Cretaceous age are absent, by the fact that exposed rocks are mostly Devonian and Carboniferous in age and are younger than the dominantly pre-Devonian rocks of the Tanana geanticline to the south and the Ruby geanticline to the north. The parts of this structural trend in which Paleozoic rocks have been uplifted and exposed are believed to be unfavorable for petroleum exploration because of the complex structure; furthermore, great masses of volcanic rocks are included in the Paleozoic sequence.

In the Tofty segment, rocks of the lower part of the Cretaceous system are cut by intrusive bodies and are thermally and dynamically metamorphosed. Rocks of the middle part of the Cretaceous system are strongly deformed and are of small extent. Therefore, this area is relatively unattractive for exploration. In the area of the Kandik segment, however, the structure appears to be simpler, marine Mesozoic rocks are present, and marine rocks of Paleozoic age are within drillable depth. This area is described further in the section on possible petroleum provinces.

RUBY GEANTICLINE

In the area of the Ruby geanticline metamorphic rocks of Precambrian and Paleozoic age and igneous rocks in the form of large intrusive bodies are exposed.

✓ YUKON-KOYUKUK GEOSYNCLINE

Cretaceous rocks exposed throughout the Yukon-Koyukuk geosyncline are moderately to strongly deformed. This, nevertheless, is one of the relatively more favorable regions in central Alaska for further exploration and is described in the section on possible petroleum provinces.

HOGATZA ARCH

The Hogatza arch constitutes a linear high that extends eastward from the northeast end of the Seward Peninsula to the Koyukuk River (pl. 2). Bedrock along this trend is older than that in the Kobuk trough to the north and in the Yukon-Koyukuk geosyncline to the south and east. According to Patton and Bickel (written communication, 1955), it consists mostly of pre-Albian sedimentary and volcanic rocks and granitic intrusives. The abundance of igneous rocks, together with strong deformation and the metamorphic character of some of the rocks, makes this area unattractive for petroleum exploration.

KOBUK TROUGH

Cretaceous rocks of the belt designated as the Kobuk trough are moderately to strongly deformed and are lithologically similar in several respects to those of the Yukon-Koyukuk geosyncline. Although less favorable, in general, than the Yukon-Koyukuk province, this belt is considered as a possible petroleum province and is described in a later section of this report.

CHUKOTSKIY-SEAWARD UPLIFT

Igneous rocks and Paleozoic and Precambrian metamorphic rocks and limestone constitute the bulk of the bedrock in the structurally complex Chukotskiy-Seward uplift, which is not here considered as a possible petroleum province.

TROUGHS CONTAINING NONMARINE ROCKS OF EOCENE AGE

The Healy trough, lying north of the front of the Alaska Range, contains a maximum of about 2,000 feet of coal-bearing rocks of Eocene age. Because the rocks are entirely nonmarine and rest on a schistose basement of Precambrian, early Paleozoic, and Mississippian(?) age, this tectonic element is unfavorable for exploration. Reported oil seeps in the Nenana coal field area of the Healy trough (pl. 2) have not been verified. Field and laboratory investigations of one of these reported seeps, according to G. C. Martin (1923, p. 137–147), indicates that the supposed petroleum residue is a tar distilled from burning coal beds. Nonmarine Eocene(?) deposits are exposed elsewhere in central Alaska as erosional remnants in topographic trenches referred to as the Eagle, Rampart, and Porcupine troughs. These do not merit consideration.

CENOZOIC BASINS

The topographic basins that constitute about one-third of central Alaska contain considerable thicknesses of Quaternary deposits. Whether or not these basins are also pre-Quaternary structural basins and contain a considerable thickness of Tertiary sediments is one of the most important questions bearing on the petroleum possibilities of Alaska. In the section on possible petroleum provinces the basins are described and possible interpretations of their history are outlined.

POSSIBLE PETROLEUM PROVINCES

KANDIK MESOZOIC AND PALEOZOIC PROVINCE

Mesozoic rocks representing the Kandik segment of the Kuskokwim geosynclinal trend (pl. 2) are exposed in the area here referred to as the Kandik province (pl. 1). Also present are rocks of Devonian through Permian age that, like the rocks of Mesozoic age, are mostly absent in the relatively positive belts to the north and south. The province is bounded on the south by the Yukon River, on the east by the Nation arch and the international boundary, on the northwest by the Yukon flats, and on the north by rocks of the Tindir group, of Precambrian and Early Cambrian(?) age, which crop out north of the point where Orange Creek crosses the international boundary. The province as thus defined has an area of about 3,000 square miles. It lies in the Charley River and Black River quadrangles of the Alaska reconnaissance topographic series.

Drainage from the province is southward into the Yukon through the Kandik River and northwestward into the Porcupine River through the Black and Little Black Rivers and their headwater tributaries. Valley bottoms in the province are at an altitude of 1,000 to 2,000 feet, and ridges and hilltops have an altitude of 3,000 to 4,000 feet in the southern part and about 2,000 feet in the northern part.

Geologic mapping in the province is mostly limited to the area along the international boundary (Cairnes, 1914) and along the Yukon River (Mertie, 1930, 1932, 1937). Aerial reconnaissance over the province by geologists of the Geological Survey has indicated that Mesozoic rocks may form the bedrock in much of the area as defined above.

The stratigraphic sequence in this province is described in table 4, the descriptions having been abstracted from the reports by Mertie and Cairnes. Although the contact relations are not well known, there is no evidence of marked angular unconformity between the various post-Devonian units. Contact relationships of the Devonian and Mississippian units are unknown.

TABLE 4.—*Stratigraphic sequence in Kandik Mesozoic and Paleozoic province*

Age	Unit	Minimum thickness (feet)	Character
Middle Cretaceous			Nonmarine and marine(?). Graywacke, shale, and coal. Underlies nonmarine Eocene(?) of Eagle trough and may overlie Kandik formation in parts of area north of the Yukon.
Early Cretaceous (neocomian).	Kandik formation	2,400	Marine. Upper part is mostly sandstone, quartzite, and conglomerate. Lower part is black shale and slate, sandstone, and quartzite.
Late Triassic		575	Marine. Thin-bedded highly fossiliferous limestone and shale, including beds of oil shale.
Permian	Tahkandit limestone	527	Marine. Fossiliferous limestone, shale, sandstone, and conglomerate. Upper part is mostly limestone.
Pennsylvanian(?)	Nation River formation	[1] 3,700	Nonmarine. Sandstone, conglomerate, shale; one bed of bituminous coal.
Late Mississippian	Calico Bluff formation	1,270	Marine. Alternating beds of fossiliferous limestone and shale, with some slate. Most shale beds and some limestone beds are bituminous.
		1,700	Marine. Bituminous and siliceous shale, argillite, and chert.
Mississippian (position in system unknown).	Circle volcanics		Marine. Basaltic lava flows of greenstone type, with interbedded tuff, breccia, argillite, and chert. (Exposed only in the vicinity of Circle.)
Middle Devonian	Woodchopper volcanics		Marine. Basaltic lava flows of greenstone type and associated pyroclastic beds, interbedded with massive limestone, shale, slate, and chert.

[1] Less than 6,000.

The structure of the Kandik province appears to be simpler than that of the area to the south, along and south of the Yukon River. The dominant strike of the beds is northeast and almost at right angles to that in the area to the south, which approximately parallels the course of the Yukon River. A major fault zone follows the course of the Yukon and extends southeastward into Canada. Because the strong deformation of the rocks south of the river has involved rocks at least as young as the middle part of the Cretaceous, it is believed that this area may have been affected by an orogeny, probably early Tertiary in age, that had relatively little effect on the Kandik area. Such a condition might explain the less intense deformation and the different strike of the rocks to the north, which may have been affected primarily by the Early Cretaceous orogeny.

The major structures of the province are broad, open folds, on which minor folding and crumpling, particularly in shale beds, are superimposed. Dips measured by Cairnes and Mertie range in general from 10 degrees to 60 degrees and commonly are 30 degrees to 40 degrees. Locally steeper dips were recorded and were believed to be in the vicinity of faults. Numerous departures from the prevailing northeast strike are believed to indicate plunge of the folds, suggested by Mertie's observations north of the Yukon River. Some or perhaps most of the shale beds exposed along the Yukon River show fracture cleavage. Cairnes, however, does not mention slate in the rocks of Cretaceous age along the international boundary and describes some of the shale and sandstone beds as friable.

Seeps have not been reported in the Kandik province. The Upper Triassic rocks, however, include a considerable thickness of oil shale, and beds of bituminous limestone and shale are common in the Mississippian sequence. A distillation test on a sample of Triassic oil shale from the valley of Trout Creek indicates 28 gallons of crude oil per ton (Mertie, 1937, p. 263–264). Triassic oil shale also occurs at the mouth of Nation River. Both localities are shown in plate 1.

The Kandik province may be the best place in central Alaska in which to determine the petroleum possibilities of the Paleozoic sequence. The structure of this province probably is as simple as, or simpler than, that of other parts of the central Alaska region. Furthermore, the evidence available, although meager, indicates that intrusive bodies may be rare or absent. The Kandik formation of Early Cretaceous age contains sandstone beds, is probably not more than a few thousand feet thick, and, unless a formation of Jurassic age intervenes, is underlain by Triassic oil-shale-bearing rocks. There are no measurements or visual impressions available as to the porosity and permeability of the sandstone of Cretaceous age. Geologic mapping in this province may be hampered by a relative lack of good bedrock exposures.

YUKON-KOYUKUK CRETACEOUS PROVINCE

The Yukon-Koyukuk province (pl. 1) contains a great thickness of rocks of the middle part of the Cretaceous system, which were deposited in the Yukon-Koyukuk geosyncline (pl. 2). Rocks of the Koyukuk group, belonging in the early part of the Cretaceous (Neocomian), are exposed in the area of the Hogatza arch and probably underlie the middle Cretaceous rocks of the geosyncline. They are relatively unfavorable because they are complexly deformed, in part metamorphosed, cut by numerous intrusive bodies, and include much volcanic rock. Paleozoic rocks exposed in areas adjoining the Yukon-Koyukuk geosyncline show complex structure and metamorphism. These conditions suggest that, in the Yukon-Koyukuk province, all rocks older than the middle part of the Cretaceous are apt to be unfavorable for exploration.

Bedrock throughout most of the province is of the middle part of the Cretaceous system. The rocks are best known along the Yukon River, in exposures at bluffs between Melozi and Louden and between Koyukuk and Kaltag, and along the Shaktolik River. The lithologic sequence indicates a predominantly marine unit at the base, a marine and nonmarine unit in the middle, and a predominantly nonmarine unit at the top.

According to published interpretations, conglomerates of Cretaceous age in the western part of the province were derived from volcanic rocks of Mesozoic age and older metamorphic rocks of the Seward Peninsula, and those in the eastern part from old rocks to the southeast in the Ruby geanticline. Thus it would seem that the Chukotskiy-Seward uplift and the Ruby geanticline were emergent during Albian and Cenomanian time and that sediments were entering the Yukon-Koyukuk geosyncline from both sides.

The stratigraphic sequence along the Yukon River between Melozi and Louden as described by Martin (1926) is shown in table 5.

TABLE 5.—*Stratigraphic sequence along Yukon River in Yukon-Koyukuk Cretaceous province*

[Adapted from Smith and Eakin (1911) and Martin (1926)]

Unit	Thickness (feet)	Character
Shaktolik group		
Kaltag formation	800; probably much thicker.	Mostly nonmarine. Sandstone, shale, and numerous beds of coal; mined at several places.
Nulato formation	3,000±	Marine. Sandstone and shale.
Melozi formation	At least 1,000+	Nonmarine and marine. Shale and sandstone.
Ungalik conglomerate	3,000±	Marine. Conglomerate, sandstone, and shale.

Recent studies of the rocks equivalent to the Shaktolik group along the Yukon River by Patton and Bickel (1956a) indicate that Martin's stratigraphic sequence probably is partly erroneous. The Kaltag and Melozi formations appear to represent the same part of the stratigraphic sequence. The Ungalik conglomerate is considered a "border facies" and equivalent in part to the Nulato and Kaltag formations. These studies suggest that the name Melozi formation should be abandoned and that the Ungalik conglomerate probably should be considered as a marginal facies of the Shaktolik group.

In their report Patton and Bickel (1956a) recognize a border facies and an interior facies of the Shaktolik group. The border facies lies along the southeastern margin of the geosyncline and is divided into an upper unit of shale, siltstone, sandstone, and conglomerate, mostly nonmarine in origin, and a lower unit of conglomerate and sandstone, mostly marine in origin and having a minimum thickness of about 1,200 feet. The interior facies is divided into three parts: (a) a nonmarine upper unit about 1,100 feet thick consisting of shale, siltstone, sandstone, and coal, (b) a littoral marine middle unit also about 1,100 feet thick, consisting of sandstone and subordinate shale, and (c) a lower offshore marine unit, the base of which is not exposed, consisting of dark-gray and greenish-gray sandstone and subordinate siltstone and shale. Patton and Bickel (1956b) also recognize a border and an interior facies in the Shaktolik River area, and each facies is subdivided in a manner similar to that of the lower Yukon River area. In the Shaktolik area, however, the border facies lies in general west of the interior facies and represents the northwestern margin of the geosyncline.

The Yukon-Koyukuk province is probably the best area in central Alaska in which to test the rocks of Cretaceous age. The structure, although fairly complex, is as simple as or simpler than that of the Cretaceous rocks elsewhere in central Alaska, with the possible exception of the Kandik province. In regard to porosity and permeability the sandstone compares favorably with that in other Cretaceous areas. Although determinations of porosity and permeability have not been made, it is believed that sandstone in the lower part of the sequence generally is unfavorable with respect to these reservoir properties. It may be classed petrographically as graywacke. With regard to the beds of the lower part of the Shaktolik group along the Shaktolik River, Smith and Eakin (1911, p. 57–58) state, "The sandstones are usually fine grained, dense, and compact, and in some places resemble fine-grained igneous rocks so closely in appearance and in constituent minerals that their true character was determinable only with the aid of the microscope". Sandstone beds of the middle and upper parts of the sequence, however, appear in general to be texturally cleaner and more favorable as potential reservoirs for petroleum.

The middle Cretaceous rocks of the Yukon-Koyukuk geosyncline are similar in several respects to those of the Colville geosyncline of northern Alaska. The Fortress Mountain formation, which includes a great thickness of conglomerate along the southern margin of the Colville geosyncline, probably is equivalent in part to the Ungalik conglomerate. The lower part of the Nanushuk group in northern Alaska is mostly marine and contains some of the same Albian ammonite species as are found in the Shaktolik group (Imlay and Reeside, 1954, p. 237). The upper part of the Nanushuk group is of Cenomanian age (Imlay and Reeside, 1954, p. 242–243) and consists of nonmarine beds that intertongue northward with marine beds; these rocks may be equivalent in part to the mostly nonmarine Kaltag formation. It seems that in both provinces sedimentation began with a marine transgression during which a thick lower unit of marine graywacke and shale was deposited, with conglomeratic facies along the margins of the geosynclines. This was followed in both provinces by a period of marine regression, attended by repeated minor transgressions and regressions, during which a marine and nonmarine middle unit was deposited. Further regression of the sea attended deposition of a more nonmarine upper unit. The sea probably did not return to the Yukon-Koyukuk geosyncline in later Cretaceous time; no evidence has been found of rocks equivalent to the Colville group of northern Alaska (Turonian through Campanian in age).

Oil of the Umiat field, as well as of seeps and shows in holes in other parts of northern Alaska, occurs in the transgressive and regressive marine sandstones of the Nanushuk group, particularly its upper part. The analogous sedimentary conditions in the Shaktolik group of the Yukon-Koyukuk province constitute the main reason for considering this as a possible petroleum province. Structural conditions in this province, however, are somewhat more complex than in the Umiat area and other parts of northern Alaska where oil shows have been found.

Exploration in this province by photogeologic and surface geologic methods should be directed toward locating areas in which the structure is relatively the most simple and the theoretically more favorable upper parts of the sequence are not completely breached at anticlinal axes. In the course of measuring stratigraphic sections to gain a better understanding of the sequence, particular attention should be given to sampling of sandstone beds for porosity and permeability determinations, because these properties may be as critical as structure in evaluation of the petroleum possibilities of the province.

Although the stratigraphic sequence seems to be rather consistent in different parts of the province, the structure, terrain, and amount of information available vary considerably. Therefore, the following areas within the province are discussed separately.

AREA WEST OF YUKON AND KOYUKUK RIVERS AND NORTH OF UNALAKLEET RIVER

On the basis of information available, the part of the province west of Yukon and Koyukuk Rivers and north of Unalakleet River would seem to be the most favorable for exploratory work. Main sources of geologic information and maps are reports by Collier (1903), Smith and Eakin (1911), Martin (1926), Hollick (1930), and Patton and Bickel (1956a, b). In addition to these reports photogeologic maps of the area have been prepared by Cass (1957; and written communication, 1955). One favorable aspect of this area is the apparent lack of igneous rocks. The only body of intrusive igneous rock thus far reported is at Christmas Mountain near Norton Bay. Tertiary extrusive bodies evidently are rare or absent.

Drainage from the area is eastward into the Koyukuk and Yukon Rivers by way of the Kateel, Gisasa, and Nulato Rivers and westward into Norton Sound by way of the Inglutalik, Ungalik, Shaktolik, and Unalakleet Rivers. A study of the topography shown on the quadrangle maps, supplemented by aerial reconnaissance by geologists of the Geological Survey, has indicated that this area is a well-developed ridge-and-valley province, in which drainage is well adjusted to structure. The ridges and hilltops generally range in altitude from 2,000 to 4,000 feet, the valley bottoms are less than 1,000 feet in altitude, and both ridges and valleys strike in general northeastward to northward and express the structural trends.

The photogeologic maps by Cass (1957; and written communication, 1955), give an excellent general picture of the structure of this area. The many folds, some overturned, are cut by a complex system of rather closely spaced bifurcating faults. The distance between anticlinal axes is in general 2 to 5 miles. The faults commonly strike in a more northerly direction than the fold axes, which mostly strike northeast. The rock sequence of Cretaceous age probably is thicker in the central part of the geosyncline than where measured in bluffs of the Yukon River along the eastern margin. At least 5,000 to 10,000 feet of Cretaceous rocks are indicated.

Along the Yukon River between Koyukuk and Nulato the structure is relatively simple, and few faults were observed. The dips recorded by Patton and Bickel average only 26 degrees, and about three-fourths of the dips are less than 30 degrees. Between Nulato and Kaltag the structure is somewhat more complex, and overturning was noted in one area. The recorded dips average 34 degrees, and about one-half are less than 30 degrees. Along the Shaktolik River the dips, as recorded by Patton and Bickel, average 53 degrees and in some places are vertical. Here only about one-tenth of the dips are less than 30 degrees.

Search for a structure favorable for drilling should be directed toward finding an open, relatively simple anticline in which the younger part of the Cretaceous sequence is present at the axis. This statement is tentative pending further study of the porosity and permeability of the sandstone, particularly in the lower part of the rock sequence.

AREA FROM UNALAKLEET RIVER SOUTHWARD TO BETHEL BASIN

The geology of the area from Unalakleet River southward to Bethel basin has not been mapped by surface methods except for a narrow belt along the Yukon River, which forms the eastern and southern border of the area, and a narrow belt along Norton Sound. Approximately all the northern half of the area is included in a photogeologic map by Cass (written communication, 1955). Information on the geology along the river is in reports by Collier (1903), Harrington (1918), and Martin (1926). Drainage is southward and eastward into the Yukon and westward into Norton Sound. Ridges and hilltops are 1,000 to 3,000 feet in altitude, and much of the area is less than 1,000 feet. The relatively few ridges trend northeastward, as do most of the stream courses.

Both northeastward-trending drainage that is apparently adjusted to structural trends, and the known Cretaceous rocks to the east and south along the Yukon suggest that bedrock represents a southwestward continuation of middle Cretaceous rocks of the area north of the Unalakleet River. The area differs, however, from the area to the north in that it includes several large bodies of volcanic rocks, probably Tertiary and Quaternary in age, that have been mapped along the Yukon River and the coast of Norton Sound by field methods, and in the intervening area by photogeologic methods. Intrusive bodies, probably cutting rocks of Cretaceous age, occur in the headwaters area of the Anvik River and near Marshall.

Coal beds are known on the Unalakleet River, 40 miles above its mouth, on the coast 10 miles south of Unalakleet, and on the Yukon River 40 miles southeast of Unalakleet. The coal-bearing rocks at the last-named locality, according to Martin (1926, p. 375) are probably part of the Kaltag formation. Therefore, an equivalent of the upper part of the Shaktolik group is believed to form at least part of the bedrock in this area; marine fossils have been found, and thus both marine and nonmarine beds are indicated. The stratigraphic position of Cretaceous strata along the Yukon in the southern part of this area is unknown. Rocks of Paleozoic as well as Cretaceous age are exposed between Holy Cross and Marshall, and the latter rocks may be low in the middle Cretaceous sequence; the presence of conglomerate in this area suggests correlation with the Ungalik conglomerate. At least one coal bed is known in the sequence of shale, sandstone, and conglomerate downstream from Andreafsky. Marine fossils have been found in cutbank outcrops along the Andreafsky River.

Little is known of the structure of this part of the Yukon-Koyukuk province except what is shown on the photogeologic map by Cass (1957). According to Harrington (1918, p. 25), the Cretaceous strata along the Yukon strike north to northeast and dip generally less than 45°. Faults, mostly of small displacement, were observed in many outcrops.

Oil and gas seeps at several localities along the lower course of the Yukon River have been reported by residents of that area. Robert M. Chapman (oral communication, 1953) of the Geological Survey investigated these localties but did not find oil or gas indications at any of them; at some places iron-oxide films on water were thought by the residents to be oil. The reports that gas collects in pockets under the ice of the Yukon at Anvik, however, probably are valid. According to residents of that village, breaking the ice and igniting the gas, which burns for periods as long as a minute, is a favorite winter pastime of the children. The gas may be "marsh gas" derived from decaying vegetal material in the alluvial deposits. The gas seepage at Anvik and most of the reported seepages that were not confirmed are in areas of alluvium at the west side of the Innoko basin (pl. 1). The nearest exposed bedrock is volcanic rock that locally contains beds of lignite and is probably of Tertiary age. It is doubtful that oil or petroleum gas, if present, is coming from rocks of Cretaceous age.

MELOZITNA RIVER AREA BETWEEN YUKON AND INDIAN RIVERS

The Melozitna River area between Yukon and Indian Rivers is bounded on the west by the Cenozoic Galena basin and on the east by the Ruby geanticline. It is drained by the Melozitna River and its tributaries and by streams flowing westward into the Koyukuk River. Ridges and hilltops range from 2,000 to 3,000 feet and valley bottoms from 500 to 1,000 feet in altitude.

The area has been mapped by Eakin (1916), and photogeologic maps have been prepared by Cass (written communication, 1955). The stratigraphic sequence described by Martin and shown in table 4 is based on study of exposures in bluffs along the Yukon River between Melozi and Louden. A section of the stratigraphic sequence exposed in these bluffs, at the southern border of the area, is included with the map by Patton and Bickel (1956a). The dips recorded by them average 38 degrees, and about one-third are less than 30 degrees. Numerous faults were observed.

According to Eakin, the sequence exposed along the Yukon River extends northeastward and probably forms the sedimentary bedrock as far as Allakaket on the Koyukuk River. The sedimentary rocks of Cretaceous age have been intruded by several igneous bodies of Tertiary age which, as shown on Eakin's map, have metamorphosed the Cretaceous beds. In addition to the intrusives there are many extrusive bodies of Tertiary and (or) Quaternary age.

Although ridges are present and drainage is adjusted to structure, the ridges and stream courses lack the striking linearity characteristic of the country to the west in the area of the Kateel, Gisasa, and Nulato Rivers. Furthermore, the hills and ridges are more rounded. These differences may be due to the metamorphism of the rocks in parts of the area and to the presence of relatively narrow canoe-shaped plunging folds noted by Eakin. The predominant strike of the beds is to the northeast; several departures from this strike further suggest plunge on the folds. Apart from the schistosity and other metamorphic effects of the intrusive bodies, slaty cleavage has been developed in the argillaceous rocks.

This area is regarded as the least favorable in the Yukon-Koyukuk province for petroleum exploration. No seeps have been reported.

KOBUK CRETACEOUS PROVINCE

The tectonic element designated as the Kobuk trough (pl. 2) represent an eastward-trending belt of rocks in the middle part of the Cretaceous system. It is bounded on the north by pre-Mesozoic rocks of the Brooks Range and on the south by Lower Cretaceous and older sedimentary and volcanic rocks and granitic intrusive rocks of the Hogatza arch. Rocks of the Kobuk trough are similar in age and general character to those of the Yukon-Koyukuk geosyncline. The trough merges with the geosyncline in the area of the Koyukuk River upstream from Hughes.

The province includes the Waring Mountains, the eastern part of the Lockwood Hills, and various unnamed upland areas, the tops of which range from 1,500 to 4,000 feet in altitude. Nearly half of the area lies below an altitude of 1,000 feet. The province is drained by the Kobuk River and its tributaries from the south, including the Pah River, and by the Koyukuk River and its various forks and tributaries, including the Alatna River.

The geology of the area is described in reports by Mendenhall (1902), Schrader (1904), and Smith (1913). It has recently been studied (1953–55) by Patton.

The Cretaceous rocks of the Kobuk trough were named Bergman series by Schrader. Coal-bearing rocks exposed along the southern margin of the Brooks Range formerly were regarded as Tertiary (Eocene) but now are believed, on the basis of plant fossils, to be of Cretaceous age and to be part of the Bergman group. Coal beds have been mined at two places.

As in the Shaktolik group of the Yukon-Koyukuk province the Cretaceous rock sequence probably includes a marine lower unit, a littoral marine middle unit, and a predominantly nonmarine upper unit. The sequence probably is several thousand feet thick. According to Patton (oral communication, 1953), conglomerate along the southern margin of the Brooks Range is believed to be equivalent, on the basis of fauna, to conglomerate of northern Alaska ranging from the Fortress Mountain formation through the Chandler formation. It probably is also equivalent to the Ungalik conglomerate or border facies of the Yukon-Koyukuk province. Sandstone and conglomerate associated with coal beds resemble the upper unit of the Shaktolik group of the Yukon-Koyuk province (Patton, written communication, 1953) and also the nonmarine part of the Chandler formation of northern Alaska.

Strata of the Bergman group are strongly folded and faulted; steep dips and overturned beds are common. In the northern part of the province the strike is approximately east, and the dips commonly are southerly. To the south the attitudes are more variable, the ridges do not show a consistent trend, and a series of plunging folds striking in general eastward, is indicated. A number of small intrusive bodies occur in the Bergman group along the Koyukuk River between Allakaket and Hughes (Patton, written communication, 1953).

Three oil seeps have been reported in the vicinity of Allakaket on the Koyukuk River. The occurrence of seeps at this place is regarded as doubtful because the report is based on observations made by a prospector many years ago, and seeps have not been seen by, or reported to, geologists who recently have been in Allakaket.

The geology of the Kobuk province is not as well known as that of the Yukon-Koyukuk province. Pending further study it is believed that this province is structurally less favorable for petroleum exploration than the province to the south.

CENOZOIC BASIN PROVINCES

Approximately one-third of the 275,000 square miles of terrain in central Alaska is in the form of topographic basins that are floored by alluvium of Quaternary age. These basins are shown and named on the tectonic map (pl. 2); a few small basins have been omitted. The floors of the basins average less than 600 feet in altitude, excepting the Holitna, Minchumina, and Upper Tanana basins, which are somewhat higher. Locally as much as 200 feet of Quaternary rocks are exposed in terraces and cliffs along the Bering Sea coast and along the rivers of the interior region. At some places hills of pre-Tertiary rock protrude from alluvium of the basin floors, but this is a rare condition, except at the margins of the basins.

The origin and Cenozoic history of the topographic basins and the thickness, age, and character of their deposits of Cenozoic and older age are major geologic problems that may have a bearing on petroleum exploration in the Territory. One possibility is that the surface of the pre-Tertiary rocks, which forms the "basement" of the basins, is nearly flat and that the Tertiary and Quaternary deposits are not appreciably thicker in the central areas than in the marginal areas. Another possibility is that these topographic basins are also structural basins and that the Cenozoic deposits thicken inward from the basin margins at a considerable rate. A corollary of this possibility is that Tertiary strata may be present in the central areas but are not exposed in the marginal areas of the basins because they are overlapped by Quaternary deposits. Furthermore, if this corollary is applicable to the basins, they might contain marine deposits of Tertiary age even though there is little evidence of such deposits in the region here considered. Marine beds that probably are Pleistocene in age have been reported in the Norton and Nushagak basins. Marine fossils that are of Miocene, Pliocene, or Pleistocene age have been found in Quaternary gravels near Fairbanks, at the northern edge of the Middle Tanana basin. They may have been derived from marine Tertiary beds that have been eroded from the adjacent upland area. These occurrences are described in the discussion of the various basins.

Central Alaska is geologically analogous in several respects to the region of the western United States between the Rocky Mountains and the Sierra-Cascade belt, where some basins that are bordered by ranges of older rocks contain considerable thicknesses of Tertiary and Quaternary deposits. Although central Alaska is barricaded from the Pacific Ocean by high mountain ranges, as is the comparable region of the United States, the lowland and upland belts of the interior trend into the Bering Sea. Four of the lowland areas, including the Selawik, Norton, Bethel, and Nushagak basins (pl. 2), are marginal to the sea and are indented by prominent bays and sounds. Thus the sea may have had access to the interior during Cenozoic time, and there are some reasons for believing that the interior region stood at low altitude during much of this time. One line of reasoning is based on geomorphic evidence (Wahrhaftig, 1950, p. 1532). Roland W. Brown of the Geological Survey (written communication, 1953) has stated his belief that the lands that supported the recognized Tertiary floras in general stood but slightly above sea level. Eardley (1938, p. 338) has suggested that Quaternary deposits of blue loam and peat, which are widespread along the lower Koyukuk River and the lower part of the Yukon River, may have been deposited in an estuary from the Bering Sea.

Marine fossils of Pliocene age in the Pribilof Islands (Hanna, 1919) and marine fossils of Eocene age and Miocene or Pliocene age in the area of Port Moller and Pavlof Bay on the Alaska Peninsula indicate that the southern part of the Bering Sea was in existence as a marine body in Tertiary time.

The Cenozoic history of central Alaska cannot as yet be described with much assurance. Theories that have been discussed by geologists of the Geological Survey are summarized below because they are pertinent to consideration of the petroleum possibilities of the topographic basins. According to geomorphic and stratigraphic evidence, Alaska was reduced by erosion to a surface of low relief and probably low altitude following the first phase of the Laramide orogeny, which was post-Cretaceous and probably was post-Paleocene or late Paleocene in age. On this surface a discontinuous cover of early Tertiary, probably Eocene, sediments was deposited (Wahrhaftig, 1950, p. 1532). The Cenozoic basins probably originated at this time as areas of extensive accumulation, whereas the present uplands were areas of thin and localized accumulations. These inferences are based in part on numerous exposures of early Tertiary deposits on the margins of the basin areas. These marginal deposits are of nonmarine origin, but the presence of marine early Tertiary deposits in the basins, although considered unlikely, cannot be ruled out. After this stage another phase of the Laramide orogeny occurred during which the early Tertiary beds were in most areas gently and in some areas strongly deformed. Gravel was deposited in basins during and following this orogeny. Then central Alaska again was reduced by erosion to a lowland surface, a condition which may have been attained during or at the close of Miocene time and may have existed almost to the end of Tertiary time.

Although the history of central Alaska during the latter part of Tertiary time is highly conjectural, two theories may be presented. According to one theory subsidence was renewed in the basin areas during Miocene and (or) Pliocene time, and a considerable thickness of sediments accumulated. The Bering Sea transgressed the marginal basins and may have invaded the interior basins. The late Tertiary deposits thus may be in part marine. The opposing theory for this stage is that the basin areas did not subside, that late Tertiary sediments were deposited only in minor thickness, and that the sea did not invade the interior areas. The basins may have been at different altitudes in this stage of their history, and one theory may better characterize some of the basins and the opposing theory, others.

There is abundant evidence that about at the close of Tertiary time Alaska was uplifted, the sea regressed from the marginal lowlands, and the mountain ranges attained most of their present stature. Here again, two opposing theories may be presented for the topographic basins. According to one, the uplift was differential; the present upland areas arose by warping and (or) faulting. Early Tertiary deposits that had survived the post-Eocene orogeny and erosion, and also any later Tertiary sediments that may have accumulated, were mostly preserved in the relatively downwarped or downfaulted basin areas. According to the other theory, the basins also were elevated, most of the Tertiary deposits were flushed out, and the basins are lowlands because of the removal of the Tertiary fill.

Most details of the Quaternary history of central Alaska are not pertinent to the subject of this report. The stage of deformation that began at the end of Tertiary time continued during Quaternary time and included further uplifting, tilting, some folding, and small displacements along high-angle faults. Glaciers occupied the higher parts of the upland areas. The basin areas had been lowlands during Quaternary time, although in some areas Quaternary deposits have been incised by rivers and the sea as a result of relatively recent minor uplifting. At least two and probably three Pleistocene marine transgressions are recorded in the lowlands bordering Norton Sound. At least one of the interior basins, the Middle Tanana basin, has undergone subsidence, as indicated by water wells that bottomed in Quaternary fluvial deposits at depths below sea level and by northward-tilted terrace surfaces in the area south of the basin. Furthermore, a short seismic line run by the Geological Survey between Fairbanks and the Tanana River, at the northern edge of this basin, has shown that the surface of the Birch Creek schist, on which the Quaternary deposits rest, slopes southward to a depth of about 700 feet, or about 250 feet below sea level (David Barnes, oral communication, 1953).

The problem as to whether or not marine Tertiary deposits are present in significant thickness and in favorable structural conditions for the accumulation of petroleum in the Cenozoic basins can only be solved by exploratory drilling and by reconnaissance seismic surveying. Whether or not the possibilities of these basins, as suggested in the above discussion, are sufficient to justify exploration is questionable.

It should be noted that most of the seeps reported in central Alaska are in or at the margins of the basin areas (pl. 1). This adds some weight to the suspicion that the gas in reported seeps may be "marsh gas" from the alluvial deposits. Some of the seeps have been examined and classed as doubtful; others have not been examined but are believed to be doubtful; and only two, which have not yet been examined by the Geological Survey, are quite possibly valid. One of these has been examined by oil company geologists and is regarded by them as doubtful but not disproved; oil from the other has been analyzed, but the reported source has not yet been examined. Both of these seeps are in basin areas. Details of the reported seeps and other indications of petroleum are given under the heading of the basins in which they have been reported.

Most of the basin areas are flat and studded with swamps and lakes. Those bordering the Alaska Range, however, slope gently away from the range and contain fans of outwash gravel. The basins are crossed by numerous meandering streams and by some larger rivers having flood plains and terraces. Higher level terraces are also represented. The interior basins tend to be heavily wooded, but those bordering the Bering Sea include large areas of treeless tundra.

NUSHAGAK BASIN

The lowland of the Nushagak basin has an area of about 10,000 square miles and is bounded on the west by the Wood River and Tikchik Mountains, on the north by the Nushagak Hills, and on the

506319—59——6

east by the Aleutian Range. It is indented by Bristol, Nushagak, and Kvichak Bays. The major river is the Nushagak, which is centrally located in the basin. The area is covered by the Bristol Bay, Ugashik Naknek, Iliamna, Dillingham, Nushagak Bay, Chignik, Port Moller, and Fort Randall quadrangles. The main sources of geologic information are reports by Spurr (1900) and Mertie (1938).

Unconsolidated deposits of Quaternary age are exposed in low coastal bluffs and along streams and consist of fluvial deposits, including glacial outwash overlain by beach, estuarine, and fluvial deposits. Several water wells have been drilled, the deepest being 213 feet; they are believed to be bottomed in fluvial deposits in channels scoured in the Nushagak formation described below.

The unconsolidated Quaternary deposits overlie the erosionally truncated, semiconsolidated beds of the Nushagak formation, which consists of gravel, sand, and clays probably of beach, estuarine, and fluvial origin. The beds are regionally tilted as much as 25 degrees and are locally deformed in small folds. At least 100 feet of the formation is exposed in cliffs along much of the coastline. Twelve species of fossil marine mollusks reportedly collected about 1884 at the present site of Nushagak were originally described by Dall (1896, p. 842–847) as Miocene. This collection was reexamined in 1950 by F. S. MacNeil (written communication, 1950), who identified only four species, all of which are found elsewhere in deposits of Pleistocene and Recent age but not in deposits of unquestioned Tertiary age. Furthermore, D. J. Miller (oral communication, 1955), on the basis of his examination of the Nushagak formation at Nushagak and other localities on Nushagak Bay in 1949, and later study of the matrix of the fossils, believes that the fossils attributed by Dall to the Nushagak locality either were collected at some other locality or occurred as secondarily deposited pebbles in the Nushagak formation.

The thickness of the Nushagak formation and the thickness and character of any earlier Cenozoic deposits that may underlie it can only be determined by exploratory drilling. Early Tertiary plants are reported from beds associated with volcanic rocks and exposed on the shores of Iliamna Lake, at the eastern border of the basin, but no deposits thought to be of Tertiary age have been found along the western margin of the basin.

Cretaceous rocks of the Alaska Range geosyncline and of a fork of the Kuskokwim geosyncline (pl. 2) are exposed north of the basin in the Nushagak Hills. The upper part of the Cretaceous system is believed to be represented here, and the beds consist of graywacke and shale with a minor amount of conglomerate. The strike is northwest; the few dips observed average 58 degrees. These rocks undoubtedly underlie Cenozoic deposits in the northern part of the Nushagak basin and may extend southward under the central part of the basin. In the western part of the province, Cenozoic deposits overlie the relatively unfavorable rocks exposed farther west in the Goodnews arch. In the eastern part of the province the pre-Tertiary rocks are those of the Talkeetna geanticline (pl. 2) and, as exposed in the Aleutian Range, include large intrusive and extrusive igneous bodies.

Oil seeps have been reported at Clarks Point on Nushagak Bay and on the lower part of the Nushagak River (pl. 1), but are regarded as doubtful. The Clarks Point locality was examined in 1948 by D. J. Miller (oral communication, 1955), who found only iron oxide films associated with tidal pools and with water seepage from the surficial layer of peat exposed in the beach bluff. In 1949 geologists of the Union Oil Co. of California and the Ohio Oil Co. visited a locality at the first north tributary of the Nushagak River northeast of Black Point where, according to John Walatka, an oil slick could be seen from the air (Eugene Borax, oral communication, 1953). A very thin oil slick was found at the entrance to the tributary creek. The source of the slick was not observed and its significance is not known, but in the opinion of the geologists it may be waste oil from boats or fish oil from canneries near the mouth of the Nushagak River. The river bluffs in this area are said to be composed of unconsolidated yellow-brown clays and sands that are probably of Pleistocene age.

BETHEL BASIN

The Bethel basin province consists of a coastal lowland having an area of about 24,000 square miles and embracing the lower courses of the two largest rivers of Alaska, the Yukon and the Kuskokwim. The province is bounded on the southeast by the Kuskokwim, Kilbuck, and Ahklun Mountains and on the north by the Yukon River, north of which lies the upland area of the southern part of the Yukon-Koyukuk Cretaceous province. The area is included in the Goodnews, Kuskokwim Bay, Cape Mendenhall, Bethel, Nunivak Island, Baird Inlet, Russian Mission, Marshall, and Hooper Bay quadrangles.

Most of the area is a low treeless plain occupied by fresh- and brackish-water marshes and countless lakes. The mouth of the Kuskokwim River has been drowned to form Kuskokwim Bay, and oceangoing freighters travel up the river as far as Bethel. The drowning of the lower course of the Kuskokwim River indicates either that the area has been sinking or the sea level has been rising relatively recently. The opposite relative movement, however, is indicated by the fact that large areas of the "delta" plain stand as much as 100 feet higher than the present level of the Kuskokwim River. The area has been regarded as representing a compound delta of the Yukon and Kuskokwim Rivers, but the validity of this concept is doubtful. The present delta of the Yukon is to the north, on the south side of Norton Sound.

The surficial deposits are chiefly silt and fine sand. A water well drilled in 1952 at the Alaska Native Service hospital at Bethel penetrated unconsolidated deposits to a depth of 450 feet. Hard drilling, possibly in sandstone, was noted from 450 feet down to 454 feet, at which depth the well was bottomed. Sand and small pebbles were interbedded with silt below a depth of 147 feet. Considerable woody material was found throughout the entire section. Below a depth of 410 feet, woody fragments are reported to be "partly petrified." Permafrost was present to a depth of 403 feet. The bottom of the well is more than 300 feet below sea level.

Several small volcanic cones, the tops of which are mostly less than 500 feet in altitude, protrude from the Quaternary alluvium in the western part of the province. Two other islandlike bedrock areas, the Kusilvak and the Askinuk Mountains, near Scammon Bay, rise to altitudes slightly greater than 2,300 feet above the surrounding water and Quaternary deposits. Interpretation of aerial photographs (Coonrad, 1957) indicates that the Kusilvak Mountains are probably a fault block of rocks of Cretaceous age. Observable structures are steep, and there appears to be a stocklike intrusive body exposed at the northern end of the mountains. It is not known definitely what type of rocks form the Askinuk Mountains and Cape Romanzof, but the limited information available suggests that there probably are some intrusive rocks present and possibly metamorphic and volcanic rocks as well.

Graywacke-type sandstone and siltstone containing a few thin coal beds crops out in cliffs on the western side of Nelson Island. Similar rocks have been reported from the north side of Nunivak Island. Fossil plants suggest a probable Late Cretaceous age according to R. W. Chaney (Coonrad, 1957). Most of the upland areas of both Nelson and Nunivak Islands are capped by basaltic volcanic rocks of late Tertiary or early Quaternary age. There are no apparent eruptive centers on Nelson Island, but Nunivak Island does have several recognizable volcanic cones and craters.

Much of the sediment eroded from interior Alaska during Cenozoic time discharged into or passed through the Bethel basin area, and the basin may locally contain thick Cenozoic deposits. The Cretaceous rocks and structures of the Yukon-Koyukuk province trend southwestward into, and probably underlie, the Cenozoic deposits of the Bethel basin area (pl. 2) and afford an additional possibility that should be considered in evaluating the area. In the eastern part of the basin Cenozoic deposits probably are underlain by the complexly deformed rocks of the Ruby geanticline and Kuskokwim geosyncline (pl. 2), which are relatively unfavorable for petroleum.

An oil seep near the Eek River at the eastern margin of the basin (pl. 1) is reported to have been seen from the air, and natives say they have seen oil in this area. Other oil seeps have been reported near Toklik (formerly called Bennetts) on the Yukon River at the northern border of the basin, and near Whitefish Lake, south of the Kuskokwim River. A friable sandstone having an oil odor and causing a smudge on the hands has been reported on Nelson Island; the sandstone probably is part of the Cretaceous coal-bearing sequence. These reports have not yet been investigated by the Geological Survey.

NORTON BASIN

The Norton basin province includes Norton Sound, Norton Bay, and about 6,000 square miles of bordering coastal plain. The delta of the Yukon, which has been built into the Sound, and the coastal plain south of the delta include more than half of the land area. The province is bounded on the north by the upland of the Seward Peninsula and on the east and southeast by the upland of the Yukon-Koyukuk Cretaceous province. The province is covered by the Kwiguk, St. Michael, Unalakleet, Norton Bay, Solomon, and Nome quadrangles.

Bedrock in the coastal plain is covered by Quaternary alluvium, and the only subsurface information is from the mine shafts, drifts, and drill holes of the Nome and Solomon areas at the northern margin of the basin (Moffit, 1913; Mertie in MacNeil, Mertie, and Pilsbry, 1943, p. 69–73; Smith, 1910, p. 207–214). The Cenozoic deposits here generally consist of till and gravel of glacial origin and sand of glaciofluvial and littoral marine origin, having a maximum thickness of about 200 feet. The sediments rest on Paleozoic schist, slate, and limestone.

MacNeil, Mertie, and Pilsbry (1943) assigned approximately the upper half of the Cenozoic rock sequence to the Pleistocene and the lower half to the Pliocene on the basis of percentage of extinct species in several collections of marine fossils. Later geologic studies by Hopkins (oral communication, 1953) strongly suggest, however, that the entire sequence is of Pleistocene age. Several beach and near-shore deposits have been exploited for their gold content; they record at least one Pliocene or early Pleistocene marine transgression, probably Pleistocene according to Hopkins, which extended inland about 3 miles from the present coast. In addition, a middle Pleistocene and a late Pleistocene transgression are recorded; these are believed by Hopkins to reflect eustatic fluctuations of sea level during interglacial periods rather than subsidence of the basin.

In the coastal plain areas south of Norton Bay, including the Yukon delta area, Cenozoic deposits probably lie on the folded, northeastward-striking Cretaceous rocks of the Yukon-Koyukuk geosynclinal belt. Thus Cretaceous as well as Tertiary rocks should be regarded as possibly favorable for petroleum in this part of the Norton basin province. Pre-Tertiary rocks in coastal plain areas on the north side of Norton Sound and Norton Bay are unfavorable for petroleum because they consist of metamorphic and intrusive igneous rocks of the Chukotskiy-Seward uplift. Volcanic rocks, in part of Quaternary age, occur in the area around St. Michael, including Stuart Island.

In 1906 two holes were drilled for oil in the coastal plain at Hastings Creek, east of Nome, where seeps are supposed to have been found. In 1918 two more holes were drilled at this place. Cathcart (1920, p. 196–197) has described the results of the drilling as follows:

> In 1906 it was reported that at a depth of 122 feet gas was encountered which blew a 1,200-pound stem 75 feet up the hole. A second hole, 176 feet deep, drilled in 1906, is said to have shown a trace of oil. During the summer of 1918 two wells were drilled. The first well was abandoned at 210 feet owing to the loss of a bailer in the hole; the second had reached a depth of about 150 feet at the end of the season * * * It is believed that any gas which may have been encountered was derived from the alluvial deposits * * * The hard rocks of the locality are granite and schist * * *

Oil seeps have been reported in the Sinuk Valley near the junction of the Sinuk and Stewart Rivers, about 20 miles northwest of Nome. The Bartholomae Oil Company is said to have drilled several exploratory holes in this area; the location and date of this work has not been ascertained. Hopkins (oral communication, 1953) has described the geology of this area as follows:

> The Sinuk and Stewart Rivers join in an east-northeastward-trending trench that extends from the mouth of the Tisuk (Tishue) River to the head of the Nome River.. Most of the trench bears a thick mantle of till and outwash. Paleozoic metamorphic rocks crop out in the hills on each side of the trench and also at the east and west ends. However, a small patch of unmetamorphosed coal-bearing sediments is exposed in the valley of Independence Creek, south of the trench. Much of the trench may be underlain by infolded, unmetamorphosed Cretaceous or Tertiary sediments.

Oil shale has been reported on Besboro Island in Norton Sound, and an oil seep has been reported near the mouth of the Inglutalik River, which drains into Norton Bay. These have not been investigated by the Geological Survey.

SELAWIK BASIN

The western part of the Selawik basin is occupied by Kotzebue Sound, Eschscholtz Bay, Hotham Inlet, Selawik Lake, and adjacent land areas; it also includes the coastal plain on the north side of the upland of the Seward Peninsula. The eastern part is mostly land, drained by the Selawik River, and is bounded on the north by the Waring Mountains, on the south by the upland area of the Yukon-Koyukuk Cretaceous province, and on the east by the upland that includes Purcell Mountain. The basin has a land area of about 5,000 square miles and is covered by the Shishmaref, Kotzebue, Selawik, Shungnak, and Noatak quadrangles.

Volcanic rock masses protrude from the alluvium of Quaternary age in the coastal lowland of the Seward Peninsula; Devil Mountain and rolling hills between Candle and Elephant Point are composed of volcanic rocks of Pleistocene age. Bedrock, probably Paleozoic in age, is exposed on the Baldwin Peninsula, west of Hotham Inlet. Coal has been reported in the coastal plain between Devil Mountain and Shishmaref and also in the headwaters area of the Espenberg River a few miles northeast of Devil Mountain. The coal may be of Tertiary age. Deposits that may be of Tertiary age have been observed in the valley of the Selawik River near Purcell Mountain during aerial reconnaissance by geologists of the Geological Survey. Elsewhere the Selawik basin is floored by Quaternary alluvium.

In 1950 a hole was drilled at Kotzebue to test the possibility of occurrence of fresh water in Quaternary deposits (Cederstrom, 1952, p. 34–35). Gravel and blue mud were penetrated to a depth of 79 feet. Between 79 feet and 83 feet thawed gravel containing salt water was found. Between 83 feet and 238 feet frozen blue clay, containing sand and gravel, was penetrated. At 238 feet gas under high pressure lifted the heavy string of tools several feet in the air, showered the area with mud, and continued to flow for more than 24 hours. From 238 feet to the bottom of the hole at 325 feet thawed brown silt saturated with salt water was penetrated. The gas may have been derived from decaying vegetal material in the Quaternary deposits.

Three oil seeps have been reported in or very near Selawik basin province. The one on the Noatak River near the northern border of the province (pl. 1) has been investigated by the Geological Survey and is regarded as very doubtful. The other two are in the vicinity of Devil Mountain in the northern coastal plain of the Seward Peninsula, and have not been investigated by the Geological Survey. One of these, located in the headwaters area of Nugnugaluktuk River, 10 to 15 miles south of Devil Mountain, is said to be indicated by an oil slick on a small lake. Leases were filed in 1921 by residents of the Seward Peninsula but were cancelled in 1932. A sample reported to have been collected from the seep was submitted in 1922 to Thomas B. Brighton, a chemist of the University of Utah, and according to his report gasoline was obtained by distillation, indicating that the sample undoubtedly was a petroleum oil. The other reported seep is about 15 miles southeast of Devil Mountain where an Eskimo found a spring that never freezes and leaves a red stain, tasting like gasoline in the snow. This later was examined by a bush pilot who reported a pond covered with slush ice in which there were 5 holes from which water was issuing. One smelled strongly of "gasoline or crude oil." David M. Hopkins, a geologist of the Geological Survey, flew over the site in 1949 and has stated (oral communication, 1953):

> I am inclined to think that this site is a warm spring, and that any gases present are marsh gases from decaying peat interbedded with ash. However, it is conceivable that it could indeed be an oil seep.

GALENA BASIN

The Galena basin, having an area of about 5,000 square miles, is bounded on the east and west by uplands of Cretaceous rocks of the Yukon-Koyukuk province, on the north by the upland composed of older rocks of the Hogatza arch, and on the south by the Kaiyuh Mountains that are composed of metamorphic rocks of Paleozoic age. The basin area is included in the Nulato, Kateel River, and Melozitna quadrangles. The major rivers are the Koyukuk and the Yukon. The main sources of information are the reports cited under the discussion of the Yukon-Koyukuk province and a paper by Eardley (1938), in which the alluvial deposits are described.

Exposures of Tertiary rocks have not been reported in or marginal to the Galena basin, but two hills of Cretaceous rock, known as Bishop Rock and Pilot Mountain, protrude from the Quaternary alluvium. These are along the Yukon River near the mouth of the Koyukuk.

The Cenozoic deposits evidently overlie the Cretaceous rocks of the Yukon-Koyukuk province throughout most of the basin area. Thus the possibilities of Cretaceous rocks, as well as Tertiary rocks that might be present below the alluvium, should be considered. Seeps have not been reported in this area.

LOWER TANANA BASIN

The lower Tanana basin is occupied by the Yukon River between Tanana and Ruby, by the part of the Tanana River below Cosna, and by the lower course of the Nowitna River, which enters the Yukon from the south. It has an area of about 2,500 square miles and is contained in the Kantishna, Ruby, Tanana, and Melozitna quadrangles.

The middle part of the basin is only 10 miles in width (pl. 2), and here, at what is known as the Palisades, deposits of Tertiary and Quaternary age have been incised by the Yukon and are exposed in bluffs as much as 250 feet in height. At this locality Eardley (1938, p. 318) measured about 600 feet of Tertiary, 200 feet of Tertiary or Quaternary, and about 430 feet of Quaternary beds. The total thickness of the Tertiary sequence is unknown because the base was not seen; it consists of woody lignite in beds up to 20 feet thick, somewhat compacted loam, and slightly cemented sandstone. The Tertiary beds are tilted and form the upthrown block of a fault that has brought them into juxtaposition with the Quaternary deposits. The Tertiary or Quaternary sequence is exposed farther downstream in the Palisades, is flat-lying to gently tilted, and consists of beds of sandstone and conglomerate, gravel and sand, peaty lignite, and loam. The Quaternary deposits consist of gravel, sand, silt, and loam.

The Tertiary rocks may be of early Tertiary age and equivalent to the nonmarine rocks of the Healy trough and other troughs of central Alaska (pl. 2). If this correlation is correct, then the overlying strata regarded by Eardley as of Tertiary or Quaternary age may be entirely of Tertiary age and perhaps equivalent to the Nenana gravel of the Healy trough and Alaska Range area. On the other hand, the woody character of the lignite in the Tertiary unit and the relatively unconsolidated nature of the sand and loam suggests that the beds may be of late Tertiary age, in which case the overlying unit represents basal Quaternary deposits. In either case the order of events at this locality evidently was as follows: (1) deposition of Tertiary rocks, (2) folding or at least strong tilting, (3) erosional truncation of these rocks, (4) deposition of Tertiary or Quaternary rocks, (5) deposition of Quaternary rocks, (6) faulting, with a throw of at least 200 feet, and further gentle tilting of the beds, (7) erosional truncation to form the present basin surface, and (8) uplift and entrenchment of the Yukon River to form the Palisades.

Although there is no evidence of marine deposits of Tertiary age in this province, the presence of such deposits cannot be ruled out, because the thickness and character of Tertiary beds underlying the exposed section are unknown, and the exposures are limited to such a small part of the basin province. The possibilities of finding oil in pre-Tertiary rocks are not good because they evidently consist of metamorphic rocks of the Ruby geanticline and of the part of the Kuskokwim geosyncline adjacent to the basin (pl. 2). Seeps have not been reported in this basin.

HOLITNA AND MINCHUMINA BASINS

The Holitna and Minchumina basins, like the Middle and Upper Tanana basins, lie north of the arcuate highland belt of the Alaska Range. A great gravel apron lies between the front of the range and the basins. The two basins are separated by a low mountainous area, and the Holitna basin is separated from the Nushagak basin by the Nushagak Hills. The Kuskokwim Mountains form the northwestern border of the basins.

The two basins are considered together because of their similar geographic setting and because of the lack of geological information on this part of Alaska. Their total area is about 7,000 square miles, which is covered by the Lime Hills, Sleetmute, McGrath, Mt. McKinley, and Medfra quadrangles. The basin floors have an altitude of about 1,000 feet along their poorly defined southeastern borders, from which they slope gently northwestward. Drainage from the Holitna basin is by way of the Kuskokwim and its tributaries; the Holitna, Hoholitna, Stony, and Swift Rivers. Drainage of the Minchumina basin is southward by way of the Kuskokwim and its various forks and tributaries and northward by way of the Kantishna and its tributaries.

There is no information available concerning the Cenozoic history of these basins, but because they lie in the same physiographic trend as the Middle Tanana basin the conditions described below for that basin may in part be applicable. It is likely that they contain Tertiary deposits. The Cenozoic deposits of the basins evidently lie on the complexly deformed old rocks of the Tanana geanticline (pl. 2). Seeps have not been reported.

MIDDLE TANANA BASIN

The middle Tanana basin, commonly designated as the Tanana flats, is bounded on the south by an upland composed of the early Tertiary coal-bearing sequence of the Healy trough and of the Totatlanika schist of Mississippian(?) age. The south boundary is rather straight, but the north boundary is irregular and includes two large alluvial embayments that extend into the Yukon-Tanana upland, which is composed of the Birch Creek schist of Precambrian age and rocks of Paleozoic age. Fairbanks is located at the northern margin of the basin in the eastern embayment.

The basin has an area of about 6,500 square miles and is shown on the Big Delta, Fairbanks, Kantishna River, and Livengood quadrangles. The Alaska Railroad enters from the south by way of the canyon of the Nenana River and crosses the lowland to the town of Nenana, located on the Tanana River at the southwestern end of an upland promontory of Birch Creek schist. The main published source of information on this area is a report by Capps (1940).

The alluvium exposed in the southern part of the basin consists of gravel in the form of coalescing alluvial fans. This part as well as the central part, where the alluvium is finer, slopes gently northward and is crossed by northward-draining streams. The northern part of the basin is level and includes the present and former meander belts of the Tanana River.

In the southern part of the upland area of the Healy trough (pl. 2) a sequence of at least 5,000 feet of nonmarine strata of Tertiary age is known to occur. This includes a coal-bearing unit of Eocene age and the overlying Nenana gravel. The Tertiary sequence thins northward in this trough area, but is 1,000 to 2,000 feet thick where it disappears northward under the alluvium of the Middle Tanana basin. This condition, together with the presence of Tertiary beds in small remnants on the north side of the basin at Richardson and in the upland area north of the Tanana River, suggests that Tertiary beds underlie at least part, and perhaps a large part, of the Middle Tanana basin. The Tertiary sequence along the south side of the Middle Tanana basin consists mostly of sandstone and gravel of the Nenana formation, for the coal-bearing unit extends northward to the basin only in the area at the mouth of Tatlanika Creek.

Northward-tilted terraces, water wells, and a short seismic line near Fairbanks indicate, as mentioned in the general discussion of the basin provinces, that the Middle Tanana basin subsided during Quaternary time, and lowered fluvial deposits below sea level. An important problem is whether or not the basin also subsided and received sediments during the latter part of Tertiary time and whether or not such sediments, if deposited, have been preserved in the basin. Marine fossils, of Miocene, Pliocene, or Pleistocene age have been found in dredge tailings in the area between Cripple and Ester Creeks west of Fairbanks (Péwé, 1954). The fluvial gravel from which they were obtained is near the base of the Quaternary sequence and is believed to be of early Quaternary age. The fossils consist of five specimens, at least four of which are the same species; they show evidence of transportation and may have been derived from marine beds of Tertiary age in the adjacent upland area. If such beds were deposited in the upland, it would be logical to assume that they were also laid down in the basin to the south.

The Middle Tanana basin thus is known to contain a considerable thickness of Quaternary deposits; it may contain late Tertiary deposits, and probably contains early Tertiary deposits. Unless they change in facies northward in the basin area the early Tertiary deposits probably are nonmarine, as in the Healy trough area. The Tertiary deposits rest on a basement of Precambrian schist and Paleozoic rocks. A few hills of basement rocks protrude from the alluvium in the central part of the basin and are shown on the Fairbanks quadrangle. They include the Wood River Buttes, Clear Creek Butte, and some low hills in the vicinity of Blair Lakes. Three possible explanations of these basement hills are: (a) they rise but little above the general basement floor and are flanked by only a small thickness of Cenozoic deposits, (b) they are mountains mostly buried by a considerable thickness of Cenozoic deposits, or (c) they represent cores of folds or domal structures, from the tops of which the Cenozoic sequence has been eroded. If a Tertiary sequence favorable for petroleum is found by drilling in this basin, buried basement hills might constitute compaction structures suitable for testing.

In the early 1920's a seep is said to have been observed on Totatlanika Creek at the edge of the basin, and a hole which did not strike oil was drilled to a depth of 40 feet where it bottomed in sandstone. A sample reported to be from the seep was analyzed by Paul Hopkins, a chemist of the U.S. Bureau of Mines stationed at the University of Alaska. The 40-lb sample of oily sand and gravel was treated with solvent and yielded 5 oz of oil. Hopkins reported the following analysis of this oil:

Temperature		Product	Specific gravity	Percent by weight	Remarks
°C	°F				
≦150	≦302	Gasoline and naphtha.			
150–300	302–572	Illuminating oil.	0.9235 at 15° C (22° Baumé at 60° F).	88.5	
240–360	464–662			4.0	Partial vacuum.
		Asphalt and coke.		7.5	Residue.
Total				100.0	

Another seep has been reported near the head of Clear Creek in the central part of the basin. It is further reported that the freighters operating in the early days over the Bonnifield trail burned oil-saturated tundra tussocks at the place in the Fairbanks quadrangle where the trail crosses the Wood River. In 1954, Clyde Wahrhaftig and Alan Cox, geologists of the Geological Survey, examined the Wood River locality and observed iron-oxide scum on the surface of ponds, but found no indication of oil. Oil seeps also have been reported near the mouth of the Nenana River. Numerous water wells and test holes in the unconsolidated alluvium in the Fairbanks area have struck marsh gas.

UPPER TANANA BASIN

The upper Tanana basin is in the upper area of the Tanana River, near the international boundary. It lies northeast of the Nutzotin Mountains of the Alaska Range and is in the same general trend as the Holitna, Minchumina, and middle Tanana basins. The history of this basin probably is similar in a general way to that of the middle Tanana Basin.

Gas has been found in two shallow wells drilled during 1955 in unconsolidated Quaternary deposits. The first well was drilled for water at Seaton's Service Station on the Alaska Highway, about 10 miles northwest of the international boundary. After penetrating permafrost, gas (mostly methane) was found at a depth of about

200 feet. The second well, about 3 miles northwest of the first well, was drilled by Alaska Propane Co., Inc., to a depth of about 350 feet. Gas was found between depths of 195 and 220 feet; the bottom of permafrost was at about 250 feet.

YUKON FLATS BASIN

The Yukon Flats, with an area of about 11,000 square miles, is the largest of the interior basins. Most of the area is included in the Black River, Fort Yukon, and Beaver quadrangles. The Yukon River flows in a great arc through the center of this lowland and is joined by several tributaries of which the Porcupine River is the largest. The floor of the basin slopes on an average of about 10 feet per mile toward the Yukon and has a westward slope component of about 1 foot per mile. The average altitude is somewhat less than 600 feet. The basin includes broad heavily wooded flood-plain or meander-belt areas, low terraces, and in the northern part, alluvial fans composed of glacial outwash from the Brooks Range. The maximum relief is about 70 feet. The surficial deposits are commonly silt and sand, several feet thick, which overlie sand and gravel.

Marginal escarpments that stand 100 to 650 feet above the lowland floor separate the basin from the surrounding piedmont uplands. The piedmont surfaces, deeply incised by streams, rise at a rate of 5 to 25 feet per mile toward the mountains that completely surround the basin. The piedmont area consists of bedrock veneered by alluvium.

Coal-bearing strata, presumably early Tertiary in age, have been reported at two localities at the northwestern margin of the basin, one on the Dall River and the other on the Hodzana River. This nonmarine sequence also occurs in the Rampart, Eagle, and Coleen troughs, which nearly adjoin the basin. Cenozoic volcanic rocks have not been found in the basin area.

The basin is bounded on the north and northwest by metamorphic rocks of the Ruby and Brooks Range geanticlines (pl. 2). Complexly deformed rocks of Paleozoic age lie to the south, in the Kuskokwim geosyncline and the structurally more favorable Kandik Mesozoic and Paleozoic province, described in a separate section of this report, lie to the east and southeast. It is believed that the Cenozoic deposits of the basin are underlain mostly by Paleozoic rocks, which may include part or most of the rocks described for the Kandik province. If the relatively simpler structural conditions of this province extend northwestward, the Paleozoic rocks may be favorable for petroleum in the adjoining part of the Yukon Flats basin.

The Yukon Flats area probably is underlain by the same rocks and has undergone the same pre-Eocene history of deformation as the mountainous areas around it. If this interpretation is correct, then the lowland originated either by deep erosion and broad lateral planation of bedrock by streams, or directly or indirectly by subsidence, through downwarping or downfaulting, during some part of Cenozoic time. The first explanation of its origin does not seem plausible because of the vast size and nearly flat floor of this basin and the fact that the streams enter and leave it through canyons. The presence of coal-bearing rocks in marginal areas suggests the second explanation, including early Tertiary subsidence and accumulation. The possibility of subsidence and sedimentary accumulation during the latter part of Tertiary time is an interesting speculation but is indeterminable from surface evidence. Seeps have not been reported in this province.

NORTHERN ALASKA

By George Gryc

Northern Alaska includes the Brooks Range and all the region to the north, an area of about 125,000 square miles. This region includes 3 known oil fields, Umiat, Simpson, and Fish Creek, and 2 gas fields, South Barrow and Gubik. Indications of oil and gas have been found in nearly all test wells drilled, several oil and gas seeps have been found, and geologic conditions favorable for accumulation of oil and gas are present in approximately one-half the region.

The summary of the geology and the discussion of possible petroleum provinces in northern Alaska is based primarily on the work of the many geologists who participated in the Navy Department oil exploration program in Naval Petroleum Reserve No. 4 (NPR-4) and adjacent areas. The discussion of the history of petroleum exploration is based primarily on the writings of Leffingwell (1919) and Smith and Mertie (1930).

Technical data and reports on the Navy Department oil exploration program are available for public inspection in the files of the U. S. Geological Survey. This information is now being published as Geological Survey Professional Papers 301–305.

GEOGRAPHY

Northern Alaska comprises three geomorphic provinces: the Brooks Range, the Arctic foothills, and the Arctic coastal plain (Payne and others, 1951). These provinces are outlined on plate 1 and figure 3.

BROOKS RANGE PROVINCE

The Brooks Range includes several groups of mountains extending from the Chukchi Sea, on the west, eastward in a gentle arc to the international boundary. Here the mountain arc swings southward into the Canadian Rockies. The highest peaks, Mount Michelson (9,239 feet) and Mount Chamberlin (9,131 feet), are in the Romanzof Mountains in the eastern part of the Brooks Range. Jagged peaks and ridges characterize the entire range but diminish in height from an average of 5,000 to 6,000 feet in the east to 3,000 to 4,000 feet in the west. Small glaciers are common in the Romanzof Mountains but decrease in number westward.

The Brooks Range has been described as "the backbone that separates the waters flowing southward into the Yukon and its tributaries or westward into Kotzebue Sound from those flowing northward into the Arctic Ocean" (Smith and Mertie, 1930, p. 32). Although the rugged topography of the mountains forms a barrier to easy ground traverse, several major rivers have cut back into the range to form low passes. Perhaps the best and most widely known is Anaktuvuk Pass, at an elevation of 2,200 feet in the central part of the Range, almost due south of Umiat, site of the largest known oil deposit in the region. A pipeline to transport oil and gas out of northern Alaska to the major population centers or to an ice-free port would probably be routed through Anaktuvuk Pass.

Geologic parties have traversed the Brooks Range on foot, by boat and canoe, and recently by weasel (fully tracked military personnel carrier). These vehicles have been driven across the drainage divide at Anaktuvuk Pass, at the head of the Okokmilaga River, and at the pass at the head of the Utukok River. Bush planes on floats can be operated readily out of large glacial lakes such as Chandler, Shainin, and Galbraith Lakes in the Endicott Mountains and Lakes Schrader and Peters in the Romanzof Mountains. Many of the rivers and streams which head in the range are navigable by small boat and canoe. However, these rivers commonly cut through fields of glacial boulders and form impressive and nearly impassable rapids. As in most treeless areas, the amount of water in streams and rivers of the Arctic slope varies considerably, and a stream that is a rushing torrent in early spring may be a mere trickle in late fall or just before the spring breakup. Similarly a stream may rise several feet in a few hours after a heavy rain. These factors are critical in the successful operation of field parties in this region.

North of the Brooks Range, and sloping gently to the Arctic Ocean, lies a treeless tundra region, referred to by Brooks (1906, p. 46–47) as the "Arctic Slope." It includes the Arctic foothills and Arctic coastal plain provinces of Payne and others (1951).

ARCTIC FOOTHILLS PROVINCE

The hilly region north of the Brooks Range in the vicinity of the Anaktuvuk River was named "Anaktuvuk Plateau" by Schrader (1904, p. 45). The name "Arctic Plateaus" was used by Smith and

Mertie (1930, p. 29) for the entire belt "of plateaus standing at different elevations" between the Brooks Range and the Arctic coastal plain. Recent studies (Payne and others, 1951) indicate that this belt is topographically and geologically a foothills province and thus was renamed the Arctic foothills province. This province is subdivided into two sections, the southern foothills and the northern foothills.

SOUTHERN FOOTHILLS SECTION

The southern foothills (pl. 1, and fig. 3) are characterized by isolated, irregular hills and ridges of sandstone, limestone, and chert which rise above low shale areas of little relief. This section has the structural complexity of the Brooks Range but differs in being composed of less resistant rocks, including a great thickness of shale. Ridges and hilltops are at altitudes of 2,500 to 3,500 feet and rise 1,000 to 2,000 feet above the surrounding plains. The southern foothills are readily traversable by such vehicles as the weasel but not so easily by boat, plane or foot. Lakes suitable for landings by small float planes (1 to 2 passengers) are not abundant and only a few lakes such as Noluk and Liberator Lakes are suitable for larger float planes (3 to 6 passengers). The flat areas between the hills or along ridgetops are ideally suited to the use of tracked vehicles.

NORTHERN FOOTHILLS SECTION

The northern foothills section (pl. 1 and fig. 3) differs from the southern section in having more regular topography, including persistent ridges and elongate mesas that reflect a simpler structure of Appalachian-type folds, with minor cross faults, and a few major overthrusts. Anticlines are commonly asymmetric with steeper limbs on the north.

ARCTIC COASTAL PLAIN PROVINCE

The Arctic coastal plain province has been divided on the basis of geology and topography into the Teshekpuk Lake section and the White Hills section.

TESHEKPUK LAKE SECTION

The Teshekpuk Lake section (pl. 1 and fig. 3) is a monotonous, treeless tundra plain covered by thousands of lakes and swamps and poorly drained by meandering streams. The bedrock is largely mantled by a thin layer of Quaternary sediment. Smith and Mertie (1930, p. 48) describe this section as follows:

Perhaps the most striking characteristic of the coastal plain is the uniformity and monotony of its landscapes. Except for minute minor details, its appearance is everywhere the same. Its slope is so slight that to the unaided eye it appears to stretch away to the horizon as an endless flat. Prominent landmarks are entirely absent. Owing to its featurelessness even minor elevations such as sand dunes 10 feet high appear to be notable prominences; in fact, it is said that one of the earlier explorers reported a range of mountains east of the Colville where subsequent explorations have proved that only low sand dunes exist. Over these plains the winds sweep with unbroken severity, and the traveler caught in the sudden storms that are common in the winter finds it next to impossible to get any natural shelter. In the summer the poorly drained tracts of upland afford only spongy footing, which makes travel laborious and slow, and lakes and deep sloughs necessitate circuitous deviations from direct courses.

Although the annual precipitation is only 5 to 7 inches, a general wetness results from little evaporation, poor drainage, and the inhibited underground seepage due to permafrost that extends from a few inches or a few feet below the surface to a depth of about 1,000 feet.

The Teshekpuk Lake section can be readily traversed by tracked vehicles. While the ground is frozen, heavy equipment can be moved easily by sled and tractor, but during July and August, seasonal thaw hinders movement of heavy equipment. Small or large float planes can be landed on many of the numerous lakes to reach almost any part of the area. All streams are navigable by small boat during high water but may be unnavigable during dry seasons. Traverse by foot is extremely difficult and laborious because of the spongy wet tundra.

WHITE HILLS SECTION

The White Hills section (pl. 1 and fig. 3) is an area of slightly greater relief and fewer lakes and swamps than the Teshekpuk Lake section. Tertiary rocks form the white-sand-and-gravel-covered hills from which the section is named.

SURFACE INDICATIONS OF PETROLEUM DEPOSITS

The occurrence of petroleum in northern Alaska has been known at least since early 1900. A description of the Cape Simpson oil seeps on the Arctic coast was first published by Brooks in 1909 and was based on information and materials collected by E. de K. Leffingwell. Leffingwell included essentially the same data in a later report (1919, p. 178), and also noted a reported seep locality between Humphrey Point and the Aichillik River. The oil seeps in the Cape Simpson area were also visited by A. M. Smith in 1917. On the basis of his oral description, oil company geologists inspected and mapped the area in 1921.

No additional seeps were found by members of the Geological Survey working in the region from 1923 to 1926 but a reported occurrence in the "so-called White Mountains" east of the Colville River was noted (Smith and Mertie, 1930, p. 275). The seeps at Cape Simpson

506319—59——7

were mapped in some detail and a report by Paige and others (1925) was published. Paige also searched for reported seeps in the region adjacent to the coast from the vicinity of Cape Smyth to a point east of Peard Bay and the portage to the Inaru River but none were found. Other reported seeps near the mouths of the Kokolik, Kukpowruk and Meade Rivers could not be located.

In 1943 a field party of the U. S. Bureau of Mines again examined the Cape Simpson area and made a further search for reported seeps (Ebbley, 1944, and Thomas, 1946). The results of this work were published in Bureau of Mines War Minerals Report 258 (1944). Seeps were located and described at Umiat Mountain, Fish Creek, Dease Inlet, Manning Point and Un-goon Point.

During the course of the Navy Department oil exploration program (1944–53) all the known seeps were again examined, and in addition, the following three were discovered: two gas seeps, one on the upper Meade River near the junction with Pahron Creek and another along the Colville River near the mouth of Aupuk Creek, and an oil seep at Skull Cliff on the Arctic coast about 35 miles southwest of Barrow. Several attempts were made to locate the reported seep in the White Hills but without success, nor could the reports of seepage sites near the mouths of the Meade, Kukpowruk, or Kokolik Rivers be substantiated.

Information on the three new seepage discoveries had not been published previously. Webber (1947) describes the Skull Cliff seep as follows:

> At the base of Skull Cliff a light petroleum drips slowly from an area a few inches across in a bed of fine-grained sandstone. The thickness of sandstone exposed is eight feet; the bottom of the bed was not seen.

Webber (1947) also visited the Pahron gas seep near the headwaters of the Meade River; he states that—

> gas bubbling from the bed of a lake near the headwaters of the Meade River has been reported to be coal gas (methane) according to an analysis made for the U. S. Navy.

Whittington (Whittington and Keller, 1950) revisited this site in 1949. He states:

> The Pahron gas seep occurs at the lake about a quarter of a mile north of the Meade River at longitude 157° 36′ W. The main seepage zone, about 50 feet in length, trends N. 75° E. approximately 100 feet off the west shore of the lake. Most of the gas is escaping at the extremities of this zone. In addition, two small centers of escape are 50 feet from shore and 50 feet apart, one on either side of the projection of the main zone. When the lake is calm, the seepage appears in the form of continuous bubbling at the surface of the water.

The Aupuk gas seeps are described by Eberlein, Chapman, and Reynolds (1950) as follows:

Two seeps of dry gas have been reported at the eastern end of the Aupuk anticline. The most active of these is located at the southeast end of a small lake about 1¾ miles above the mouth of Aupuk Creek. This seep was mapped by Navy geological party No. 3 in 1945 and again by a U. S. Geological Survey party in 1946. It was also examined by R. F. Thurrell during 1947 caching operations. At the time of the 1946 investigation gas bubbles rose to the lake surface at the rate of about one per second in 20 or more spots within an area of 150 square feet. When visited during the 1950 field season the seep was apparently more active. The area of bubbles was found to include approximately 300 square feet of lake surface. Five spots were observed to be bubbling continuously. Bubbles were rising at a rate of one every two or three seconds in two other spots. No trace of oil was observed at the surface.

A sample of this gas was collected in 1946 and analyzed by the National Bureau of Standards. The results of the analysis by mass spectrometer on a dry, air-free basis were as follows:

Methane	98.8
Ethane	.07
Nitrogen	.7
Oxygen	------
Argon	.06
Carbon dioxide	.4
	100.03 percent

Calculated heating value=986.7 B.t.u. per cu ft
Calculated specific gravity=0.5622

R. F. Thurrell, in May 1947, reported a second gas seep located in a small lake on the north side of the Colville River approximately 3¼ miles west of the Aupuk seep. The lake was frozen at the time of his visit and the gas was observed to be bubbling intermittently at the lake surface in a small ice-free area. Attempts were made to revisit this occurrence during the 1950 season but it could not be located. Occasional bubbles were observed to rise to the surface of several lakes in the vicinity but no obvious seepage was noted.

* * * Samples of the gas he collected at this occurrence and at the Aupuk seep were submitted to the National Bureau of Standards and analyzed by mass spectrometer on a dry air-free basis. The results were as follows:

	North Colville seep	*Aupuk seep*
Methane	98.5	99.4+
Ethane	----------	.06
Propane	0	-------
Butanes	----------	-------
Pentanes	----------	-------
Carbon dioxide	1.3	0.4
Argon	.2	.1
Helium	----------	-------
Others	----------	-------
	100.0	99.96
Calculated heating value B.t.u. per cu ft	889	987

No specific gravity determination

It is of interest to note that both seeps occur on the eastern structural high of the Aupuk anticline and are evidently structurally controlled by the longitudinal fault.

Exposures of sandstone, containing small amounts of oil, have been mapped at several localities. Chapman and Sable (1950) report that:

One 7-foot silty sandstone on the Kokolik River north of the axis of syncline 10 has a high asphaltic content. About 6 cubic centimeters of the sample yielded approximately 1 cubic centimeter of brownish-black tarry substance. A strong petroliferous odor was noticed. * * * the oil sand lies in the coaly sequence of the Nanushuk group * * *

Whittington (oral communication, 1951) reports sandstone containing petroleum residues in the Carbon Creek and Kigalik-Awuna Rivers areas. Regarding samples from the Carbon Creek anticline, Whittington (Whittington and Stevens, 1951) reports:

Some sandstones in the area of the Carbon Creek anticline contain petroleum residues, but because of low permeability they are not considered likely reservoirs * * * Sample 50AWh11 was collected on Omicron Hill from a sandstone bed cut by one of the small faults. Adjacent to this fault this sandstone is moderately dark brownish-gray, but in about 100 feet on either side of the fault the dark color disappears.

A sample of this dark brownish-gray sandstone was analyzed and found to contain asphalt. Tailleur and Kent (1951) report fracture fillings of grahamite in exposures of the Torok formation (Lower Cretaceous) in the Etivluk-Kiligwa Rivers area. Webber and Detterman (1947) report evidences of petroleum in sandstone exposed along the lower Nanushuk River and at Schrader Bluff on the Anaktuvuk River. The author found petroleum residues in sandstone exposed along the Kavik River.

Oil shale is common in an almost continuous belt of Triassic rocks exposed along the north front of the Brooks Range. The oil shale is characteristically dark brown or brownish black, with a leathery appearance, commonly has a paper-thin parting, may be slightly flexible, and burns readily giving off a black smoke with an oil smell. In the Arctic foothills province, pebbles of Triassic oil shale have been reported in Lower Cretaceous conglomerate. Triassic oil shale has also been reported from a few widely spaced localities along the south side of the Brooks Range. Thus, surface indications of petroleum, including seeps and petroliferous sandstone and oil shale, are abundant throughout northern Alaska.

HISTORY OF PETROLEUM INVESTIGATIONS

Excellent summaries of the early geographic exploration of northern Alaska are given in the reports of Brooks (1906), Leffingwell (1919), and Smith and Mertie (1930).

Geologic exploration in northern Alaska was started by the Geological Survey in 1901 as part of a systematic scientific exploration of the Territory. In 1901 Schrader (1904) crossed the Brooks Range and mapped the geology along the Anaktuvuk and lower Colville Rivers. In 1904 Collier (1906) mapped the geology along the west coast from Cape Thompson to Cape Beaufort, and in 1908 Kindle reexamined the Cape Lisburne area. In 1906 to 1914 Leffingwell (1919) made extensive geologic and geographic studies in the Canning River region. These geologic studies first pointed out the petroleum potential of northern Alaska.

In February 1923, President Harding issued an Executive order reserving an irregularly shaped area of approximately 37,000 square miles in northern Alaska (fig. 1) as Naval Petroleum Reserve No. 4. As a first step to the proper administration of this reserve the Navy Department requested the Geological Survey to examine and report on the area. This was done in the years 1923 through 1926, and the results were published in 1930 as Geological Survey Bulletin 815. This report concluded that anticlines apparently favorable for the accumulation of petroleum were numerous and widely distributed. Very little information was given on possible reservoir rocks, but possible source beds were discussed as follows: (Smith and Mertie, 1930, p. 287).

A strongly indicated source of oil is the oil shale, whose position, though uncertain, is tentatively placed near the base of the Lower Cretaceous series. This shale is likely to be widespread and therefore is likely to have supplied extensive pools in widely distributed favorable structural features in the overlying rocks, many of which should be found at depths within reach of the drill.

This oil shale was thought to be the same as the material found by W. L. Howard of the Stoney expedition on his trip down the Etivluk River in 1886 (Smith and Mertie, 1930, p. 283). More recent field studies have established the age of this oil shale as Triassic.

Little interest was shown and no study was made of the petroleum possibilities of northern Alaska until 1944, when the Navy Department began the recently suspended exploration program. This program was begun as a wartime measure and until 1945 was carried on by the Navy Construction Battalion, Seabees. In 1945 the Navy Department entered into a contract with Arctic Contractors, Inc., for all drilling and most supporting activities. In 1944 the Geological Survey began a mapping program in northern Alaska and in 1945 the Survey was asked to carry out the geologic phases of the Navy Department program. Since that time geologic mapping of nearly all the Reserve and most of the adjoining areas has been completed (fig. 1). In addition the Geological Survey maintained

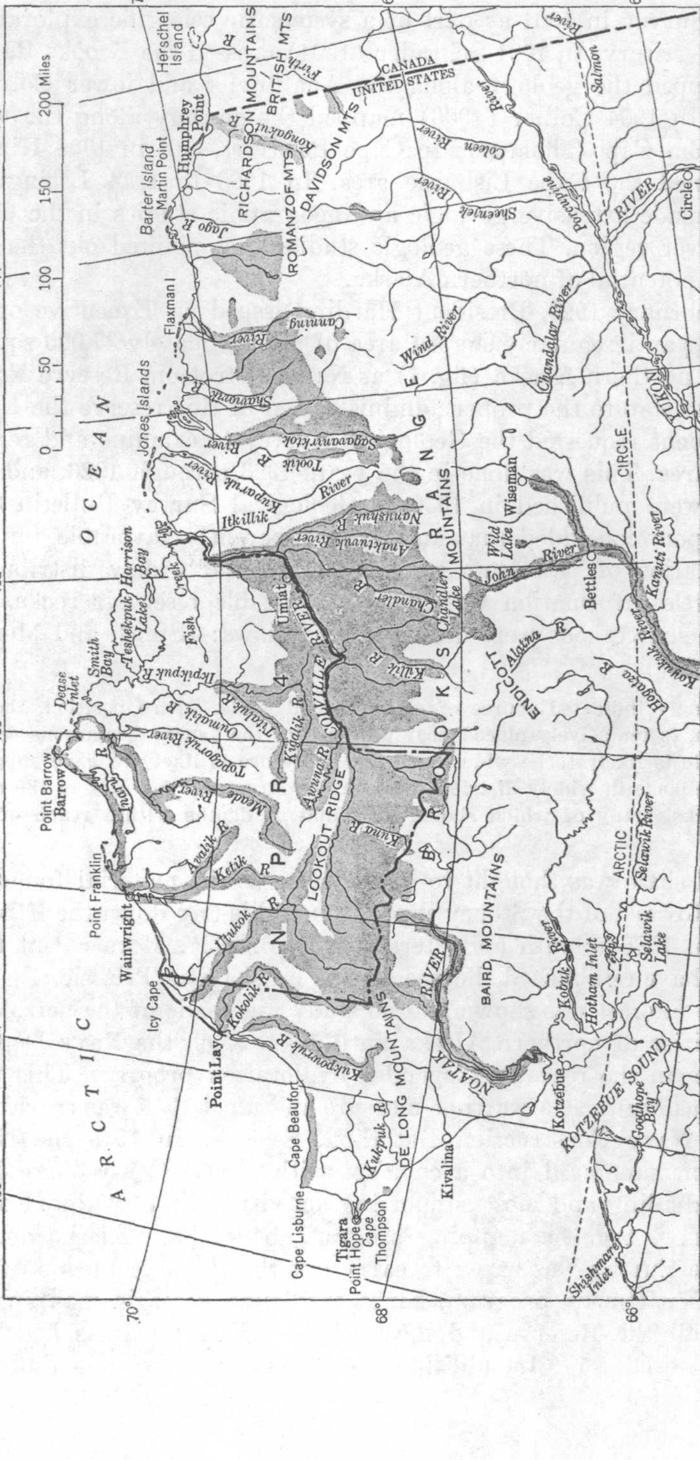


FIGURE 1.—Index map showing area covered by surface geologic studies in northern Alaska, 1944 to 1953. Naval Petroleum Reserve No. 4 stippled (NPR–4) is enclosed by dashed line in upper middle part of map.

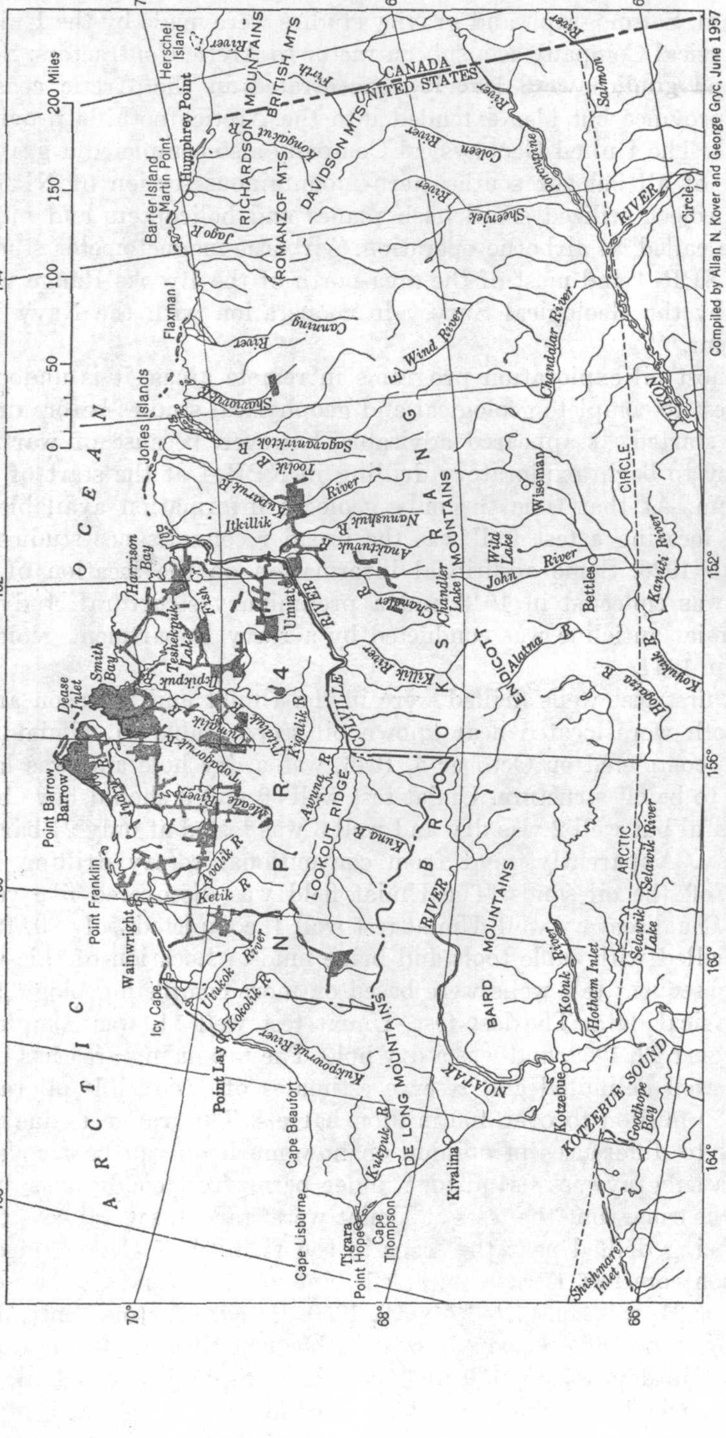


FIGURE 2.—Index map showing area covered by seismograph surveys in northern Alaska, 1945 to 1953. Naval Petroleum Reserve No. 4 stippled (NPR–4) is enclosed by dashed line in upper middle part of map.

a core analysis laboratory in Fairbanks, Alaska, expressly for this program. Seismograph and gravity studies were made by the United Geophysical Company as a subcontractor to Arctic Contractors. Seismograph studies were largely concentrated in the Arctic coastal plain province but also extended into the Arctic foothills province (fig. 2). The United Geophysical Company also completed a gravity survey of all but the southeastern mountainous section of NPR–4. This project utilized small bush planes and helicopters and might also be called an airborne operation. Airborne-magnetometer studies of all NPR–4 and most of the area north of the Brooks Range were made by the Geological Survey in cooperation with the Navy Department.

In most oil exploration programs in remote areas, it is undoubtedly best to complete geological and geophysical studies before drilling is started. It appeared advisable, however, because of wartime urgency to begin exploratory drilling in NPR–4 at the start of the program. At that time the only geologic information available to aid in locating a test well was the broad reconnaissance studies of 1923 to 1926. Some additional information on the location of oil seeps was collected in 1943 and a preliminary structural study of the Umiat anticline was conducted by a Navy Department geologic party in 1944.

The first test wells drilled were in the Umiat and Simpson areas and both were located near known oil seeps (table 6). Umiat test well 1, completed on October 5, 1946, was a dry hole and was later found to be off structure. Umiat test wells 2 and 3 should have been successful but well 2 was dry and well 3 was tested at only 24 barrels per day. Apparently, mud from conventional rotary drilling had sealed off the oil sands. The Umiat field was discovered five years later. The discovery well, Umiat test well 4, completed July 29, 1950, was drilled with cable tools and brine muds. Location of this well and subsequent test wells were based on more complete geologic and geophysical data. The last test, Umiat test well 11, was completed on August 29, 1952, and was a dry hole. The producing area has been fairly well delimited and reserve estimates of producible oil range from 30 million to over 100 million barrels. This range is due primarily to differences in opinion on how much oil can be recovered from a subgraywacke sandstone under permafrost conditions.

At the same time the tests at Umiat were started, several core tests were being drilled near the seeps in the vicinity of Cape Simpson. Simpson core test 1 was completed June 29, 1945, and the last one, core test 31, was completed May 9, 1950. Because factors controlling the occurrence of oil proved to be rather complicated, 31 core tests ranging in depth from 150 to 1,500 feet were drilled to delimit the deposit, which is believed to have accumulated in a stratigraphic

TABLE 6.—*Test wells drilled for petroleum in northern Alaska, through 1955* [1]

Location No. (fig. 1)	Name of well	Date spudded	Date completed	Total depth (feet)	Age of bedrock penetrated	Results [2]
5	Avak test well 1	Oct. 21, 1951	Jan. 14, 1952	4,020	Lower Cretaceous, Jurassic, Triassic	Dry and abandoned.
14	East Oumalik test well 1	Oct. 23, 1950	Jan. 7, 1951	6,035	Lower Cretaceous	Do.
9	East Topagoruk test well 1	Feb. 18, 1951	Apr. 16, 1951	3,589	do	Do.
10	Fish Creek test well 1	May 17, 1949	Sept. 4, 1949	7,020	Upper and Lower Cretaceous	Oil well, plugged and abandoned.
24	Grandstand test well 1	May 1, 1952	Aug. 8, 1952	3,939	Lower Cretaceous	Dry and abandoned.
20	Gubik test well 1	May 20, 1951	Aug. 11, 1951	6,000	Upper and Lower Cretaceous	Gas well, plugged and abandoned.
21	Gubik test well 2	Sept. 10, 1951	Dec. 14, 1952	4,620	do	Junked and abandoned.
11	Kaolak test well 1	July 21, 1951	Nov. 12, 1951	6,952	do	Dry and abandoned.
22	Knifeblade test well 1	Oct. 13, 1951	Dec. 22, 1951	1,805	Lower Cretaceous	Do.
23	Knifeblade test well 2	July 26, 1951	Aug. 5, 1951	373	do	Junked and abandoned.
23	Knifeblade test well 2A	Aug. 6, 1951	Oct. 7, 1951	1,805	do	Dry and abandoned.
12	Meade test well 1	May 2, 1950	Aug. 21, 1950	5,305	do	Junked and abandoned.
6	North Simpson test well 1	May 6, 1950	June 3, 1950	3,774	Upper and Lower Cretaceous	Dry and abandoned.
13	Oumalik test well 1	June 11, 1949	Apr. 23, 1950	11,872	Lower Cretaceous	Plugged and abandoned.
7	Simpson test well 1	June 14, 1947	June 9, 1948	7,002	Lower Cretaceous, Jurassic, Triassic, Paleozoic(?).	Dry and abandoned.
1	South Barrow test well 1	Aug. 15, 1948	Nov. 11, 1948	3,553	Lower Cretaceous, Jurassic, Paleozoic(?)	Do.
2	South Barrow test well 2	Dec. 18, 1948	Apr. 15, 1949	2,505	do	Gas well. Junked and abandoned.
3	South Barrow test well 3	June 23, 1949	Aug. 26, 1949	2,900	Lower Cretaceous, Jurassic, Triassic, Paleozoic(?).	Dry and abandoned.
4	South Barrow test well 4	Mar. 9, 1950	May 9, 1950	2,538	Lower Cretaceous, Jurassic, Paleozoic(?)	Gas well; flowed 1,805,000 cu ft per day.
2	South Barrow test well 5 [3]	May 17, 1955	June 17, 1955	2,456	do	Gas well; 7,900,000 cu ft per day.
15	Square Lake test well 1	Jan. 26, 1952	Apr. 18, 1952	3,987	Upper and Lower Cretaceous	Plugged and abandoned.
16	Titaluk test well 1	Apr. 22, 1951	July 6, 1951	4,020	do	Dry and abandoned.
8	Topagoruk test well 1	June 15, 1950	Sept. 28, 1951	10,503	Lower Cretaceous, Jurassic, Triassic, Permian, Devonian.	Do.
Umiat field	Umiat test well 1	June 22, 1945	Oct. 5, 1946	6,005	Upper and Lower Cretaceous	Do.
	Umiat test well 2	June 25, 1947	Dec. 12, 1947	6,212	Lower Cretaceous	Do.
	Umiat test well 3	Nov. 15, 1946	Dec. 26, 1946	572	do	Pumped 24 bbl per day; abandoned.
	Umiat test well 4	May 26, 1950	July 29, 1950	840	do	Pumped 100 bbl per day; shut in.
	Umiat test well 5	July 5, 1950	Sept. 22, 1950	1,077	do	Pumped 400 bbl per day; shut in.
	Umiat test well 6	Aug. 14, 1950	Dec. 12, 1950	825	Upper and Lower Cretaceous	Pumped 80 bbl per day, estimated; junked and abandoned.
	Umiat test well 7	Dec. 14, 1950	Apr. 12, 1951	1,384	do	Dry and abandoned.
	Umiat test well 8	May 2, 1951	Aug. 28, 1951	1,327	do	Oil and gas well; shut in.
	Umiat test well 9	June 25, 1951	Jan. 15, 1952	1,257	Upper(?) and Lower Cretaceous	Pumped 217 bbl per day; abandoned.
	Umiat test well 10	Sept. 9, 1951	Jan. 10, 1952	1,573	Upper and Lower Cretaceous	Pumped 222 bbl in 24 hrs; abandoned.
	Umiat test well 11	June 3, 1952	Aug. 29, 1952	3,303	do	Dry and abandoned.
17	Wolf Creek test well 1	Apr. 29, 1951	June 4, 1951	1,500	do	Junked and abandoned.
18	Wolf Creek test well 2	June 6, 1951	July 1, 1951	1,618	do	Dry and abandoned.
19	Wolf Creek test well 3	Aug. 20, 1952	Nov. 3, 1952	3,760	do	Do.

[1] Does not include 45 core tests drilled for structural, stratigraphic, or engineering information or to test drill rigs.

[2] The term "dry" is used for tests which struck no gas or oil in quantity. However, shows of oil and (or) gas were found in nearly all tests.

[3] Drilled by U.S. Air Force after suspension of U.S. Navy program.

trap. Two flowing wells were discovered, but the oil reserves tapped by these wells, about 2½ million barrels, are small.

Geophysical studies in the Simpson area indicated a structural prospect just west of the westernmost seep. Simpson test well 1, drilled on this prospect to a depth of 7,002 feet, was completed as a dry hole on June 9, 1948. This was the first test to penetrate basement rocks.

Meanwhile, a very large domed structure, Oumalik, was mapped by geophysical methods near the center of the Cretaceous depositional trough. Two core tests were drilled on the structure in 1947, and a deep test was begun in 1949 and completed April 23, 1950, at a depth of 11,872 feet. The deep test, in which no significant shows of oil were found, began and ended in Cretaceous rocks.

By 1948, geophysical studies had established the presence of a major basement high in the Barrow area. Four tests were drilled on this high in 1948–50, and South Barrow test well 2 was completed on April 15, 1949, as a producing gas well. The gas was used for heating purposes at the Barrow camp until April 1950, when the well caught fire and was subsequently junked. South Barrow test well 4 was drilled as a standby gas well, but was put into service almost immediately. Wells 1 and 3 were dry holes. South Barrow test well 5 was drilled by the U. S. Air Force in 1955 after the suspension of the Navy Department program. It serves as a standby gas well at the Point Barrow base.

A test drilled at the site of the Fish Creek oil seep was completed on September 4, 1949, at 7,020 feet. Heavy oil that has an asphalt base of 13 degrees to 14 degrees API gravity was discovered between 2,915 and 3,020 feet in Upper Cretaceous sandstone. The reserves are estimated to be small and the cause of the accumulation appears to be stratigraphic rather than structural.

Several wells were drilled in 1950 and 1951 on local structures around and "stepping down" from the Barrow high. No further discoveries were made. One of the most geologically interesting of these test wells, Topagoruk test well 1, was completed on September 28, 1951, at a depth of 10,503 feet. It penetrated Cretaceous, Jurassic, Triassic, and probable Carboniferous rocks and bottomed in middle Lower Devonian rocks. Only small shows of gas and oil were found. These tests around the Barrow high indicated that no new reservoir beds are present within what was considered to be practical drilling depth, about 12,000 feet. This drilling completed the evaluation of the Barrow high and nearly all the coastal plain province.

Concurrently with the drilling and geophysical exploration in the coastal plain, geologic field work had delineated several additional closed anticlines similar to the Umiat anticline in the northern foothills section. Ten test wells ranging from 1,500 to 6,000 feet in depth were drilled in 1951–52 on six structures which were believed to be in sandstone favorable as reservoir rock. One gas field, Gubik, was discovered, but only shows of oil, including bleeding cores, were found. Strong shows of gas were noted in wells on the Wolf Creek and Square Lake anticlines.

The Gubik anticline was first mapped by geologic field parties in 1945 and 1947, and in 1950 a detailed seismic survey was made to delineate the structure. The structure is about 12 miles long and a little over 2½ miles wide with a closure of 400 or 500 feet. Gubik test well 1, near the apex of the structure, was completed August 11, 1951 as a gas well. Gas was discovered in sandstone of Late Cretaceous age at depths ranging from 890 to 1,750 feet and from 3,350 to 3,700 feet. Gubik test well 2 was drilled on the south flank of the anticline to test for oil in the gas-bearing sandstones near the apex. Shows of both gas and oil were found but unfortunately the well blew out and was destroyed by fire before testing was completed. Gas in commercial quantities is believed to be present in this structure. An analysis of the commercial possibilities has been made by the Alaska Development Board (1954).

By 1950, geophysical field studies had covered much of the coastal plain area, including the extreme western part of NPR–4. Two closed structures, Meade and Kaolak, were mapped. These structures were known to be in areas of largely nonmarine beds of Cretaceous age, and older prospective reservoir beds were believed to be beyond practical drilling depth. The structures were drilled, however, primarily as stratigraphic tests. In Meade test well 1, which was completed on August 21, 1950, at a depth of 5,305 feet, traces of both oil and gas were found. Traces of oil were found in Kaolak test well 1, which was completed on November 21, 1951 at a depth of 6,952 feet. Both wells started and bottomed in Cretaceous rocks.

Early in the exploration program, much interest and considerable fieldwork was devoted to areas in which pre-Cretaceous prospective reservoirs might be drilled under favorable structural conditions and reasonable depths. The Barrow area was tested for such possibilities but none were found or indicated. Drilling in the northern foothills section around Umiat and Oumalik, plus geophysical studies in these areas, strongly indicated that pre-Cretaceous beds and, more certainly, Paleozoic beds were beyond drilling depth. It seemed, therefore, that a location would have to be found in the southern foothills section, possibly in the belt of more complexly folded and faulted sediments along the front of the Brooks Range, or in the area east of NPR–4 where sediments of the Cretaceous depositional trough rise and lap up against the Romanzof uplift. Geologic and geophysical field studies of these possibilities were in progress when the exploration program was suspended on July 1, 1953.

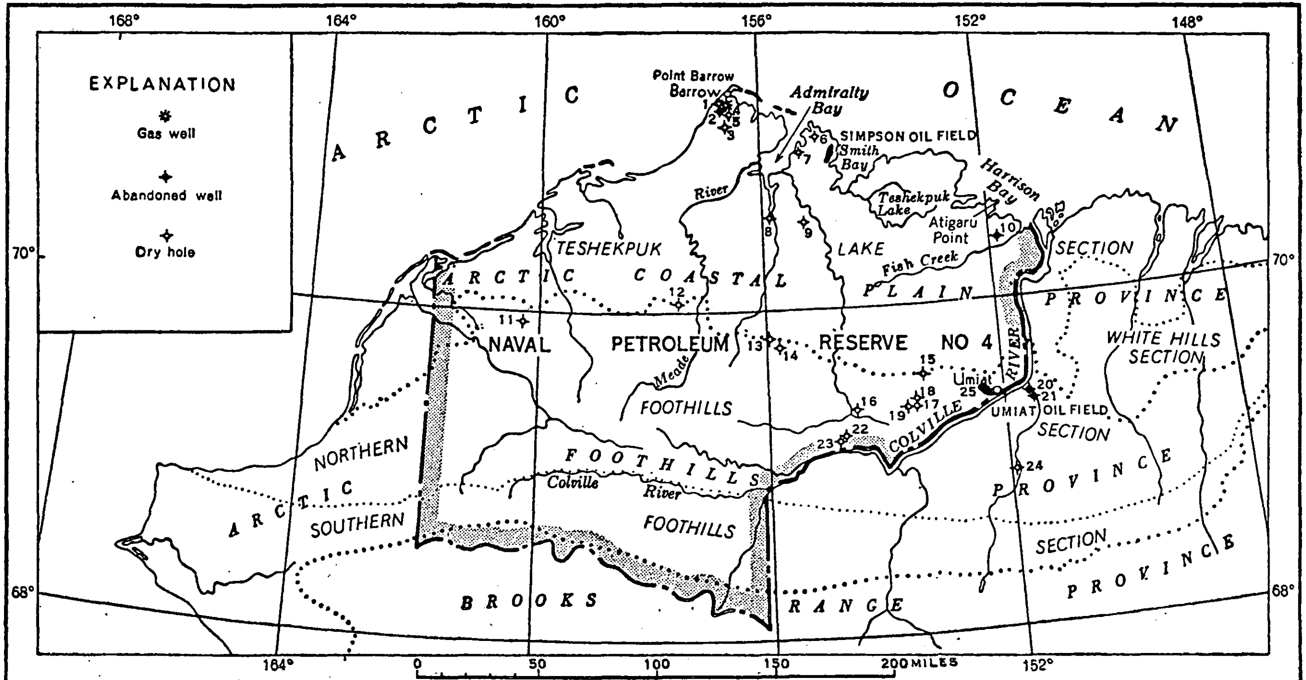
As a result of the Navy Department program and earlier geologic studies, northern Alaska is now geologically the best known large area in Alaska. Thirty-seven test wells and 45 core tests, with a total footage of about 175,000 feet, were drilled on 18 structures (fig. 3) in the years 1945 through 1955. Three oil fields (Umiat, Simpson, and Fish Creek), two gas fields (South Barrow and Gubik), and at least two other prospective gas fields were discovered. Gas for use at Barrow is being produced from the South Barrow gas field. Total reserve estimates for all discoveries of oil range from 30 to 100 million barrels, and for gas from 370 billion to 900 billion cubic feet. The estimates of gas reserves are based on limited data, with the exception of the South Barrow field which is reliably estimated at 10 billion cubic feet.

GENERAL GEOLOGY

BROOKS RANGE

The northern half of the Brooks Range province is underlain by slightly metamorphosed eastward-striking rocks of Devonian and Carboniferous age. The structure is dominated by tight folds and faults overthrust northward in such a way that they repeat the formations in numerous subparallel belts. Metamorphic rocks of early Paleozoic age, and limestone of Silurian age make up the southern half of the province. East of long 149 degrees W., the northern margin of the Brooks Range swings north, and rocks of the southern belt crop out far north of their position west of long 149 degrees W. This northward swing of the Brooks Range is due to greater uplift in the Canning River region rather than to a swing of structural axes, which maintain a general easterly trend. The belt of imbricate thrust faults, which is characteristic of the front of the range in the Anaktuvuk River region, does not follow the front of the range northeastward, but continues eastward and is present near the crest of the eastern part of the Brooks Range. The predominant westerly plunge of structural axes at the Canning River reverses at the Sadlerochit River to form a northward-trending structural high that is traceable from the Arctic coast southward across the entire Brooks Range. Several other northward-trending highs such as this have been mapped in other parts of the range and in the Arctic foothills province.

At least 10,000 feet, and possibly as much as 15,000 feet, of Devonian and Carboniferous sedimentary rocks, including much limestone, were deposited in a Paleozoic geosyncline in the area of the present Brooks Range. Most of the clastic materials were probably



1 SOUTH BARROW TEST WELL 1
2 SOUTH BARROW TEST WELL 2
3 SOUTH BARROW TEST WELL 3
4 SOUTH BARROW TEST WELL 4
5 AVAK TEST WELL 1
6 NORTH SIMPSON TEST WELL 1
7 SIMPSON TEST WELL 1
8 TOPAGORUK TEST WELL 1
9 EAST TOPAGORUK TEST WELL 1
10 FISH CREEK TEST WELL 1
11 KAOLAK TEST WELL 1
12 MEADE TEST WELL 1
13 OUMALIK TEST WELL 1
14 EAST OUMALIK TEST WELL 1
15 SQUARE LAKE TEST WELL 1
16 TITALUK TEST WELL 1
17 WOLF CREEK TEST WELL 1
18 WOLF CREEK TEST WELL 2
19 WOLF CREEK TEST WELL 3
20 GUBIK TEST WELL 1
21 GUBIK TEST WELL 2
22 KNIFEBLADE TEST WELL 1
23 KNIFEBLADE TEST WELLS 2 AND 2A
24 GRANDSTAND TEST WELL 1
25 UMIAT TEST WELLS 1-11

FIGURE 3.—Index map showing location of test wells, oil fields, and physiographic provinces in northern Alaska.

derived from an uplifted area or Paleozoic shield that was north of the present land area. Some clastic material may have been derived from local highs within the geosyncline. Permian clastic rocks in the Canning River area become coarser and conglomeratic toward the north. The Paleozoic era probably was not closed by orogeny.

Rocks of Triassic age overlie the Carboniferous systems with no apparent structural unconformity. They are readily identifiable as a continuous belt along the front of the range, with little or no facies change from the DeLong Mountains on the west to the Canadian border on the east.

Movement that formed the Brooks Range geanticline (pl. 2) apparently began in Jurassic time. Mafic and ultramafic intrusions were emplaced in Late Jurassic time. An Early Cretaceous (late Neocomian or Aptian) orogeny deformed and metamorphosed the rocks of the Brooks Range province and formed a general eastward-trending structural pattern. Uplift continued throughout Cretaceous time and some volcanism continued throughout Late Cretaceous time. An early Tertiary orogeny further deformed the rocks of this province, and intensified the east-west structural pattern. Peneplanation, followed by uplift during late Pliocene or Quaternary time and later by stream and glacial erosion, formed the present jagged surface of the Brooks Range.

ARCTIC FOOTHILLS PROVINCE

SOUTHERN FOOTHILLS SECTION

Structurally the southern foothills section of the Arctic foothills province is similar to the Brooks Range. The southern foothills differ chiefly in being composed of less resistant rocks of Triassic and Early Cretaceous age. Jurassic rocks are thin or missing in most of the southern foothills section, but in the eastern part about 4,500 feet of shale of Jurassic age has been measured. The Triassic rocks range in thickness from about 500 feet to 2,000 feet and are composed of marine shale, including oil shale, limestone, and chert. The thickness of the Lower Cretaceous rocks decreases from about 10,000 feet or more along the southern limit of outcrop to about 5,000 feet along the northern limit. These rocks apparently were derived from an uplift to the south in the area of the present Brooks Range.

The northern shield or uplifted area that supplied the sediments deposited in late Paleozoic time probably began to subside at the close of the Paleozoic. The Triassic rocks seem to have been deposited under relatively quiescent conditions. The Brooks Range geanticline began to rise in Jurassic time and the Colville geosyncline came into being at about the same time. Scattered exposures of Jurassic rocks indicate localized sedimentation over a wide area during various stages in the Jurassic period. They also appear to have been subjected to several periods of erosion, which may account in part for the scattered exposures and extreme variations in thickness. The Romanzof uplift (pl. 2), which was part of the Colville geosyncline in Jurassic time, became a positive element; since that time only a thin layer of sediments has been deposited in this area. Cretaceous sedimentary rocks (Torok formation, Albian stage) were deposited under orogenic conditions, as evinced by great thicknesses of graywacke and conglomerate and profound angular unconformities. In contrast to the Jurassic rocks, which appear to thicken to the east with a maximum thickness in the Canning River area, the Cretaceous deposits thin rapidly east of the Umiat basin, and several units pinch out entirely.

The southern foothills section was further deformed by an early Tertiary (late or post-Paleocene) orogeny. Glacial deposits extend northward from the Brooks Range into this section in several areas, but little evidence of glacial erosion has been recognized.

NORTHERN FOOTHILLS SECTION

During middle Cretaceous time (Albian and Cenomanian) approximately 6,000 feet of sediments (Nanushuk group) was deposited in a broad area of the Colville geosyncline (pl. 2). The axis of these sediments in the geosyncline is in the northern foothills north of the main mass of the earlier Mesozoic sediments in the geosyncline. These rocks range in composition from shale to conglomerate and include coal and minor amounts of pyroclastics. The pattern of facies changes indicates a gradual northerly overlap of nonmarine on marine sediments, with numerous transgressive and regressive movements of the shoreline. The source area of these Cretaceous sediments was the Brooks Range geanticline to the south and probably earlier Mesozoic rocks along the southern edge of the Colville geosyncline. After the Nanushuk group was deposited the Colville geosyncline was subjected to gentle folding and to slight emergence, which formed or accentuated the Meade arch and the Chukchi and Umiat basins. Approximately 5,000 feet of Upper Cretaceous beds (Colville group) was deposited in the Umiat basin. At the same time, sediments were undoubtedly being deposited over the Meade arch and in the Chukchi basin. The distinctive faunas and lithologic characteristics of the Colville group in the Umiat basin, however, cannot be identified in the Chukchi basin, nor can they be identified east of the Kuparuk River. The Colville group differs from the underlying Nanushuk group mainly in the greater proportion of volcanic debris and the lighter color of the sandstone. Fossils in the Colville group are better preserved, and original shell material is common. Fossils in the Nanushuk group are mainly molds and casts; very little original shell material remains. There is some evidence of slight emergence, but evidence indicates little or no deformation after the Turonian stage and possibly after the Coniacian stage. The next major orogenic movement apparently occurred in late- or post-Paleocene time. Deformation was strong in the southern area, moderate in the central area, and gentle in the northern area of the foothills province. The Tigara uplift was probably formed at this time. During most of Tertiary time the foothills province was an emergent area and was probably eroded to a low plain. The area was further uplifted in the Quaternary epoch.

ARCTIC COASTAL PLAIN PROVINCE

TESHEKPUK LAKE SECTION

In the Teshekpuk Lake section the Gubik formation (Quaternary) unconformably overlies the Colville group. The Gubik formation is as much as 150 feet thick and includes unconsolidated marine and nonmarine gravel, sand, silt, and clay. Bedrock exposures are extremely scarce and are confined largely to small cutbanks. Geophysical and surface geologic studies indicate that the Colville group and older sedimentary rocks in general are nearly flat-lying down to the contact with the basement rocks. Basement rocks of Paleozoic and (or) Precambrian age have been reached in several wells in the Barrow region. The surface of the basement rocks plunges southward from approximately 2,400 feet below sea level near Barrow to a depth of more than 16,000 feet below sea level near the southern boundary of the section.

The tectonic history of this section is similar to that of the northern foothills section but differs in the intensity of deformation; since Paleozoic time the coastal plain province in general has undergone only mild deformation compared with the areas to the south. The Arctic landmass that shed clastic materials into the Paleozoic geosyncline to the south began to submerge in early Mesozoic time to form the Arctic Ocean basin. The Barrow arch is probably a remnant of this landmass and remained as a positive element throughout the Mesozoic. The center of deposition in the Colville geosyncline continued to move north, probably by a process of outbuilding of a shelf into the Arctic Ocean. This process possibly continued through the Tertiary and established the Beaufort shelf.

WHITE HILLS SECTION

The White Hills section is characterized by white and red sand-and-gravel-covered uplands, ridges, and bluffs. In the Kuparuk and Sagavanirktok Rivers area these sedimentary rocks, which include coal and red beds, are probably all nonmarine and on the basis of plant fossils are believed to be of Paleocene or Eocene age. East of the Sagavanirktok River, in the Shaviovik River area, comparable unconsolidated sediments have been mapped, as have steeply dipping beds of unconsolidated sediments farther east, in the Katakturuk River area. Marine fossils from these beds indicate a late Tertiary age, probably either late Miocene or Pliocene.

Geophysical studies east of the Umiat area indicate a regional easterly plunge from Umiat to the White Hills. Detailed geophysical studies in the Shaviovik River area indicate subsurface structural complexity not present in the Teshekpuk Lake section.

GEOLOGY OF TECTONIC ELEMENTS

BROOKS RANGE GEANTICLINE

The northern limb of the Brooks Range geanticline (pl. 2) consists primarily of only slightly metamorphosed Devonian and Carboniferous rocks. Dark clastic rocks of the Sadlerochit formation (Permian and Early Triassic) generally overlie the lighter carbonate rocks of the Lisburne group (Mississippian) and form conspicuous hogbacks along the northern edge of the range. The structure of the northern half of the geanticline is dominated by tight folds and thrust faults. The southern limb consists of early Paleozoic metamorphic rocks and Silurian limestone. Igneous rocks, primarily basic but including some acidic rocks, are scattered throughout the geanticlinal area but appear to be concentrated largely in the western half.

The Brooks Range geanticline probably originated in Early Jurassic time.

ROMANZOF UPLIFT

The Romanzof uplift, originally part of the Colville geosyncline, was raised up in Tertiary time. However, stratigraphic evidence in the Canning-Shaviovik Rivers area suggests that it was a positive element relative to the Colville geosyncline to the west since the middle Cretaceous and possibly earlier.

The uplift exposes primarily Carboniferous, Devonian, and possibly Precambrian rocks. Mesozoic rocks have been preserved and are exposed in structural valleys.

TIGARA UPLIFT

Complexly folded and faulted rocks of Devonian, Carboniferous, and early Mesozoic age are exposed in the area of the Tigara uplift.

COLVILLE GEOSYNCLINE

The exposed bedrock in the Colville geosyncline is primarily of Cretaceous age but includes thick sections of older Mesozoic rocks and scattered exposures of Carboniferous rocks. The southern edge of the Colville geosyncline is outlined nearly everywhere by a belt of dark easily recognized Triassic beds (Shublik formation) and hogback-forming Permian and Triassic beds. (Sadlerochit formation). The exposed bedrock becomes progressively younger northward and includes Jurassic, Cretaceous, and Tertiary rocks. Near the mountain front the structure is similar to that of the Brooks Range but becomes progressively less complex to the north, and in the coastal plain the beds above the basement complex are essentially flat lying.

The Colville geosyncline probably originated in early Mesozoic time and existed as one depositional trough until about late Cenomanian time.

The rocks of the Colville geosyncline, Chukchi Basin and Brooks Range geanticline are believed to extend westward beneath the broad shallow marine shelf north of Siberia. The geology of Wrangell Island, at about lat 71 degrees N., long 178 degrees E., is similar to that of the northern part of the Brooks Range.

MEADE ARCH

The presence of the Meade arch is strongly suggested by geophysical data. It is expressed at the surface only by the absence of post-Cenomanian beds and apparent thickening of Lower Cretaceous sedimentary rocks to the west.

The Meade arch originated or perhaps was uplifted and accentuated in late Cenomanian or Turonian, (early Late Cretaceous) time. The exposed bedrock is of Cenomanian and Albian age. Turonian and younger beds are not known and apparently were never deposited over the Meade arch.

UMIAT BASIN

The Umiat basin is expressed and delimited at the surface by approximately 5,000 feet of rocks of the Colville group of Late Cretaceous age. These rocks are characterized by abundant volcanic debris and sandstone of a lighter color than older Cretaceous sandstone. The distinctive faunas and lithologic character of the Colville group have not been identified over the Meade arch or in the Chukchi basin, nor can they be identified east of the Kuparuk River. The Mesozoic sequence in the Umiat basin and Colville River region has recently been described by Gryc and others (1956).

Several test wells have been drilled in this basin. Oumalik test well 1, the deepest one, bottomed at 11,872 feet and, like all other wells in the Umiat basin, began and ended in Cretaceous sedimentary rocks. Seismograph surveys suggest that basement rocks are at a depth in excess of 20,000 feet in the Umiat and Oumalik areas.

CHUKCHI BASIN

The Chukchi basin is characterized by a thick sequence of Cretaceous sedimentary rocks, lithologically similar to the Nanushuk group of the Umiat basin. Beds faunally and lithologically similar to those of the Colville group of the Umiat basin appear to be absent although correlative beds may be present. The Cretaceous rocks exposed in the Chukchi basin have been recently described by Sable (1956).

BARROW ARCH

The presence of the Barrow arch is well documented by geophysical and drilling data. There are practically no pre-Quaternary bedrock exposures in this area and thus no surface evidence for the presence of the arch. The South Barrow test wells 1 through 4 all penetrated basement rocks at depths of 3,405, 2,446, 2,800, and 2,428 feet, respectively. Simpson test well 1 was drilled on the east flank of the arch about 40 miles east of Barrow and penetrated the basement at a depth of 6,543 feet. Topagoruk test well 1, about 50 miles southeast of Barrow, penetrated the basement at 9,320 feet. The basement rocks include hard shale, phyllite, quartzite, and quartzite conglomerate of Carboniferous, Devonian and, possibly Precambrian age. These are overlain by Triassic, Jurassic, and Cretaceous beds.

ARCTIC PLATFORM

The Arctic platform is a pre-Albian tectonic feature that occupied the northern part of the present Arctic coastal plain and the adjacent area of the present-day Arctic Ocean. This served as a source area for sediments during Paleozoic time. Paleozoic formations wedge out northward toward the platform. Thin accumulations of Triassic and Jurassic rocks of platform facies, including fossiliferous limestone, and glauconitic and limonitic oolite, mantle the platform in some places.

ARCTIC COASTAL PLAIN

The Arctic coastal plain is a lake-studded lowland covered in most places with Quaternary deposits. Pliocene(?), Miocene, and possibly earlier Tertiary deposits have been reported in a thick folded Tertiary sequence north of the Romanzof uplift. Quaternary and Tertiary deposits have been uplifted in the eastern part of the coastal plain.

BEAUFORT SHELF

A thick sequence of rocks of the upper part of the Cretaceous occurs in the Cape Simpson area and extends into the Beaufort shelf. A similar condition exists north of the Romanzof uplift where the thick Tertiary sequence of the coastal plain possibly extends northward into the shelf. The Beaufort shelf was constructed by the building out of Tertiary and Quaternary deposits into the Arctic Ocean basin.

POSSIBLE PETROLEUM PROVINCES

ARCTIC COASTAL PLAIN PROVINCE

TESHEKPUK LAKE SECTION

The Teshekpuk Lake section, although largely covered by sediments of Quaternary and Recent age, has been explored sufficiently to permit some evaluation of its petroleum possibilities. Scattered exposures of Cretaceous rocks and information from seismic records and drill cores indicate that the Quaternary cover in this section is underlain by about 2,000 to perhaps 11,000 feet of Cretaceous marine and nonmarine beds. This cover is underlain by a few hundred to perhaps 2,000 feet of Jurassic beds, which overlie a basement complex of a few hundred feet of Triassic rocks and an unknown thickness of clastic beds of late Paleozoic age. The gas-producing strata in the Barrow gas field are basal Cretaceous or Jurassic, and the reservoir beds in the Simpson oil field are in the lower part of the Upper Cretaceous series. In general the reservoir characteristics of known rocks in the Teshekpuk Lake section are only fair. Continued exploration on and south of the Barrow uplift was justified on the possibility that more favorable reservoir rocks, such as the limestone of the Lisburne group, may extend into this section. The results of the Topagoruk and Oumalik test wells indicate that no new reservoir beds are present within present practical drilling limits.

Above the basement complex the bedrock in the Teshekpuk Lake section appears to be essentially horizontal or very gently dipping. With the exception of the Oumalik structure, dips on the other few known structures are very low. The two known oil accumulations appear to be the result of stratigraphic traps rather than structure.

In spite of the results to date, this region cannot be excluded as a future petroleum province. Geologic studies indicate the possibility of overlaps, pinchouts, and other basement highs. More porous sands are to be expected in the Cretaceous rocks in parts of the region. The Teshekpuk Lake section is also more accessible than the inland provinces in northern Alaska. For these reasons 11 test wells and 35 core tests have been drilled here. One gas field, which supplies gas for the Barrow camp, and two oil fields (Simpson and Fish Creek) have been discovered.

WHITE HILLS SECTION

The White Hills section, distinguished topographically from the Teshekpuk Lake section by the presence of white-gravel-covered uplands and fewer lakes, is blanketed by both marine and nonmarine sediments of Tertiary age. The Sagavanirktok formation in the type locality along the lower Sagavanirktok River consists of about 2,000 feet of nonmarine beds. Plant fossils near the base of the formation have been referred to the Paleocene or Eocene period. In the Carter Creek area a thickness of more than 7,000 feet of Tertiary beds has been recorded (Morris, 1957). Although these beds cannot be definitely correlated with the Sagavanirktok formation they appear to be traceable laterally into that formation. The upper part of the section on Carter Creek contains Miocene and probably Pliocene marine fossils. The Tertiary rocks are probably underlain everywhere by about 5,000 to 7,000 feet of Cretaceous rocks. Known unconformities within the Cretaceous sequence may reduce this amount in the covered areas to the north.

Along the southern edge of the White Hills section 2,500 to 3,000 feet of Jurassic, about 300 feet of Triassic, 1,000 to 1,800 feet of Triassic and Permian, and 1,000 to 2,000 feet of Mississippian strata are exposed. Thus a total thickness of possibly 10,000 to 15,000 feet of strata underlies the Tertiary sequence in the White Hills section.

The White Hills section is characterized by low surface dips in the Sagavanirktok formation. There is some indication, however, that these dips steepen at depth. Along the southern edge of the section and in the Carter Creek area, dips of 20 degrees to 60 degrees have been recorded in beds of Tertiary age.

To date there has been no drilling exploration in the White Hills section, although at least one structure, the Shaviovik anticline, has been considered as a possible drill site. Other similar structures are undoubtedly present. The petroleum possibilities of this section have not been tested but it is geologically favorable for such accumulations.

ARCTIC FOOTHILLS PROVINCE

NORTHERN FOOTHILLS SECTION

In the northern foothills section, which has many closed anticlines, 27 wells drilled on 11 folds have revealed one medium-sized oil field, Umiat, one gas field, Gubik, and good indications of other gas fields. Shows of oil or gas were present in nearly all the test wells.

Much of the northern foothills section is covered by a thin layer of a variety of unconsolidated sediments collectively called the Gubik formation. On the basis of surface exposures and the deep test of

Oumalik, the total thickness of Cretaceous beds in this section is believed to be at least 15,000 feet.

Oumalik test well 1 began near the base of the Upper Cretaceous series and bottomed near the base of the Cretaceous system at a depth of 11,872 feet. The total thickness of Upper Cretaceous strata is about 5,000 feet.

No tests have been drilled through the Cretaceous strata, and although there is no direct evidence on which to postulate what lies beneath them, it is logical to assume that Jurassic, Triassic, Permian, and Mississippian beds are present. Geophysical evidence suggests that in the Umiat area the basement rocks are at a depth of at least 20,000 feet.

Success of future prospecting at shallow to moderate depths will depend largely on locating good Cretaceous sandstone reservoirs. In general, the porosity and permeability of the Cretaceous sandstones are low, but a few samples have a porosity of 15 to 20 percent and a permeability of from several hundred to one thousand millidarcys.

SOUTHERN FOOTHILLS SECTION

Although structurally complex, the southern foothills section cannot be excluded as a potential petroleum province. The exposed bedrock is predominantly Lower Cretaceous, Jurassic, and Triassic, with a few exposures of Permian and Mississippian along the front of the range. Black marine shale is the most common Mesozoic rock, and oil shales the most characteristic rock of the Triassic. The best possibilities for reservoir beds are in the largely clastic Lisburne group of Mississippian age, which probably underlies most of the southern foothills section. The sandstone of the Mesozoic rocks is generally poorly sorted, nonporous, and impermeable.

Complex structure makes petroleum prospecting difficult in this section, but the structural similarity to the productive Alberta foothills excites the imagination. Although a variety of structural traps may exist, no test wells have been drilled in this section.

BROOKS RANGE PROVINCE

Petroleum possibilities within this province are not very encouraging because of the complex structure. Possible reservoir beds, limestone of the Lisburne group, are exposed and underlain by primarily metamorphic rocks. However, the exposed limestone has a strong fetid odor and occasional traces of petroleum residue. Outcrop samples of limestone and dolomite have a porosity of as much as 10 percent, but permeability is low.

No tests have been drilled in this province.

ANNOTATED BIBLIOGRAPHY OF U.S. GEOLOGICAL SURVEY PUBLICATIONS ON PETROLEUM AND OIL SHALE IN ALASKA

By Edward H. Cobb

The following annotated bibliography on the geology of possible petroleum provinces in Alaska includes all reports of the Geological Survey which deal with petroleum and oil shale in Alaska and which were published before January 1, 1956. A few reports which do not deal with petroleum or oil shale are included because they discuss the general geology of areas where rocks that are known to be petroliferous in other places are present, or because they deal with the general geology of areas in which there has been exploration and development activity in recent years.

The Geological Survey places in open file some preliminary reports, most of which will be superseded by formal publications. These open-file reports are not listed in this bibliography but are available for consultation in the Geological Survey Library in Washington, D.C. Those not dealing with northern Alaska are also on file at Geological Survey offices in Anchorage, College, and Juneau, Alaska; Los Angeles, Menlo Park, and San Francisco, Calif.; Denver, Colo.; Salt Lake City, Utah; Spokane, Wash.; and in the office of the Alaska Territorial Department of Mines in Juneau.

The bibliography includes about 250 reports dealing with petroleum possibilities of Naval Petroleum Reserve No. 4, including the Umiat oil field and the Gubik and Barrow gas fields, and of adjacent public lands in northern Alaska. These include reports on areal geology, stratigraphy, paleontology, petrology, petrography, sedimentation, well-core analysis, and more than 100 photogeologic maps. The reports are listed by series and number within each series, or by date of release, for unnumbered reports.

Titles of reports published by organizations other than the Geological Survey may be found in "Bibliography of North American Geology," which appears as Geological Survey Bulletins 746, 747, 823, 937, 985, 1025, 1035, 1049, 1054, and 1065.

ANNUAL REPORTS

Thirteenth, 1891–92. Pt. II-a, Second expedition to Mount St. Elias, in 1891, by I. C. Russell, p. 1–91, 1892. See p. 91.

This is a general account of early exploration in the Malaspina area and includes a few brief notes on the geology of the Chaix and Samovar Hills. Rumor of oil seepage is reported.

Seventeenth, 1895–96. Pt. I-e, Report on coal and lignite of Alaska, by W. H. Dall, p. 763–908, 1896. See p. 799, 818–819.

Coal and petroleum are reported near Katmai Bay. Tasmanite (see also Bulletin 816, p. 132) from northern Alaska is noted.

Nineteenth, 1897–1898. Pt. VI (con.), Mineral resources of the United States, 1897. Nonmetallic products, except coal and coke. Petroleum, by F. H. Oliphant, p. 1–166, 1898. See p. 110.

Twentieth, 1898–1899. Pt. VI (con.), Mineral resources of the United States, 1898: Nonmetallic products, except coal and coke. Petroleum, by F. H. Oliphant, p. 1–202, 1899. See p. 123.

Twentieth, 1898–1899. Pt. VII-b, A reconnaissance in southwestern Alaska in 1898, by J. E. Spurr, p. 31–264, 1899. See p. 263–264.

Twentieth, 1898–1899. Pt. VII-d, A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, in 1898, by F. C. Schrader, p. 341–423, 1899. See p. 423.

Twenty-first, 1899–1900. Pt. VI (con.), Mineral resources of the United States, 1899: Nonmetallic products, except coal and coke. Petroleum, by F. H. Oliphant, p. 1–292, 1901. See p. 167.

Twenty-second, 1900–1901. Pt. III-l, The coal resources of Alaska, by A. H. Brooks, p. 515–571, 1902. See p. 542, 571.

References in the 19th through 22d Annual Reports listed above contain brief notes on reported petroleum occurrences and on an unsuccessful development attempt in the Cook Inlet area.

SPECIAL PUBLICATIONS

Maps and descriptions of routes of exploration in Alaska in 1898, with general information concerning the Territory; The coast from Lynn Canal to Prince William Sound, by G. H. Eldridge, p. 103–104, 1899.

Occurrence and geologic setting of oil seepages near Katalla and Yakataga are briefly mentioned.

The geology and mineral resources of a portion of the Copper River district, Alaska, by F. C. Schrader and A. C. Spencer, 1901, 94 p. See p. 92.

Occurrence and geologic setting of oil seepages near Katalla and Yakataga are briefly mentioned.

MINERAL RESOURCES OF THE UNITED STATES

Calendar year 1900. Petroleum, by F. H. Oliphant, p. 537–627, 1901. See p. 587.

Calendar year 1901. (Extract). The production of petroleum in 1901, by F. H. Oliphant, 1902. See p. 208 (not in bound volume).

Calendar year 1902. Petroleum, by F. H. Oliphant, p. 535–630, 1904. See p. 536, 582–584.

Calendar year 1903. Petroleum, by F. H. Oliphant, p. 635–718, 1904. See p. 690–692.

Calendar year 1904. Petroleum, by F. H. Oliphant, p. 675–759, 1905. See p. 724–726.

Calendar year 1907, Pt. II, Nonmetallic products. Petroleum, by D. T. Day, p. 347–475, 1908. See p. 413.

Calendar year 1910, Pt. II, Nonmetals. Petroleum, by D. T. Day, p. 327–458, 1911. See p. 424.

Calendar year 1911, Pt. II, Nonmetals. Petroleum, by D. T. Day, p. 335–480, 1912. See p. 439–440.

1914, Pt. II, Nonmetals. Petroleum, by J. D. Northrop, p. 893–1098, 1916. See p. 1053.

1915, Pt. II, Nonmetals. Petroleum, by J. D. Northrop, p. 559–760, 1917. See p. 718.

1916, Pt. II, Nonmetals. Petroleum, by J. D. Northrop, p. 679–886, 1919. See p. 847.

1917, Pt. II, Nonmetals. Petroleum, by J. D. Northrop, p. 683–901, 1920. See p. 849.

The above listed references to Mineral Resources of the United States are reports which contain brief notes on reported petroleum occurrences at Katalla, Yakataga, on the Alaska Peninsula, and in northern Alaska, and on developments in the Katalla field up to 1917. Most information has been abstracted from other Geological Survey reports.

PROFESSIONAL PAPERS

64. The Yakutat Bay region, Alaska, by R. S. Tarr and B. S. Butler. 183 p., 1909. See p. 169–170.

Claims were staked near Yakutat Bay, but no petroleum indications were found and no drilling was done.

109. The Canning River region, northern Alaska, by E. de K. Leffingwell. 251 p., 1919. See p. 178–179.

Oil seepages at Cape Simpson are described and rumors of others on the Arctic coast are reported.

192. Areal geology of Alaska, by P. S. Smith, 100 p., 1939. See p. 56, 60.

Lower Cretaceous oil shale and petroliferous seepages in northern Alaska are mentioned. The occurrences of oil seepages in the Katalla district is noted.

268. The central Kuskokwim region, Alaska, by W. M. Cady, R. E. Wallace, J. M. Hoare, and E. J. Webber, 132 p., 1955.

Stratigraphic data is given concerning bedded rocks ranging in age from early Paleozoic to Recent, including 55,000–90,000 feet of mixed volcanic and marine sedimentary rocks most of which are of Cretaceous age. Most of these sedimentary rocks are graywacke and shale. Structural features are described and their relationship to regional tectonic elements are discussed. Petroleum possibilities are not discussed.

BULLETINS

225. Contributions to economic geology, 1903. Petroleum fields of Alaska and the Bering River coal fields, by G. C. Martin, p. 365–382, 1904. See p. 365–371, 376–382.

Preliminary to Bulletin 250.

250. The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits, by G. C. Martin, 64 p., 1905. See 9–27, 36–59.

Report contains geologic maps of the Katalla and of the Iniskin Peninsula areas. Formation names are applied, and records of wells in the Iniskin Peninsula and in the Kanatak district are quoted. The presence of oil seepages and the results of tests of petroleum samples are reported and applicable earlier published information is summarized.

259. Report on progress of investigations of mineral resources of Alaska in 1904. Notes on the petroleum fields of Alaska, by G. C. Martin, p. 128–139, 1905.

The Katalla, Iniskin Peninsula, and Kanatak districts are described briefly. Reports of petroleum seepages in other areas are noted.

284. Report on progress of investigations of mineral resources of Alaska in 1905. The mining industry in 1905, by A. H. Brooks, p. 4–9, 1906. See p. 9.

Current developments at Katalla and on the Alaska Peninsula are noted.

314–D. Reconnaissance on the Pacific coast from Yakutat to Alsek River, by Eliot Blackwelder, p. 82–88, 1907. See p. 87.

The staking of oil claims, and their abandonment, east of Yakutat are noted.

314–E. Petroleum at Controller Bay, by G. C. Martin, p. 89–103, 1907.

Preliminary to Bulletin 335.

335. Geology and mineral resources of the Controller Bay region, Alaska, by G. C. Martin, 141 p., 1908. General subjects and regional geology, p. 1–65, Katalla oil field, p. 112–130.

Report has topographic and geologic maps and gives data on the history of exploration and development of the region and on climate, harbors, and possible railway routes. The stratigraphy is discussed in detail, with lists of fossils and measured sections. Tertiary rocks are subdivided into Katalla, Stillwater, Kushtaka, and Tokun formations. Details of structure and conclusions as to regional history are presented. The results of all available analyses and tests of oil from the Katalla and Yakataga fields are presented in tabular form. Bibliography of papers on the coal and petroleum of Alaska is included.

345–A. The distribution of mineral resources in Alaska, by A. H. Brooks, p. 18–29, 1908. See p. 20, 23–26, 29.

Some information from earlier reports is repeated.

345–A. The mining industry in 1907, by A. H. Brooks, p. 30–53, 1908. See p. 52.

Lack of activity in petroleum development is noted.

379–A. The mining industry in 1908, by A. H. Brooks, p. 21–62, 1909. See p. 61–62.

Production from the Katalla field and occurrences of petroliferous materials in northern Alaska and on the Alaska Peninsula are noted.

379–C. Mineral resources of southwestern Alaska, by W. W. Atwood, p. 108–152, 1909.

Preliminary to Bulletin 467.

394. Papers on the conservation of mineral resources (reprinted from report of the National Conservation Commission, February, 1909). Mineral resources of Alaska. Petroleum, by G. C. Martin, p. 189–190, 1909.

Four producing or promising petroleum areas in Alaska are listed.

442–E. Outline of the geology and mineral resources of the Iliamna and Clark Lakes region, by G. C. Martin and F. J. Katz, p. 179–200, 1910.

Preliminary to Bulletin 485.

443. Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska, by U. S. Grant and D. F. Higgins, 89 p., 1910. See p. 79.

A reported petroleum seepage on Eyak R. (near Cordova) is noted.

467. Geology and mineral resources of parts of the Alaska Peninsula, by W. W. Atwood, 137 p., 1911. See p. 20, 96, 120–124.

Data on petroleum occurrences and developments on the Iniskin Peninsula and in the Kanatak district are abstracted or quoted from earlier publications.

480–B. The mining industry in 1910, by A. H. Brooks, p. 21–42, 1911. See p. 42.

New development in the Katalla district is noted.

485. A geologic reconnaissance of the Iliamna region, Alaska, by G. C. Martin and F. J. Katz, 138 p., 1912. See p. 113, 115, 126–130.

A general description of the regional geology is given, but with no special emphasis on petroleum.

520–A. The mining industry in 1911, by A. H. Brooks, p. 17–44, 1912. See p. 17, 43–44.
Current developments in the Katalla field are noted.

536. The Noatak-Kobuk region, Alaska, by P. S. Smith, 160 p., 1913. See p. 153.
A general description of the regional geology is given, and a geologic map is presented. Reference is made to a possible oil shale.

542–A. The mining industry in 1912, by A. H. Brooks, p. 18–51, 1913. See p. 18, 51.
Current developments in the Katalla field are noted.

592–A. The mineral deposits of Alaska, by A. H. Brooks, p. 18–44, 1914. See p. 21–22, 24, 40.
The locations of the Katalla, Yakataga, Iniskin Peninsula, and Cold (Puale) Bay districts and the occurrence of a petroleum seepage near Smith Bay (Cape Simpson) on the Arctic coast are noted.

592–A. The Alaskan mining industry in 1913, by A. H. Brooks, p. 45–74, 1914. See p. 46, 73–74.
Current developments in the Katalla field are noted.

592–E. Mineral deposits of the Yakataga district, by A. G. Maddren, p. 119–153. 1914. See p. 143–147.
A general description of the regional geology is given. Petroleum seepages are described and staking activity in 1897 is noted.

642–A. The Alaskan mining industry in 1915, by A. H. Brooks, p. 16–71, 1916. See p. 52.
Continued production at Katalla and a report of an oil seepage near Wainwright in northern Alaska are noted.

662–A. The Alaskan mining industry in 1916, by A. H. Brooks, p. 11–62, 1918. See p. 13, 31–40.
Reports of petroleum seepages and of exploration and development in known petroliferous areas are summarized.

666–P. Alaska's mineral supplies, by A. H. Brooks, p. 89–102, 1919. See p. 101.
Petroleum occurrences and developments in the Katalla field are noted.

668. The Nelchina-Susitna region, Alaska, by Theodore Chapin, 67 p., 1918.
A discussion is given of the general geology of the region. Petroleum possibilities are not mentioned. The rocks of the area include sedimentary rocks of Jurassic age which are correlated with similar rocks in the Cook Inlet region.

692–A. The Alaskan mining industry in 1917, by G. C. Martin, p. 11–42, 1919. See p. 11, 27.
Current developments in the Katalla field are noted.

712–A. The Alaskan mining industry in 1918, by G. C. Martin, p. 1–52, 1920. See p. 11, 26–27.
Reports of production in the Katalla field and of exploration on the Alaska Peninsula are given. Drilling in crystalline rocks near Nome and interest in the discovery of inflammable gas in swamps near Seward also are noted.

712–G. Mining in northwestern Alaska, by S. H. Cathcart, p. 185–198, 1920. See p. 196–197.
Drilling in crystalline rocks near Nome is described.

714–A. The future of Alaskan mining, by A. H. Brooks, p. 5–57, 1921. See p. 52–53.
Reference is made to known and reported oil or gas seeps from Admiralty Island (southeastern Alaska) to Smith Bay (Cape Simpson on the Arctic coast).

714–A. The Alaskan mining industry in 1919, by A. H. Brooks and G. C. Martin, p. 59–95, 1921. See p. 61, 74–75.

Current production (Katalla field) and earlier exploratory drilling are noted.

719. Preliminary report on petroleum in Alaska, by G. C. Martin, 83 p., 1921.

Previously published information on the geology and occurrence of petroleum in the Katalla, Yakataga, Alaska Peninsula, and Cape Simpson areas is summarized and, in some instances, expanded upon. The history of developments in the Katalla field is presented in detail. Reports of petroleum indications in various parts of Alaska, of the staking of oil claims, and of unsuccessful prospecting are summarized.

722–A. The Alaskan mining industry in 1920, by A. H. Brooks, p. 1–74, 1922. See p. 11, 31–33.

Production from the Katalla field and unsuccessful drilling near Anchorage are noted. Statistics on leasing and applications for oil prospecting are presented.

722–D. Geology of the vicinity of Tuxedni Bay, Cook Inlet, by F. H. Moffit, p. 141–147, 1922.

Preliminary to Bulletin 789.

739–A. The Alaskan mining industry in 1921, by A. H. Brooks, p. 1–50, 1923. See p. 1, 18–19.

Federal and private investigations and activities are summarized.

739–C. Recent investigations of petroleum in Alaska. The Cold Bay district, by S. R. Capps, p. 71–116, 1923.

The Cold (Puale) Bay district is defined and earlier applicable reports are reviewed briefly. A geologic map, lists of fossils, and stratigraphic sections are presented. Sedimentary rocks of Middle and Late Jurassic age in the area are divided into the Kialagvik, Shelikof, and Naknek formations, which aggregate at least 10,000 feet in thickness. The Bear Creek, Salmon Creek, Kialagvik (Wide) Bay, and Ugashik Creek anticlines are described. The highest part of the Ugashik Creek anticline is known as the Pearl Creek dome. The locations of known oil seepages and of wells in the area are plotted on the geologic map.

739–C. Recent investigations of petroleum in Alaska. The Iniskin Bay district, by F. H. Moffit, p. 117–132, 1923.

Preliminary to Bulletin 789.

739–C. Recent investigations of petroleum in Alaska. A petroleum seepage near Anchorage, by A. H. Brooks, p. 133–135, 1923.

A petroleum seepage about a mile southwest of Anchorage is described and results of an examination of a sample of the oil are presented.

739–C. Recent investigations of petroleum in Alaska. A supposed petroleum seepage in the Nenana coal field, by G. C. Martin, p. 137–147, 1923.

A bituminous deposit near Healy Creek in the Nenana coal field is determined to be coal tar rather than a petroleum residue as originally reported to the Survey. Another reported indication of petroleum in the area is noted, but not evaluated.

755–A. The Alaskan mining industry in 1922, by A. H. Brooks and S. R. Capps, p. 1–56, 1924. See p. 3, 20–22.

Withdrawal of Naval Petroleum Reserve No. 4 in northern Alaska and exploration and development in the Kanatak and Katalla districts are noted.

755–D. The Cold Bay-Chignik district, Alaska, by W. R. Smith and A. A. Baker, p. 151–218, 1924.

Report presents the results of a regional reconnaissance study of the area between Cold (Puale) Bay and Chignik, a regional geologic map, and four more detailed maps of parts of the area in which either petroleum seepages or possible favorable structures are present. The stratigraphy of the Mesozoic rocks of the area, including some lists of fossils, is described. Major anticlines, including those from which no petroleum indications have been reported, are described.

772. A reconnaissance of the Point Barrow region, Alaska, by Sidney Paige, W. T. Foran, and James Gilluly, 33 p., 1925.

Preliminary to Bulletin 815.

773–A. Alaska's mineral resources and production, 1923, by A. H. Brooks, p. 1–52, 1925. See p. 4–5, 34–36.

Current exploration and development are noted.

773–D. Petroleum on Alaska Peninsula. Mineral resources of the Kamishak Bay region, by K. F. Mather, p. 159–181, 1925.

A geologic map is presented. Structure and stratigraphy of Mesozoic rocks are described. Reported occurrence of oil seepages at two localities is noted.

773–D. Petroleum on Alaska Peninsula. The Cold Bay-Katmai district, by W. R. Smith, p. 183–207, 1925.

A geologic map is given. Descriptions of structures, stratigraphy, and gas seepages, and lists of fossils are presented.

773–D. Petroleum on Alaska Peninsula. The outlook for petroleum near Chignik, by G. C. Martin, p. 209–213, 1925.

A geologic map is presented. General geology is discussed briefly. The outlook for finding commercially significant amounts of petroleum is considered poor.

776. The Mesozoic stratigraphy of Alaska, by G. C. Martin, 493 p., 1926.

A discussion of stratigraphy is presented, with lists of fossils and stratigraphic sections. Petroleum is not discussed specifically.

783–A. Mineral industry of Alaska in 1924, by P. S. Smith, p. 1–30, 1926. See p. 28–30.

All production of petroleum was from the Katalla district. Drilling on the Pearl Creek dome in the Kanatak district was continued, with showings of oil in both of two wells. Investigations in Naval Petroleum Reserve No. 4 were continued.

783–C. Geology and oil developments of the Cold Bay district, by W. R. Smith, p. 63–88, 1926.

Lists of fossils, stratigraphic sections, and structure contour map of Salmon Creek-Bear Creek anticline are presented. Several previously unreported petroleum seepages are mentioned. The results of tests of samples of residue from Wide Bay and of petroleum from a seepage on the Ugashik Creek anticline are quoted. The area north of Becharof Lake is considered unfavorable for the occurrence of oil.

783–E. Summary of recent surveys in Northern Alaska, by P. S. Smith, J. B. Mertie, Jr., and W. T. Foran, p. 151–168, 1926.

Preliminary to Bulletin 815.

789. The Iniskin-Chinitna Peninsula and the Snug Harbor district, Alaska, by F. H. Moffit, 71 p., 1927.

Geologic maps and a correlation table of Jurassic sedimentary rocks of Alaska are presented. Stratigraphic sections and lists of fossils are included in the descriptions of Mesozoic rocks. Major structural features of the Iniskin Peninsula are the Portage Creek and Fitz Creek anticlines and several faults. Data on development work in the area and on oil seepages are given. Possibilities for finding petroleum in commercial quantities north of Chinitna Bay are considered poorer than south of the bay.

792–A. Mineral industry of Alaska in 1925, by F. H. Moffit, p. 1–39, 1927. See p. 36–38.

Activity in the Katalla, Kanatak, and Yakataga districts, in Naval Petroleum Reserve No. 4, and near Anchorage is noted.

792–C. Geologic investigations in northern Alaska, by P. S. Smith, p. 111–122, 1927.

Preliminary to Bulletin 815.

797–A. Mineral industry of Alaska in 1926, by P. S. Smith, p. 1–50, 1929. See p. 46–48.

Current production and exploration are noted. Operations on the Pearl Creek dome (Kanatak district) were terminated.

797–C. Preliminary report on the Sheenjek River district, by J. B. Mertie, Jr., p. 99–123, 1929. See p. 122–123.

This is a general report, with a geologic map. Oil shale is reported from the Christian River valley and from the Yukon River valley near the Nation River, and the results of distillation tests are given. An unverified report of an oil seepage on the Porcupine River is noted.

797–D. Surveys in northwestern Alaska in 1926, by P. S. Smith, p. 125–142, 1929.

Preliminary to Bulletin 815.

797–F. Geology and mineral resources of the Aniakchak district, by R. S. Knappen, p. 161–227, 1929.

A geologic map is presented. This is a general report with emphasis on petroleum possibilities. Sedimentary rocks range in age from Late Jurassic to Quaternary. Lists of fossils are presented in discussions of the formations recognized. Possibilities for the occurrence of petroleum in commercial amounts are considered poor.

810–A. Mineral industry of Alaska in 1927, by P. S. Smith, p. 1–64, 1930. See p. 58–61.

Current production and exploration are noted. A well in the Yakataga district was abandoned; only small shows of gas were found.

810–B. The Chandalar-Sheenjek district, by J. B. Mertie, Jr., p. 87–139, 1930. See p. 122.

A shorter version of discussion in Bulletin 797–C. Reference is to oil shale.

813–A. Mineral industry of Alaska in 1928, by P. S. Smith, p. 1–72, 1930. See p. 66–68.

Current production (Katalla field) and exploration (near Chickaloon in Matanuska Valley) are noted.

815. Geology and mineral resources of northwestern Alaska, by P. S. Smith and J. B. Mertie, Jr., 351 p., 1930. See p. 274–290, 344.

A geologic map is presented, and a general summary is given of the results of investigations in northern Alaska, especially in Naval Petroleum Reserve No. 4. The only proved petroleum seepages at the time of publication were at Cape Simpson, near Smith Bay. Many anticlines are reported in Upper Cretaceous rocks, especially in the southern part of the outcrop area of those rocks. Oil shale from the base of Lower Cretaceous sedimentary rocks or from underlying rocks is reported. The reported presence of material analogous to oil shale near the mouth of the Noatak River is noted.

816. Geology of the Eagle-Circle district, Alaska, by J. B. Mertie, Jr., 168 p., 1930. See p. 131–132, 159.

This is a general report with geologic map. Rocks exposed on the Yukon River near the mouth of the Nation River consist essentially of black bituminous shale interbedded with limestone. From a nearby locality (Trout Creek) oil shale which yields 28 gallons of oil per ton of rock has been sampled and tested. Oil shale is also reported from the valley of the Christian River. Material determined as tasmanite (a reddish-brown resinous material which yields oil) is reported from the Etivluk, Kivalina and Meade Rivers, all in northwestern Alaska.

824–A. Mineral industry of Alaska in 1929, by P. S. Smith, p. 1–81, 1932. See p. 73–76.

836–A. Mineral industry of Alaska in 1930, by P. S. Smith, p. 1–83, 1933. See p. 76–78.

836–B. Notes on the geography and geology of Lituya Bay, by J. B. Mertie, Jr., p. 117–135, 1933.

This is a general report which describes briefly the rocks of the Lituya Bay area. Lists of fossils collected from rocks of Tertiary age are given.

844–A. Mineral industry of Alaska in 1931 and administrative report, by P. S. Smith, p. 1–117, 1933. See p. 74–76.

857–A. Mineral industry of Alaska in 1932, by P. S. Smith, p. 1–91, 1934. See p. 70–72.

In references given above for Bulletins 824, 836–A, 836–B, 844–A, and 857–A, current production (Katalla field) and exploration (near Chickaloon in Matanuska Valley) are noted.

864–A. Mineral industry of Alaska in 1933, by P. S. Smith, p. 1–94, 1934. See p. 74–76.

The destruction of the refinery at Katalla is noted.

868–A. Mineral industry of Alaska in 1934, by P. S. Smith, p. 1–91, 1936. See p. 77–79.

Renewed interest by private concerns in the Iniskin Peninsula and in the Kanatak districts is noted.

872. The Yukon-Tanana region, Alaska, by J. B. Mertie, Jr., 276 p., 1937. See p. 154, 263–264.

This is a general report, with geologic map. The data on oil shale are repetitions of previously published material.

880–A. Mineral industry of Alaska in 1935, by P. S. Smith, p. 1–95, 1937. See p. 6, 82–84.

No petroleum was produced in Alaska and no development was in progress.

896. Lexicon of geologic names of the United States (including Alaska), by M. G. Wilmarth, 2396 p., 1938.

Age, brief description, and stratigraphic relations of named formations are given.

897–A. Mineral industry of Alaska in 1936, by P. S. Smith, p. 1–107, 1938. See p. 6, 92–94.

Exploratory drilling (to 2,550 feet) on Iniskin Peninsula is noted.

910–A. Mineral industry of Alaska in 1937, by P. S. Smith, p. 1–113, 1939. See p. 8, 98–101.

Exploration by drilling (Iniskin Peninsula) and field examination (Kanatak district) are noted.

917–A. Mineral industry of Alaska in 1938, by P. S. Smith, p. 1–113, 1939. See p. 8, 97–100.

Drilling on Iniskin Peninsula and near Kanatak is noted. The results of drilling on the peninsula are given. Surface investigations in the Katalla-Yakataga area are noted.

926–A. Mineral industry of Alaska in 1939, by P. S. Smith, p. 1–106, 1941. See p. 8, 89–92.

Continued drilling on Iniskin Peninsula and near Kanatak is noted.

933–A. Mineral industry of Alaska in 1940, by P. S. Smith, p. 1–102, 1942. See p. 7, 85–88.

No petroleum was produced and no exploration was under way.

1016. Wishbone Hill district, Matanuska coal field, Alaska, by F. F. Barnes and T. G. Payne, 88 p., 1956.

A geologic map and stratigraphic and structure sections are presented. More than 5,000 feet of nonmarine sedimentary rocks of Tertiary age are described and a new formation (Arkose Ridge) of probable Late Cretaceous age is defined. The term Eska conglomerate is abandoned and the rocks formerly described under this name are described as the Tsadaka and Wishbone formations. No specific mention is made of petroleum.

OIL AND GAS MAPS

95. Geology of the Iniskin Peninsula, Alaska, by C. E. Kirschner and D. L. Minard, 1949.

This is a geologic map with structure and columnar sections and a short text. Lower, Middle, and Upper Jurassic sedimentary rocks are described. One major anticline (Fitz Creek) and two minor anticlines are mapped. History of oil exploration in the district is summarized. Analyses of oil and gas from a well drilled on the Fitz Creek anticline are presented.

OM–126. Geology of the Arctic Slope of Alaska, by T. G. Payne and others, 3 sheets, 1952.

This is a geologic map of northern Alaska west of long 144° W., which gives stratigraphic, paleontologic, and petrographic information. Geophysical data and information on porosity and permeability of sedimentary rocks are presented. Logs of nine test wells are given. Paleontologic and heavy mineral studies are summarized. Structural features are described briefly. Geologic history, with paleogeologic interpretations, is discussed. Formations ranging in age from Mississippian to Pleistocene are recognized and mapped. Many favorable oil structures are indicated on the geologic and geophysical maps.

OM–187. Geology of the southwestern part of the Robinson Mountains, Yakataga district, Alaska, by D. J. Miller, 2 sheets, 1957.

This is a geologic map with structure and columnar sections, table of fossil identifications, and a short text. It describes and shows graphically the structure and stratigraphy of a belt of complexly folded and faulted rocks of Tertiary age. Three formations are recognized. The map shows the positions of all known oil and gas seepages and wells (none known to be productive to date) in the Yakataga district.

MISCELLANEOUS GEOLOGIC INVESTIGATIONS

I–84. Mesozoic and Cenozoic tectonic elements of Alaska, by T. G. Payne. 1955.

This is a tectonic map and tabular summary of geologic history.

REFERENCES CITED

Alaska Development Board, 1954, Possibility of commercial development of Gubik gas field and use of natural gas as a source of heat and power in the Railbelt area of Alaska: Juneau, Alaska.

Atwood, W. W., 1911, Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467.

——— 1909, Mineral resources of southwestern Alaska: U. S. Geol. Survey Bull. 379–C, p. 108–152.

Barnes, F. F., 1955, Notes on a coal deposit on the Beluga River, Alaska: U. S. Geol. Survey open-file report.

Barnes, F. F., and Cobb, E. H., 1959, Geology and coal resources of the Homer district, Kenai coal field, Alaska: U. S. Geol. Survey Bull. 1058–F.

Barnes, F. F., and Payne, T. G., 1956, The Wishbone Hill district, Matanuska coal field, Alaska: U. S. Geol. Survey Bull. 1016.

Barnes, F. F., and Sokol, Daniel, 1959, Geology and coal resources of the Little Susitna district, Matanuska coal field, Alaska: U. S. Geol. Survey Bull. 1058–D.

Blackwelder, Eliot, 1907, Reconnaissance on the Pacific coast from Yakutat to Alsek River: U. S. Geol. Survey Bull. 314–D, p. 82–88.

Brooks, A. H., 1906, The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45.

——— 1909, The mining industry in 1908: U. S. Geol. Survey Bull. 379–A, p. 61.

——— 1911, The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70.

——— 1922, A petroleum seepage near Anchorage: U. S. Geol. Survey Bull. 739–C. p. 133–135.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800.

Cairnes, D. D., 1914, The Yukon-Alaska international boundary, between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67.

Capps, S. R., 1913, The Yentna district, Alaska: U. S. Geol. Survey Bull. 534.

——— 1922, The Cold Bay district: U. S. Geol. Survey Bull. 739–C, p. 77–116.

——— 1935, The southern Alaska Range: U. S. Geol. Survey Bull. 862.

——— 1940, Geology of the Alaska Railroad region: U. S. Geol. Survey Bull. 907.

Cass, J. T., 1957, Reconnaissance geologic map of the Kateel quadrangle, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I–243 [1958].

Cathcart, S. H., 1920, Mining in northwestern Alaska: U. S. Geol. Survey Bull. 712–G, p. 185–198.

Cederstrom, D. J., 1952, Summary of ground-water development in Alaska, 1950: U. S. Geol. Survey Circ. 169.

Cederstrom, D. J., and Trainer, F. W., 1953, Tabulations of well records and logs and chemical analyses of ground waters in the vicinity of Anchorage, Alaska: U. S. Geol. Survey open-file report.

Chapman, R. M., and Sable, E. G., 1950, Stratigraphy and structure of the Okpikruak and Kiruktagiak Rivers area, Alaska: U. S. Geol. Survey, open-file report.

Cobb, E. H., 1950, Coal investigations on the southwest margin of the Homer district, Kenai coal field, Alaska in 1949: U. S. Geol. Survey open-file report.

——— 1951, Coal investigations on the northwest margin of the Homer district, Kenai coal field, Alaska in 1950: U. S. Geol. Survey open-file report.

Cobb, E. H., 1952, Coal investigations in the Homer district, Kenai coal field, Alaska in 1950 and 1951: U. S. Geol. Survey open-file report.

Collier, A. J., 1903, The coal resources of the Yukon, Alaska: U. S. Geol. Survey Bull. 218.

——— 1906, Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278.

Coonrad, W. L., 1957, Geologic reconnaissance in the Yukon-Kuskokwim delta region, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-223.

Dall, W. H., 1896, Report on the coal and lignite of Alaska: U. S. Geol. Survey 17th Ann. Rept., pt. 1, p. 763–875.

Eakin, H. M., 1916, The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 631.

Eardley, A. J., 1938, Unconsolidated sediments and topographic features of the lower Yukon Valley (Alaska): Geol. Soc. American Bull., v. 49, p. 303–341.

Ebbley, N. J., 1944, Oil seepages on the Alaskan Arctic Slope: Mining and Metallurgy, v. 25, no. 453, p. 415–419.

Eberlein, G. D., Chapman, R. M., and Reynolds, C. D., 1950, The stratigraphy and structure of the Aupuk anticline: U. S. Geol. Survey open-file report.

Grantz, Arthur, 1953, Preliminary report on the geology of the Nelchina area, Alaska: U. S. Geol. Survey open-file report.

Gryc, George, and others, 1956, Mesozoic sequence in Volville River region, Naval Reserve No. 4 and adjacent areas, Alaska [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 1133.

Gryc, George, Miller, D. J., and Payne, T. G., 1951, Alaska, *in* Ball, M. W., ed., Possible future petroleum provinces of North America: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 151–168.

Gryc, George, and others, 1956, Mesozoic sequence in Colville River region, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 2, p. 209–254.

Hanna, G. D., 1919, Geological notes on the Pribilof Islands, Alaska, with an account of the fossil diatoms: Am. Jour Sci., 4th ser., v. 48, p. 216–224.

Harrington, G. L., 1918, The Anvig-Andreafski region, Alaska (including the Marshal district): U. S. Geol. Survey Bull. 683.

Hartsock, J. K., 1954, Geology of the Iniskin Peninsula and adjacent area, Alaska: U. S. Geol. Survey open-file report.

Hazzard, J. C., Bryan, J. J., Borax, Eugene, and Shoemaker, Richard, 1950, Geology of Kamishak Bay area, Cook Inlet, Alaska [abs.]: Am Assoc. Petroleum Geologists Bull., v. 34, p. 2377.

Hollick, Arthur, 1930, The Upper Cretaceous floras of Alaska, with a description of the plant-bearing beds by G. C. Martin: U. S. Geol. Survey Prof. Paper 159.

Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, p. 953–992.

——— 1953, Callovian (Jurassic) ammonites from the United States and Alaska; pt. 2, Alaskan Peninsula and Cook Inlet regions; U. S. Geol. Survey Prof. Paper 249–B.

Imlay, R. W., and Reeside, J. B., Jr., 1954, Correlation of the Cretaceous formations of Greenland and Alaska: Geol. Soc. America Bull., v. 65, p. 223–246.

Keller, A. S., and Cass, J. T., 1956, Petroliferous sand of the Chignik formation at Chignik Lagoon, Alaska: U. S. Geol. Survey open-file report.

Keller, A. S., and Reiser, H. N., 1959, Geology of the Mount Katmai area, Alaska: U. S. Geol. Survey Bull. 1058–G.

Kirschner, C. E., and Minard, D. L., 1949, Geology of the Iniskin Peninsula, Alaska: U. S. Geol. Survey Oil & Gas Inv. Map OM-95.

Knappen, R. S., 1929, Geology and mineral resources of the Aniakchak district, Alaska: U. S. Geol. Survey Bull. 797-F, p. 161-223.

Leffingwell, E. de K., 1919, The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, 251 p.

MacNeil, F. S., Mertie, J. B., Jr., and Pilsbry, H. A., 1943, Marine invertebrate faunas of the buried beaches near Nome, Alaska: Jour. Paleontology, v. 17, p. 69-96.

Maddren, A. G., 1914, Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592-E, p. 119-153.

Martin, G. C., 1904, Petroleum fields of Alaska and the Bering River coal fields: U. S. Geol. Survey Bull. 225.

——— 1908, Geology and mineral resources of the Controller Bay region, Alaska: U. S. Geol. Survey Bull. 335.

——— 1921, Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719.

——— 1923, A supposed petroleum seepage in the Nenana coal field: U. S. Geol. Survey Bull. 739, p. 137-147.

——— 1926, The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776.

Martin, G. C., Johnson, B. L., and Grant, U. S., 1915, Geology and mineral resources of the Kenai Peninsula, Alaska: U. S. Geol. Survey Bull. 587.

Martin, G. C., and Katz, F. J., 1912, A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485.

Mather, K. F., 1925, Mineral resources of the Kamishak Bay region: U. S. Geol. Survey Bull. 773, p. 159-181.

Mendenhall, W. C., 1902, Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Ball, Kanuti, Allen, and Kowak rivers: U. S. Geol. Survey Prof. Paper 10.

——— 1905, Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41.

Mertie, J. B., Jr., 1930, Geology of the Eagle-Circle district: U. S. Geol. Survey Bull. 816.

——— 1932, The Tatonduk-Nation district, Alaska: U. S. Geol. Survey Bull. 836-E, p. 347-443.

——— 1933, Notes on the geography and geology of Lituya Bay, Alaska: U. S. Geol. Survey Bull. 836-B, p. 117-135.

——— 1937. The Yukon-Tanana region, Alaska: U. S. Geol. Survey Bull. 872.

——— 1938, The Nushagak district, Alaska: U. S. Geol. Survey Bull. 903.

Miller, D. J., 1951a, Preliminary report on the geology and oil possibilities of the Yakataga district, Alaska: U. S. Geol. Survey open-file report.

——— 1951b, Geology and oil possibilities of the Katalla district, Alaska: U. S. Geol. Survey open-file report.

Miller, D. J., 1953a, Preliminary geologic map and correlated columnar section of Tertiary rocks in the southeastern part of the Lituya district, Alaska: U. S. Geol. Survey open-file report.

——— 1953b, Late Cenozoic marine glacial sediments and marine terraces of Middleton Island, Alaska: Jour. Geol., v. 61, p. 17-40.

——— 1953c, Geology and petroleum possibilities of Gulf of Alaska Tertiary province [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 1132-1133.

——— 1957, Geology of the southeastern part of the Robinson Mountains, Yakataga district, Alaska: U. S. Geol. Survey Oil and Gas Inv. Map OM-187.

Moffit, F. H., 1913, Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533.

——— 1927, The Iniskin-Chinitna Peninsula and the Snug Harbor district, Alaska: U. S. Geol. Survey Bull. 789.

——— 1938, Geology of the Chitina Valley and adjacent area, Alaska: U. S. Geol. Survey Bull. 894.

Morris, Robert H., 1957, Reconnaissance study of the Marsh anticline, northern Alaska: U. S. Geol. Survey open-file report.

Paige, Sidney, Foran, W. T., and Gilluly, James, 1925, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772.

Patton, W. W., Jr., and Bickel, R. S., 1956a, Geologic map and structure sections along part of the Lower Yukon River, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I–197.

——— 1956b, Geologic map and structure sections of the Shaktolik River area, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I–226.

Payne, T. G., 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I–84.

Payne, T. G., and Gryc, George, 1951, Alaska petroleum in relation to geologic history [abs.]: Geol. Soc. America Bull., v. 62, p. 1557.

Payne, T. G., and others, 1951, Geology of Arctic slope of Alaska: U. S. Geol. Survey Oil and Gas Inv. Map OM–126.

Pettijohn, F. J., 1949, Sedimentary Rocks: New York, Harper and Brothers.

Péwé, T. L., 1954, Evidence for possible marine Tertiary(?) sediments in central Alaska: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2222–2225.

Plafker, George, and Miller, D. J., 1957, Reconnaissance geology of the Malaspina district, Alaska: U. S. Geol. Survey Oil and Gas Inv. Map OM–189.

Reed, J. C., 1946, Recent investigations by United States Geological Survey of petroleum possibilities in Alaska: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1433–1443.

Russsell, I. C., 1891, An expedition to Mount St. Elias, Alaska: Natl. Geog. Mag., v. 3, p. 53–204.

——— 1893, Second expedition to Mount St. Elias: U. S. Geol. Survey 13th Ann. Rept., pt. 2, p. 1–91.

Sable, E. G., 1956, New and redefined Cretaceous formations in western part of northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 11, p. 2635–2643.

Schrader, F. C., 1904, A reconnaissance in northern Alaska across the Rocky Mountains along Koyukuk, John, Anaktuvuk and Colville Rivers and the Arctic coast to Cape Lisburne, in 1901: U. S. Geol. Survey Prof. Paper 20.

Smith, P. S., 1910, Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 433.

——— 1913, The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536.

——— 1929, Mineral industry of Alaska in 1927 and administrative report: U. S. Geol. Survey Bull. 810–A, p. 1–85.

——— 1931, Mineral industry of Alaska in 1930 and administrative report: U. S. Geol. Survey Bull. 836–A, p. 1–115.

——— 1941, Possible future oil provinces in Alaska: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 1440–1446.

Smith, P. S., and Eakin, H. M., 1911, A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449.

Smith, P. S., and Mertie, J. B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U. S. Geol. Survey Bull. 815.

Smith, W. R., 1925, The Cold Bay Katmai district: U. S. Geol. Survey Bull. 773-D, p. 183-207.

——— 1926, Geology and oil developments of the Cold Bay district, Alaska: U. S. Geol. Survey Bull. 783-C, p. 63-88.

Smith, W. R., and Baker, A. A., 1924, The Cold Bay-Chignik district, Alaska: U. S. Geol. Survey Bull. 755-D, p. 151-218.

Spurr, J. E., 1900, A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey 20th Ann. Rept., pt. 7, p. 31-264.

Tailleur, I. L., and Kent, B. H., 1951, Stratigraphy and structure of the Southern Foothills section between the Etivluk and Kiligwa Rivers, Alaska: U. S. Geol. Survey open-file report.

Taliaferro, N. L., 1932, Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., v. 43, p. 749-782.

Tarr, R. S., and Butler, B. S., 1909, The Yakutat Bay region, Alaska; Areal geology: U. S. Geol. Survey Prof. Paper 64, pt. 2, p. 145-178.

Thomas, H. F., 1946, Oil in Alaska, a report on an expedition to the far north to locate rumored seeps and secure samples: Oil Weekly, v. 120, no. 10, p. 39-48.

U. S. Bureau of Mines, 1944, War Minerals Report 258.

Wahrhaftig, Clyde, 1950, Physiographic history of southern Alaska, a hypothesis [abs.]: Geol. Soc. America Bull., v. 61, p. 1532.

Webber, E. J., 1947, Stratigraphy and structure of the area of the Meade and Kuk Rivers and Point Barrow: U. S. Geol. Survey open-file report.

Webber, E. J., and Detterman, R. L., 1947, Preliminary report of the stratigraphy and structure of the area of the Nanushuk River, Alaska: U. S. Geol. Survey open-file report.

Whittington, C. L., and Keller, A. S., 1950, Stratigraphy and structure of the area of the upper Meade River, Alaska: U. S. Geol. Survey open-file report.

Whittington, C. L., and Stevens, J. M., 1951, Stratigraphy and structure of part of the Carbon Creek and Ketik anticlines, Alaska: U. S. Geol. Survey open-file report.

INDEX