Geology of the Mount Katmai Area Alaska

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MINERAL RESOURCES OF ALASKA

GEOLOGICAL SURVEY BULLETIN 1058-G

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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ABSTRACT

The Mount Katmai area is on the Alaska Peninsula and comprises the Mount Katmai quadrangle, the Cape Douglas area of the adjoining Afognak quadrangle, and parts of the Karluk and Naknek quadrangles. The area, which includes nearly all the Katmai National Monument, is one of high relief and is drained by streams of preglacial origin. At least two ice advances are indicated by the moraine configuration. Present-day glaciation is restricted to numerous alpine glaciers in the mountain areas. Fifteen recently active volcanoes roughly form a line from Mount Douglas to Martin Mountain.

Sedimentary rocks older than Middle Jurassic age, and of Late Jurassic, Late Cretaceous, and Eocene age are represented. Silicic and mafic igneous rocks of Early and (or) Middle Jurassic and Tertiary age locally intrude the sedimentary rocks. Volcanic rocks, chiefly andesite and basalt of Tertiary and Quaternary age, locally overlie the formations of Late Jurassic and Late Cretaceous age. The Naknek formation of Late Jurassic age comprises a conglomerate unit overlain by 6,000 to 9,000 feet of fossiliferous sandstone, siltstone, conglomerate, and shale. A new formation, the Kaguyak formation, of Late Cretaceous (Campanian-Maestrichtian) age is proposed. The formation has been divided into three informal members: a lower ±2,000-foot fossiliferous siltstone member, a middle 1,090-foot sandstone, siltstone, and shale member, and an upper +1,460-foot littoral sandstone and siltstone member. A largely nonmarine coal-bearing formation at least 830 feet thick consists of conglomerate, sandstone, siltstone, shale, and coal, and interfingers with layered volcanic rocks of Eocene age.

Seven northeastward-trending anticlines locally interrupt the regional southeasterly dip of the sedimentary rocks. The largest is the Kamishak anticline, whose crest is intruded by a quartz diorite stock. A reverse fault transects the mapped area from the Little Kamishak River to Contact Creek.

The rocks of the Naknek formation were derived in part from Lower and (or) Middle Jurassic intrusive rocks and were laid down as shelf deposits during a transgression of seas during Late Jurassic time. The area was at a state of base level during most of Cretaceous time. The seas transgressed during Late Cretaceous time, and this was followed by a major regression of the seas permitting the area to emerge completely during Eocene time. No major deformation occurred during Jurassic and Cretaceous time and since then there has been only one major period of folding and faulting, probably after Eocene and before Quaternary time.

Sedimentary rocks of the Naknek and Kaguyak formations may serve as both a source and a reservoir for petroleum. Locally, structural and stratigraphic traps may also be present. Any exploitation of the area for petroleum seems remote, however, and probably should not be attempted until such time as drilling in more favorable localities north and south of the Mount Katmai area delimits the petroleum possibilities of the sedimentary rocks.

INTRODUCTION

During the 1954 field season the authors made reconnaissance studies in the Mount Katmai quadrangle and adjacent areas. The map area (fig. 44), which includes nearly all the Katmai National Monument, is on the Alaska Peninsula approximately between lat 58°00′ N. and 59°00′ N. It is bounded on the west approximately

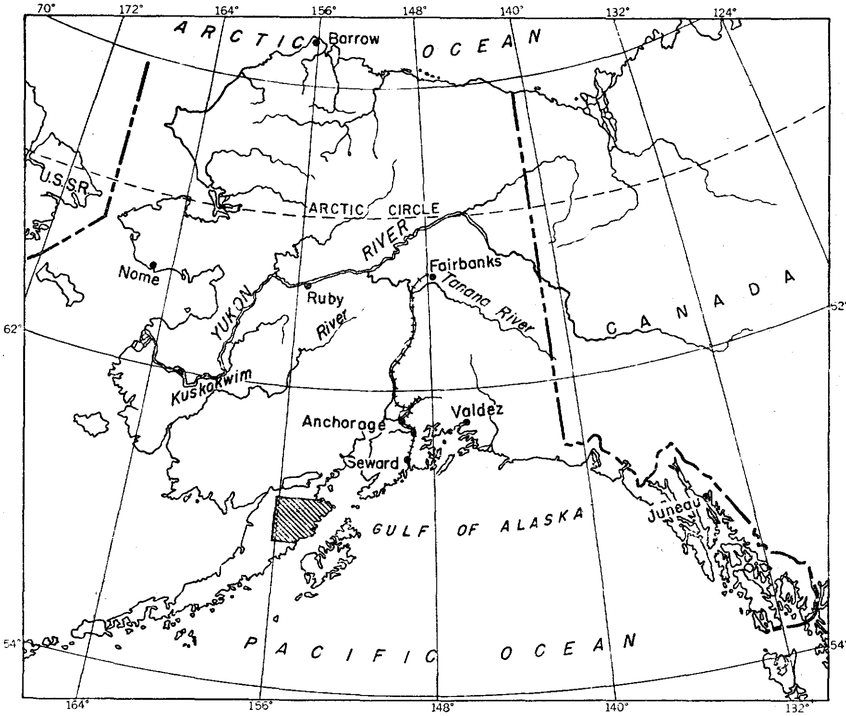


FIGURE 44.—Index map of Alaska, showing location of Mount Katmai area (shaded).

by long 156°00′ W. and on the east by Shelikof Strait, and covers about 5,000 square miles. The field season began July 1, 1954, and ended on September 2, 1954. These geologic investigations were made in collaboration with the U.S. National Park Service as part of a scientific program designed to evaluate the various geological, biological, botanical, and archeological features of Katmai National Monument.

GEOLOGIC METHODS

The area was mapped on vertical aerial photographs at a scale of 1:40,000. These geologic data were later transferred to a base map of 1:250,000 scale. The use of aerial photographs facilitated mapping and allowed the geologists to cover a considerably greater area than would otherwise be possible in a short field season. During the course of the work eight field camps were established. These camps were reached by float plane supplied by the U.S. Air Force. From these base camps, geologic investigations were made by foot traverse as far as practical. In addition to the time that was spent on the ground, a part of the season was devoted to an aerial reconnaissance of the area.

PREVIOUS WORK

Since 1898 many scientists have contributed to the knowledge of the area mapped. In that year, J. E. Spurr crossed the Alaska Peninsula from Naknek on the west coast to Katmai Bay on the east, and his studies of the geology in the vicinity of Mount Katmai and elsewhere were published in 1900. B. K. Emerson and Charles Palache, members of the Harriman Alaska Expedition of 1899, landed at several points along Shelikof Strait and made collections of plant fossils from the rocks of Eocene age at Cape Nukshak. Their findings were published in 1904. W. W. Atwood in 1911 published the results of reconnaissance work in 1908 along parts of the coastline of the area mapped by the authors. In 1923, K. F. Mather made a reconnaissance study of the rocks from Iliamna Bay to the Savonoski River, and during the same year W. R. Smith joined Mather's party at the Savonoski River after making a geologic study of the area from Cold Bay (now Puale Bay) to Mount Katmai. The studies of both Mather and Smith were published in 1925. The eruption of Mount Katmai in 1912 and the emplacement of the tuff in the Valley of Ten Thousand Smokes are treated in publications by R. F. Griggs (1922) and C. N. Fenner (1920, 1922, 1923, 1925).

In more recent years, J. C. Hazzard and others (1950) of the Union Oil Company of California and the Ohio Oil Company published the results of their findings near Kamishak Bay and Cape Kaguyak. The glacial geology of parts of the area are included in publications by E. H. Muller (1952, 1953, 1954). Also, within the past 5 years, studies of volcanology and geomorphology have been made by Garniss Curtis, and to a lesser extent by Howel Williams, J. B. Lucke, H. W. Coulter, and G. L. Snyder. Summary statements by these men are available in a report by the National Park Service (Luntey and others, 1954).

In 1953, R. Werner Juhle, a geologist of the U.S. Geological Survey, lost his life while engaged in scientific investigations in Katmai National Monument. Juhle's field notes and those of his assistant, Ronald W. Kistler, have been used in the preparation of this report, and their mapping in the vicinity of Mount Katmai has been included on plate 29.

ACKNOWLEDGMENTS

The authors wish to acknowledge the aid of Robert S. Luntey of the National Park Service, who acted as an agent for liaison between the Geological Survey and the U.S. Air Force, and provided the logistic support necessary for the completion of the geologic studies. The authors wish also to thank the pilots of the U.S. Air Force at King Salmon, Alaska, who often flew under trying conditions in order to supply the needs of the geologists. They are indebted to Ralph W. Imlay of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey for his prompt identification of Jurassic and Cretaceous invertebrate fossils and to Roland W. Brown of the same organization for his identification of Tertiary plants.

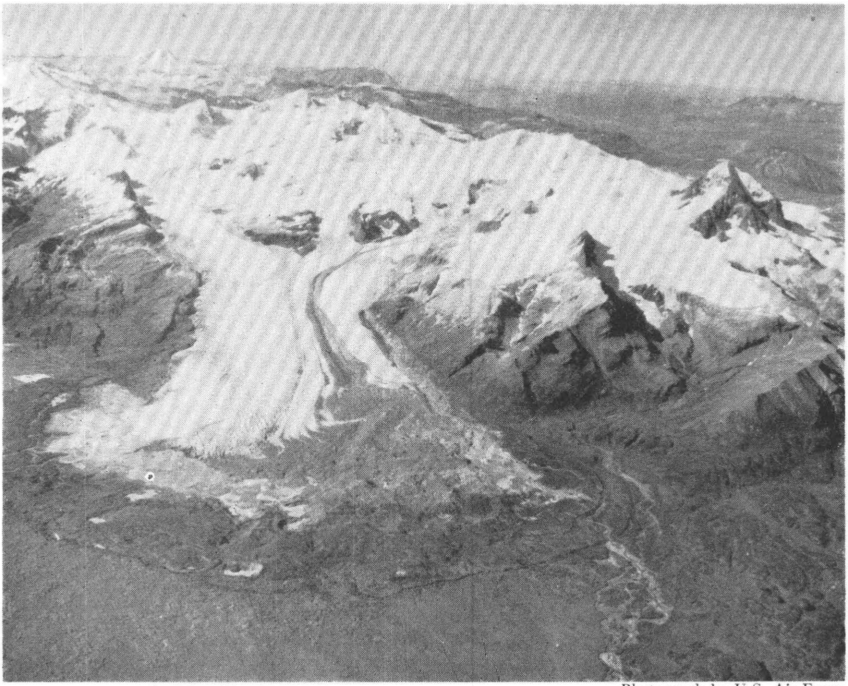
GEOMORPHOLOGY

TOPOGRAPHY

The Mount Katmai area is divided asymmetrically by the volcanic Aleutian Range. The mountains rise steeply from the fiordlike bays of the Shelikof Strait coastline to altitudes greater than 7,000 feet, and parallel the northeasterly trend of the peninsula across the entire area. From the crest of the mountain range the altitudes of the peaks drop less abruptly westward and northwestward, and beyond the limit of the area mapped the topography passes into a low coastal plain.

A line of high mountain peaks, many of which are either dormant or active volcanoes, extends from Mount Douglas on the northeast to Martin Mountain on the southeast. Between these limits lie Fourpeaked Mountain, the relatively low Kaguyak Crater, and the cones of Kukak Volcano, Mount Denison (with an altitude of 7,606 feet, the highest peak in the area mapped), Snowy Mountain, Mount Katmai, Trident Volcano, and Mount Mageik. Six miles northwest of Mount Katmai the cone of Knife Peak Volcano rises from the Valley of Ten Thousand Smokes to an altitude of 7,589 feet.

Most of the range between Martin Mountain and Kukak Volcano is built of successive volcanic flows and generally exceeds 4,000 feet in altitude, except where headward-cutting streams locally have dissected it. Within these geographic limits Katmai Pass is the only



Photograph by U.S. Air Force

HALLO BAY GLACIER SHOWING RECESSIONAL STAGE OF ICE

Photograph by U.S. Air Force

FIORDLIKE BAYS OF SHELIKOF STRAIT COASTLINE

Geographic Harbor in foreground

low route through the mountains. Two passes have been cut through the volcanic rocks into sedimentary rocks of Jurassic and Cretaceous age northeast and southwest of this part of the range, one in the watershed area of Takayoto Creek and the Kejulik River and one southwest of Kaguyak Crater near the headwaters of the Savonoski River.

The area underlain by the Naknek and Kaguyak formations, although mountainous, is less rugged than the area underlain by the volcanic rocks. Locally, glaciers have carved a fretted upland of arêtes and cirques within this part of the map area, but between the Kamishak and the Douglas Rivers the upland comprises mesalike plateaus locally capped by resistant sandstone and conglomerate.

A belt of hills along the northwest side of the mountains is underlain by intrusive rocks, and from this belt lower hills underlain by volcanic rocks merge westward with the subdued topography of the Bristol Bay coastal plain.

DRAINAGE

RIVERS

The area is drained by four major rivers: the Savonoski, Ukak, Kamishak, and Katmai. These rivers predate the Pleistocene and probably were carved in an early Tertiary surface. The glaciers probably enlarged and straightened the previously established courses. During recession of the ice, glacial deposits covered the valley floors, and these deposits, which are being constantly reworked, form the flood plains of the rivers.

The largest river in the map area, the Savonoski, heads in relict cirques and active glaciers of the Aleutian Range and flows through a glaciated valley about 5 miles wide. Within this valley many small streams interconnect to form a braided pattern; their channels total about one-fourth of the area of the river's flood plain. The gradient of the Savonoski averages 20 feet per mile between the Hook Glacier and the Rainbow River and less than 12 feet per mile between the Rainbow River and its confluence with the Ukak River.

The Ukak River rises in the volcanic slopes of the Aleutian Range, and its tributaries, River Lethe and Knife Creek, drop about 100 feet per mile from the base of Baked Mountain through the Valley of Ten Thousand Smokes. From this valley the Ukak River drops about 50 feet per mile to its confluence with the Savonoski River, where the combined waters empty into Iliuk Arm.

The Katmai River, which drains a relatively small part of the map area, heads in the volcanic spine of the Aleutian Range and flows southeastward to Shelikof Strait. The river flows transverse to the regional structure through a glaciated U-shaped valley about 5 miles wide. The floor of this valley is composed of thick ash deposits from the 1912 eruption of Mount Katmai, and the river, flowing on these deposits, comprises hundereds of small streams which interconnect to form a braided pattern. The gradient of the river, except in its headwaters, averages 10 feet per mile.

Unlike the Savonoski, Ukak, and Katmai Rivers, which flow transverse to structural trends, the Kamishak and smaller related drainages are subsequent streams. The Kamishak River, paralleling the northeastward-trending regional structure, heads in relict cirques and active glaciers of the volcanic mountains and sedimentary-rock uplands, flows northeastward, and, beyond the map area, receives the water of the little Kamishak River and empties into Akumwarvik Bay. On the upper 13 miles of the river the gradient averages 35 feet per mile. Below its junction with the South Fork the gradient averages 18 feet per mile.

LAKES

In the northwest corner of the map area a group of interconnected lakes receives the water of most of the westward- and northwestward-flowing streams. West of the map area these lakes are drained by the Naknek River, which meanders through the lake-studded Bristol Bay coastal plain and empties into Kvichak Bay. The lakes are glacial in origin, and their beds were scoured in intrusive and volcanic rocks. They lie less than 200 feet above sea level.

GLACIATION

Fieldwork by the authors was concentrated mainly on the study of Mesozoic and Cenozoic stratigraphy and structure, and less so on the study of the glacial geology of the area. Mapping of the glacial features (see pl. 29) was based in part upon observations in the field, but for the most part resulted from interpretation of vertical aerial photographs. The authors interpret that at least two separate glaciations occurred, and that these correspond to the Brooks Lake and Iliuk Arm glaciations described by Muller (1953, p. 2–3) and assigned to late Wisconsin age by Péwé and others (1953, p. 13).

In the northwestern part of the map area, terminal moraines of the two glaciations are clearly preserved (pl. 29). The older of these two, the Brooks Lake, is superimposed on what may be a partly obscured ground moraine of an earlier advance. The Brooks Lake advance is represented by a series of arcuate generally undissected lateral and terminal moraines enclosing Lake Brooks, Idavain Lake, Lake Coville, and Hammersly Lake. Muller (1953, p. 2) reports that moraines of this advance also enclose Naknek Lake. In addition, moraines in the Angle Creek area, and those bordering the south side of Nanwhyenuk Lake and Kulik Lake, probably also are related to this ice advance. Areas enclosed by the lateral and terminal moraines are characterized by knob-and-kettle topography. Streams have breached the terminal moraine ridges only to a minor extent, and in general the glacial topography in the terminal zones completely controls the drainage pattern. For example, water from Hammersly Lake flows northward by way of American Creek to a point where it is blocked by the moraines that border Nanwhyenuk Lake. From here it flows westward, and then, controlled by the arcuate trend of the moraine enclosing Lake Coville, it flows southward to join the Savonoski drainage. The water traverses an arc of almost 330° from the point at which it originates.

The Iliuk Arm glaciation, considered by Muller (1953, p. 2–3) to be the youngest major advance in this area, is represented by the moraine enclosing Iliuk Arm. Probably also associated with this readvance are moraines forming the narrow neck of land between Lake Coville and Lake Grosvenor, and small push moraines on the north side of Lake Grosvenor (pl. 29).

In addition to the area northwest of the mountains, the Shelikof Strait side probably underwent glaciation also. On this side of the map area, the Katmai River flows through a typical U-shaped glacial valley, and glacially scoured fiords typify the coastline from Katmai Bay to Cape Nukshak. Fieldwork by the authors was not detailed enough for them to correlate the times of the glaciation here with the advances on the northwest side of the mountains, but it is reasonable to believe that glaciation on both sides was concurrent.

Many active alpine glaciers are present in the area mapped. In the vicinity of Mount Douglas only the highest peaks stand above the level of the glacial ice and perennial snowfields, and, over much of the central part of the area, headward-cutting glaciers are carving a fretted upland of cols and arêtes. Judging from the position of many of the glaciers with respect to their recently deposited end moraines, it appears that the ice is now receding (pl. 30). A glacier in the crater of Mount Katmai is of special interest, as noted by Muller, Juhle, and Coulter (1954, p. 70). This crater originated during the eruption of Mount Katmai in 1912, and the glacier that now occupies it is therefore one of the few in the world whose age can be accurately determined.

COASTLINES

The coastline along Shelikof Strait between Katmai Bay and Cape Nukshak (pl. 31) is characterized by deeply indented harbors, islands, and peninsulalike projections. The beaches along the coastline are poorly developed. The most pronounced beaches are at Hallo Bay, where older beach levels are now as much as 30 feet higher than the present high-tide level. Extensive beaches are not typical of the other bays in the area, and those at Hallo Bay may be caused by the development of beach features on a more extensive glacial outwash plain than is found elsewhere in the area mapped.

RECENT VOLCANISM

Active volcanoes were observed in this region as early as 1898, when Spurr (1900, p. 232), traversing the Katmai area, noted that:

> The summit of the Aleutian Mountains in this vicinity is formed by a continuous chain of volcanoes. One of these volcanoes is said by the natives to smoke occasionally. Earthquakes and hot springs are among the volcanic phenomena actually experienced in the region, and the continuation of the chain of volcanoes extends to those which have been active in historical time, such as St. Augustine and the volcano in the vicinity of the Ugashik Lakes, as well as many others along the same range farther southwest.

In June of 1912 the natives living at Savonoski and at Katmai were forced to abandon their villages because Mount Katmai, which had been nearly dormant, explosively erupted. R. F. Griggs (1922) has published a detailed account covering both this eruption and the emplacement of the incandescent volcanic debris in the Valley of Ten Thousand Smokes.

In addition to the eruption of Mount Katmai, other volcanic activity has been observed in this area in recent time. Muller, Juhle, and Coulter (1954, p. 62–64) report that 15 recently active volcanoes have been noted. Martin, Mageik, Novarupta, Knife, Kukak, and Douglas peaks were observed to steam with varying intensities during the summers of 1953 and 1954, and Trident Volcano was steaming and extruding a blocky viscous lava.

STRATIGRAPHY

UNDIFFERENTIATED ROCKS OLDER THAN MIDDLE JURASSIC

The undifferentiated sedimentary and metamorphic rocks older than Middle Jurassic were not studied on the ground by the authors. The nature and distribution of this sequence have been inferred from the examination of vertical aerial photographs. The rocks are limited in their distribution to the vicinity of Kulik Lake where they crop out in resistant ridges and scarps. They appear to be bedded and composed of relatively massive units. With the present information they cannot be correlated with rocks of adjoining outcrop areas, but they appear to be intruded on their east side by an igneous complex of presumed Early and (or) Middle Jurassic age (see p. 287) and may be partly equivalent to the crystalline limestone schist and quartzite of Paleozoic(?) age mapped by Mather (1925, p. 163–164) at the head of the Paint River, or to the Paleozoic and early Mesozoic(?) age rocks exposed in the vicinity of Lake Iliamna (Martin and Katz, 1912).

BEDDED ROCKS OF MESOZOIC AGE

NAKNEK FORMATION

History.—The name Naknek was given to a rock "series" by Spurr (1900, p. 170), who stated:

> The Naknek series consists of a great thickness series of granitic arkoses and of of conglomerates which generally contain pebbles of granite.

He further noted (p. 169–170) that

> at Katmai Point the basal rock exposed just above tidewater is hard massive granitic arkose; above this comes a dense aphanitic rock . . . and higher up come arkoses, made up of very coarse granitic fragments, and coarse conglomerates, having pebbles of biotite granite. Through all the rocks of this series indistinct plant remains are common.

On the basis of the available information it is not quite clear where the type locality of the Naknek was intended to be, nor is it entirely clear what Spurr considered the upper and lower limits. Presumably Spurr had no specific type locality in mind, but intended that the name represent the rocks exposed from Mount Katolinat to Katmai Pass, and southward to Katmai Bay. Martin (1905, p. 44) used the word formation in place of series, and the name Naknek formation as it is used now applies to a sequence of rocks of Late Jurassic age locally having a basal conglomerate member. Martin and Katz (1912) originally applied the name Chisik to this conglomerate and treated it as a unit of formational rank overlying the Chinitna shale and underlying the Naknek formation, but in 1926 Martin treated the Chisik conglomerate as the basal member of the Naknek formation, and this is its present usage.

In 1925, Mather mapped a conglomerate unit as the Chisik conglomerate over the crest and along the flanks of the Kamishak anticline, and the authors have extended this mapping along part of the shoreline of Lake Grosvenor (pl. 29). The contact of this conglomerate unit with older rocks is not exposed in the map area, and its identification by Mather as the Chisik conglomerate apparently was based on the lithologic similarities of the conglomerate in the Mount Katmai area to the one described by Martin and Katz (1912) in the Iliamna region.

Occurrence and lithology.—The Naknek formation crops out in a mountainous belt 20 to 38 miles wide which trends northeastward across the entire area. On the northwest side of its outcrop belt the formation is in fault contact with igneous rocks of Early and (or) Middle Jurassic age. In the northeastern part of the map area it is overlain partly by rocks of Cretaceous age, and both here and over much of the central part of the map area it is overlain by volcanic rocks of Tertiary and Quaternary age.

The Chisik conglomerate member consists of irregularly bedded marine conglomerate which, north of the mapped area, may be as much as 1,000 feet thick (Mather, 1925, p. 169). Along the northeast shore of Lake Grosvenor the conglomerate contains large generally rounded cobbles and boulders of granite, chert, jasper, and metamorphic and mafic igneous rocks in a green feldspathic fossiliferous sandstone matrix. The conglomerate is lenticular and is interbedded with coarse green arkose. The thickness of the member undoubtedly varies considerably throughout the area, and its contact with the overlying beds of the Naknek formation is gradational.

The part of the Naknek formation above the Chisik conglomerate member consists of 6,000 to 9,000 feet of marine sandstone, siltstone, conglomerate, and shale. The lowest 800 feet of this sequence is composed of fine- to coarse-grained arkose of low to medium porosity and low permeability. The sandstone contains rounded fragments of gray and green chert, feldspar, and white quartz, with interbedded dense medium-gray siltstone and sandy red-weathering shale. Thin beds and lenses of conglomerate containing granite, chert, and metamorphic and mafic igneous detritus in a feldspathic green argillaceous matrix are present, and limy and nonlimy siltstone concretions and carbonaceous material occur sporadically. The 800 feet is fossiliferous, and specimens of *Aucella*, which is the predominant fossil type, are so abundant that locally the rock is coquinoid.

Overlying the lowest 800 feet is about 2,000 feet of less resistant predominantly thin-bedded siltstone, fine-grained sandstone, and sandy shale. Conglomerate similar to that described above occurs as minor lenses. The *Aucella* sp. which characterizes the lower beds is present to a lesser degree in this part of the sequence.

The upper 3,000 to 6,000 feet of the Naknek formation consists locally of massive conglomerate, similar in composition to the basal Chisik conglomerate member, interbedded with fine- to coarse-grained fossiliferous arkose, siltstone, and shale. Massive conglomerate units as much as 2,000 feet thick and composed predominantly of large boulders of silicic and mafic intrusive rocks in a green fossiliferous sandstone matrix crop out at Mount Katolinat. Pebbles of biotite granite are abundant throughout the rocks in the upper 3,000 to 6,000 feet of the formation, and as Spurr (1900, p. 170) notes, many of the upper beds contain macerated plant remains.

Measured stratigraphic sections.—Only one section which was incomplete, was measured by the authors in the field. This section is on the northeast side of Lake Grosvenor (pl. 29) where the essentially flat lying beds of the Naknek formation crop out in resistant benches. Neither the upper nor the lower contact of the formation is exposed. Units of this stratigraphic section (1, pl. 32) are described below in descending succession.

Section 1: Naknek formation on northeast side of Lake Grosvenor

[Location, pl. 29; graphic section, pl. 32]

	Thickness (feet)
1. Siltstone, sandstone, and shale. Upper beds consist of gray highly indurated massive siliceous siltstone, and gray-green sandstone; remainder of unit consists of gray-green fossiliferous sandstone, gray dense slabby siltstone, and red-weathering sandy shale. Partly covered	840
2. Siltstone, gray, resistant, dense, makes up large part of unit; minor interbedded fine-grained arkose of low porosity and permeability. *Aucella* sp. common throughout. Partly covered	600
3. Sandstone, gray-green, fine-grained, subgraywacke-type, with granules of green and gray chert, and jasper; and gray dense platy siltstone. *Aucella* sp. rare	140
4. Arkose, light-gray to green, fine-grained, *Aucella*-bearing	60
5. Sandstone, light-gray to green, slabby, argillaceous, and gray interbedded siltstone. *Aucella* sp. common	75
6. Siltstone, green, grades to green sandstone; minor thin carbonaceous seams. *Aucella* sp. common	125
7. Siltstone, gray, dense, well-indurated, noncalcareous; in ½- to 2-inch beds, abundantly fossiliferous. Fossil colln. 25277, near top of unit	300
8. Sandstone, green, fairly well sorted, locally coquinoid, fossiliferous. Fossil colln. 25276	50
9. Sandstone, green-gray, coarse-grained, noncalcareous. Detrital constituents are well rounded fairly well sorted green and gray chert and feldspar, and white quartz. *Aucella* sp. and pectinoid pelecypods abundant	90
10. Siltstone, gray, massive; contains lenses of conglomeratic sandstone with subrounded chert grains in a green fossiliferous sandstone matrix; grades into Chisik conglomerate member below. Interval abundantly fossiliferous; fossil colln. 25278	80
11. Conglomerate, marine, with large well-rounded cobbles of granite, chert, and mafic igneous rock in a green fossiliferous matrix; makes up Chisik conglomerate member. *Aucella* sp. common	80
Total measured Naknek formation	2,440

Age and correlation.—Jurassic fossils collected by the authors are listed below. Identifications are by R. W. Imlay, of the U.S. Geological Survey. In the first column in this table and other tables of fossils that follow, "USGS Mesozoic loc." refers to the Geological

Survey Mesozoic locality number under which the fossils are filed. Fossil collections 25276, 25277, and 25278 were obtained from stratigraphic section 1 at Lake Grosvenor (pls. 29 and 32). Lot 25279 was collected from an isolated cutbank on the south side of Lake Grosvenor (pl. 29).

USGS Mesozoic loc.	Identification
25276	*Aucella rugosa* (Fischer)
	Aucella mosquensis (von Buch)
	Meleagrinella sp.
25277	*Aucella rugosa* (Fischer)
	Aucella mosquensis (von Buch)
	Pleuromya sp.
25278	*Aucella mosquensis* (von Buch)
	Aucella rugosa (Fischer)
	Pleuromya sp.
25279	*Aucella mosquensis* (von Buch)
	Rhynchonellid brachiopods

Smith (1925, p. 199–200) made several fossil collections in the southwest part of the area mapped by the authors. The localities are plotted on plate 29, but, owing to the difference in the base maps used by Smith and by the authors, the positions may not be exact. Smith (1925, p. 200) lists the following fossils identified by T. W. Stanton:

12077. East side of Kejulik Pass, below Gas Creek:
Rhynchonella sp.
Pleuromya sp.
Turbo? sp.
Belemnites sp.
Phylloceras sp.
Bone fragment
Jurassic, Naknek

12078. Upper part of Gas Creek. Lowest exposed beds:
Aucella sp.
Eumicrotis sp.
Jurassic, Naknek

12079. Mountain top east of Yori Pass:
Aucella mosquensis (von Buch)
Astarte sp.
Pleuromya sp.
Jurassic, Naknek

12080. Baked Mountain, north side of Valley of Ten Thousand Smokes:
Aucella mosquensis (von Buch)
Lima sp.
Turbo? sp.
Belemnites sp.
Jurassic, Naknek

Rocks of the Naknek formation are widespread on the Alaska Peninsula as well as in other areas including the Matanuska Valley and Talkeetna Mountains. Imlay (1952, p. 977–978) points out that

The basal part of the Naknek formation is of lower Oxfordian age (*mariae* to *plicatilis* zones of northwest Europe), as shown by the presence of various species of *Cardioceras* in the Cook Inlet area. . . . [and] in the Matanuska Valley. . . . The overlying beds in the lower part of the Naknek formation are of probable upper Oxfordian age, as shown by the presence of *Amoeboceras* (*Prionodoceras*) associated with finely striate *Aucella bronni* (Rouiller) . . . A Kimmeridgian age to basal Portlandian age for the upper part of the Naknek formation is shown by the presence of *Aucella mosquensis* (von Buch) and *A. rugosa* (Fischer) . . .

Aucella bronni has been more recently designated *aucella concentrica.*

In the Mount Katmai area the *Cardioceras* zone and the *Amoeboceras* zone are not represented in the lots collected by the authors. *Aucella rugosa* and *Aucella mosquensis*, which Imlay believes are characteristic of the Middle Kimmeridgian to Lower Portlandian stages (see fig. 45), occur in beds that are not more than 80 feet above the upper contact of the Chisik conglomerate member. Unless the Chisik, as mapped by the authors, is representative of Imlay's two older zones, it would appear that there are overlap relationships within the Naknek formation. Another alternative is possible, however. It has already been noted that the assignment of this conglomerate member to the Chisik was done by Mather (1925), and that the assignment was apparently based on lithologic similarities of the conglomerate in the Mount Katmai area to that described by Martin and Katz (1912) in the Iliamna region. The authors recognize little lithologic difference between the conglomerate unit that has been mapped as Chisik in the Mount Katmai area and other conglomerate units that are higher in the Naknek formation, and, although they have retained Mather's mapping, they believe it possible that the conglomerate mapped as Chisik in the Mount Katmai area is younger than, and may not be continuous with, the type Chisik.

KAGUYAK FORMATION

History.—The name Kaguyak formation is proposed herein to designate the sequence of rocks of Late Cretaceous age that is typified by the stratigraphic section exposed in the vicinity of Kaguyak. The type section includes the exposures at Kaguyak and the sequence exposed in the sea cliffs from the mouth of the Big River to the Swikshak River. Atwood (1911, p. 41) included these rocks as part of the Chignik formation. However, as this section has relatively little in common with the coal-bearing sequence at Chignik, about 250 miles to the southwest, it seems more logical to assign a different formation name to the Upper Cretaceous beds in this area.

Other geologists have studied the rocks in this vicinity in the past. Martin (1926, p. 299) states:

The north shore of Kaguyak Bay, near Aievak or Douglas Village, not far from the east end of the Alaska Peninsula, contains an almost unbroken series of outcrops of sedimentary rocks striking slightly north of west and

System	Series	European stage		Mount Katmai area
Quaternary				Volcanic flows
Tertiary	Pliocene			
	Miocene			
	Oligocene			
	Eocene			Coal-bearing beds
	Paleocene			Not represented
Cretaceous	Upper	Maestrichtian		Kaguyak formation
		Campanian		
		Santonian		Not represented
		Coniacian		
		Turonian		
		Cenomanian		
	Lower	Albian		
		Aptian		
		Neocomian	Barremian	
			Hauterivian	
			Valanginian	
			Berriasian	
Jurassic	Upper	Portlandian		Naknek formation
		Kimmeridgian		
		Oxfordian	Argovian	
			Divesian	
		Callovian		
	Middle	Bathonian		
		Bajocian		

FIGURE 45.—Correlation chart of formations in the Mount Katmai area.

dipping 15° N. The westernmost exposures consist of dark shale with marine Upper Cretaceous fossils . . . The rocks in the east end of the cliffs consist of gray sandstone with thinner beds of dark shale in which no fossils were found, except fragmentary dicotyledonous leaves that were too imperfect for identification.

Hazzard (1950) reports as follows concerning the exposures on the Kaguyak promontory:

About 400 feet of beds comprising fossiliferous, concretionary, black limy siltstone with thin beds of dark bluish-gray limestone are exposed in the sea cliffs on the cape and in the surrounding reefs. The presumed base of the Cretaceous is in a 30-foot greenish-gray fine-grained sandstone cropping out at the mainland edge of the sandflat west of the cape. The nature of the intervening section is unknown. The basal sandstone rests with apparent conformity on the Upper Jurassic Naknek formation.

The 30-foot-thick sandstone bed described by Hazzard is considered by the authors to represent the lower limit of the Kaguyak formation in this area. The upper beds of the formation are overlain by volcanic rocks of Tertiary age of the Aleutian Range.

Occurrence and lithology.—The Kaguyak formation is confined in its geographic distribution to the northeastern part of the mapped area. Only the exposures in the vicinity of Kaguyak were visited by the authors, and the extension of the formation elsewhere in the area is based largely on the interpretation of vertical aerial photographs.

The formation has been divided into three informal members: a lower fossiliferous siltstone member, a middle massive locally cross-bedded concretionary sandstone and interbedded siltstone and silty shale member, and an upper thin-bedded sandstone and siltstone member. In the exposures at the type locality the lower member is about 2,000 feet thick, the middle member is 1,090 feet thick, and the upper member is about 1,460 feet thick. The upper contact of the formation was not seen.

Type section.—Units of the type section (2, pls. 29 and 32) are described below in descending stratigraphic succession.

Section 2: Type section of the Kaguyak formation at Kayuyak along the sea cliffs from Big River to Swikshak River.

[Location, pl. 29 ; graphic section, pl. 32]

	Thickness (feet)
1. Sandstone and silt shale, gray, interbedded, very fine grained to fine-grained, argillaceous, noncalcareous, red-weathering; sandstone locally contains carbonaceous partings and minor ironstone	760
2. Sandstone, ironstone, and silt shale; platy and rusty-weathering; sandstone is fine grained. Interval largely covered	700
3. Sandstone, siltstone, and silt shale, interbedded, light-gray, fine-grained; sandstone in beds as much as 4 feet thick, with thinner interbeds of siltstone and silt shale	75

	Thickness (feet)
4. Silt shale, predominantly; 1-inch interbeds of sandy siltstone and silty sandstone; limy dense spheroidal siltstone concretions common	75
5. Sandstone, light- to medium-gray, fine- to medium-grained, massive, shale interbeds 1 foot thick	55
6. Sandstone, gray, medium-grained, massive, slightly argillaceous. Large spheroidal sandstone concretions	50
7. Sandstone, light-gray, fine-grained, massively bedded; with siltstone concretions alined on bedding planes; black silt shale at base of unit	80
8. Sandstone, siltstone, and silt shale; rhythmically bedded. Sandstone is light gray, fine- to medium-grained, with shaly partings and large spheroidal siltstone concretions locally alined on bedding surfaces; silt shale is dark gray, with platy to hackly fracturing; sandstone units up to 6 feet thick; siltstone and silt shale units up to about 8 feet thick; interbeds in shale unit several inches thick	250
9. Silt shale, siltstone, and sandstone. Rhythmically bedded unit of dark-gray well-indurated silt shale, dense noncalcareous hackly fracturing siltstone, and light-gray fine-grained well-indurated noncalcareous sandstone. Sandstone contains shaly partings and clay galls, and is found in beds 2 inches to 10 feet thick, with thinner interbeds of siltstone and silt shale. Large spheroidal siltstone and sandstone concretions locally alined on bedding surfaces	205
10. Sandstone, silt shale, and siltstone. Sporadic outcrops of light reddish-weathering fine-grained sandstone, medium-gray platy silt shale, and dense siltstone; shale galls. Partly covered	300
11. Andesite sill. Petrographic description (sample 54 AKe 45): Megascopically a medium-dark-gray phaneritic rock. Microscopically holocrystalline and equigranular. It consists predominantly of unoriented interfingering laths of plagioclase averaging 0.25 mm in length; interstices between the plagioclase laths filled with grains of augite. The plagioclase is predominantly andesine; the augite is in part altered to amphibole. Grains of pyrite are also present	40
12. Covered interval	220
13. Siltstone, dark-gray, hackly fracturing, dense, noncalcareous, with calcite veining along distinct joint system; large spheroidal limy dark-gray fossiliferous siltstone concretions alined on bedding planes have a fetid odor on fresh break. Entire section fossil bearing; fossil colln. 25282 and 25283	490
14. Covered interval	230
15. Siltstone, medium-gray, very dense, massively bedded, siliceous, breaks down in needlelike fragments and hackly fracturing silt shale. Abundant large spheroidal limy dense siltstone concretions, locally pyritized and abundantly fossiliferous, alined on bedding planes. Section near base becomes slightly sandy. Fossil colln. 25280 and 25281	720

	Thickness (feet)
16. Covered interval. Projection of strike across to Kaguyak indicates that not more than 300 feet of additional section is present between unit 15 and the contact at Kaguyak described by Hazzard (1950, p. 227)	300
Total measured Kaguyak formation	4, 550

Naknek formation.

Age and correlation.—Fossils collected from the lower siltstone member of the Kaguyak formation were identified by Imlay. These samples were collected from stratigraphic section 1, the location of which is shown on plate 29. The positions of the collections in the stratigraphic column are shown on plate 32.

USGS Mesozoic loc.	Identification
25280	*Inoceramus* sp.
	Pleuromya sp.
25281	*Pachydiscus* (*Neodesmoceras*) sp.
	Inoceramus cf. *I. kusiroensis* Nagao and Matumoto
	Nemodon sp.
	Anomia cf. *A. vancouverensis* Gabb
25282	*Lytoceras* (*Gaudryceras*) sp.
25283	*Inoceramus* cf. *I. kusiroensis* Nagao and Matumoto
	Inoceramus cf. *I. shikotanensis* Nagao and Matumoto

Concerning these collections, Imlay (1954, written communication) states:

The fossils from the Kaguyak formation are of Campanian or Maestrichtian age and are younger than any fossils found in the Chignik formation in the southern part of the Alaska Peninsula. In the Talkeetna Mountains fossils identical with those in the Kaguyak formation occur at the top of the siltstone member of the Matanuska formation just below the highest sandstone member. The smooth compressed pachydiscid ammonite from fossil lot 25281 is good evidence of a position high in the Upper Cretaceous sequence. The small *Inoceramus* with sharp, equally-spaced ribbing that is compared with *I. kusiroensis* Nagao and Matumoto is likewise common in the high Cretaceous beds.

In addition to the collections made by the authors at this locality, fossils of Late Cretaceous age are known also to occur in the upper beds that form the hills between the Kamishak and Douglas Rivers. Imlay and Reeside (1954, p. 234) state:

Ammonites of Late Cretaceous age, probably Campanian, have been found at Cape Kaguyak on the Shelikof Strait in the upper part of a sequence consisting of about 400 feet of black siltstone and thin beds of limestone overlying the Naknek formation (Hazzard 1950, p. 227). The ammonites include *Pachydiscus* cf. *P. ootacodensis* Stoliczka, *P. suciaensis* (Meek), *Phylloceras ramosum* (Meek), *Gaudryceras* cf. *G. denmanense* Whiteaves, and *Diplomoceras notabile* Whiteaves. With these is one specimen of *Inoceramus* that is probably an immature form of *I. subundatus* (Meek). The same assemblage has been found, also, about 7 miles southeast of the mouth of the Kamishak River.

BEDDED ROCKS OF CENOZOIC AGE

COAL-BEARING ROCKS

History.—The term coal-bearing rocks is here used to designate the coal-bearing rocks of Tertiary age that are exposed in the Katmai area. Coal-bearing rocks on the Alaska Peninsula were mentioned by Dall and Harris (1892, p. 238), who stated that

> along the shores of Alaska Peninsula, west and south from Cook's Inlet, lignite beds, doubtless associated with plant impressions, are not uncommon, but the exploration of this shore has been very imperfect.

Atwood (1911, p. 49–51) described coal-bearing rocks of Tertiary age at Cape Douglas and between "Hallo Bay and Amalik."

Coal-bearing sedimentary rocks were said by Smith (1939, p. 62) to be found in patches all the way from Cape Douglas to and beyond Pavlof Bay.

Occurrence and lithology.—The coal-bearing rocks crop out on the northward-facing fault scarp along the south side of Hallo Bay, at Dakavak Lake, and at Geographic Harbor. These rocks probably are also present on the south side of Katmai Canyon, and judging from a sketch map by Stone (*in* Atwood, 1911, p. 50) they may be present also in the vicinity of Cape Douglas. They locally interfinger with volcanic rocks of Eocene age and cannot be mapped throughout the area.

The Unit consists predominantly of nonmarine conglomerate, sandstone, siltstone, coal, and plant-bearing mudstone, and ranges from rocks deposited in lagoons or swamps to those deposited on the Eocene beaches. Volcanic rocks are locally interbedded.

Conglomerate units of the coal-bearing rocks are up to 50 feet thick and contain pebbles, cobbles, and boulders of mafic igneous rocks, granite, chert, silicified wood, and silicified tuff in a light-gray to green coarse-grained tuffaceous matrix. The fine- to coarse-grained light-gray sandstone units consist of chert, white quartz, granite, and mafic igneous detritus. Disseminated carbonaceous material and plant impressions are common. The sandstone units are in general moderately porous and permeable. The sequence is further characterized by thin seams of lignite and low-rank coal, associated with plant-bearing light-gray mudstone.

Measured stratigraphic sections.—Two stratigraphic sections of the coal-bearing rocks were measured in the field, one at Geographic Harbor (4, pls. 29 and 32) and one at Cape Nukshak (3, pls. 29 and 32). The one at Cape Nukshak, the more complete of the two, is exposed on the northward-facing fault scarp that forms the divide between Kukak and Hallo Bays. The measured sequence dips 26° S. Neither the top nor the bottom contact of the unit was observed at this locality, but on the hillside facing Kukak Bay volcanic rocks crop out not more than 500 feet stratigraphically higher than the top beds of the measured section. Units of the Cape Nukshak section are described below in descending stratigraphic succession.

Section 3: Coal-bearing rocks at Cape Nukshak

[Location, pl. 29; graphic section, pl. 32]

		Thickness (feet)
1.	Sandstone and conglomerate; sandstone is light gray, fine to coarse grained, quartzose; conglomerate contains pebbles, cobbles, and boulders of white quartz, mafic and silicic igneous rocks, chert, and wood fragments. Thin seams of carbonaceous material, lignite, and plant-bearing claystone	200
2.	Sandstone, fine-, medium-, and coarse-grained, quartzose; and conglomerate containing very well rounded pebbles of white quartz and black chert. Thin seams of lignite and carbonaceous material. Claystone with abundant leaf impressions. Colln. 54 AKe 36	100
3.	Conglomerate with coarse-grained tuffaceous matrix; massive, containing pebbles, cobbles, and boulders of mafic and silicic igneous rocks, chert, and white quartz	40
4.	Sandstone, light-gray to green, fine-grained, massive quartzose, containing carbonaceous wood impressions; and interbedded green-gray leaf-bearing siltstone	50
5.	Sandstone, light-gray, fine- to coarse-grained, locally carbonaceous, moderately porous and permeable; and conglomerate containing pebbles of black chert, white quartz, granite, and mafic igneous rocks. Top of unit consists of lenses and beds 1 foot thick of carbonaceous material and lignite containing gray plant-bearing claystone. Colln. 54 AKe 35	120
6.	Sandstone, greenish-gray, coarse-grained, friable, slabby weathering. Detrital constituents are predominantly quartz and minor black chert	30
7.	Conglomerate with light-gray tuffaceous matrix, massive; contains pebbles and cobbles, as much as 8 inches in diameter, consisting of mafic igneous rock, granite, white quartz, silicified wood, black chert, green chert, and silicified tuff	50
8.	Sandstone, light-gray, coarse- to fine-grained, locally carbonaceous; beds 2 inches thick	50
9.	Conglomerate, massive, contains pebbles and cobbles of silicic and mafic igneous rock as much as 8 inches in diameter; carbonaceous matrix	25
10.	Sandstone and conglomerate, interbedded	20
11.	Conglomerate, massive; contains pebbles, cobbles, and boulders of mafic igneous rock, granite, chert, and silicified wood; constituents mostly well rounded; carbonaceous sandstone interbeds	25
12.	Sandstone, coarse, pebbly, crossbedded; contains large lenses of lignite and coaly wood and lamellae of carbonaceous material	35

		Thickness (feet)
13.	Siltstone, sandstone, and conglomerate. Siltstone is coaly, in 1-inch beds interbedded with fine- to coarse-grained sandstone, and chert- and quartz-bearing conglomerate	45
14.	Sandstone, medium-gray, coarse-grained, pebbly	40
	Total measured coal-bearing rocks at Cape Nukshak	830

The rocks exposed in the 280-foot incomplete stratigraphic section at Geographic Harbor (4, pls. 29 and 32), crop out along the southwest shore of Geographic Harbor and form the south flank of a northeastward-plunging anticline. Units of the section are described below in descending stratigraphic succession.

Section 4: Coal-bearing rocks at Geographic Harbor

[Location, pl. 29; graphic section, pl. 32]

		Thickness (feet)
1.	Sandstone, platy	12
2.	Sandstone, gray, friable, crossbedded, with conglomerate lenses	19
3.	Sandstone, coarse to conglomeratic, carbonaceous, with pebbles of white quartz, and mafic and silicic rocks	7
4.	Volcanic flow rock, with interbedded carbonaceous material. Petrographic description of the flow (sample 54 AKe 17): Megascopically a medium-gray aphanitic porphyritic extrusive rock. The phenocrysts are white and average about 1 mm in length. Microscopically the rock is identified as sodic andesite. The microlites of plagioclase have the approximate composition An_{30}. The laths of plagioclase are oriented in subparallel flow lines. Phenocrysts of former plagioclase and ferromagnesian minerals are completely replaced by calcite. Contains finely disseminated limonite and a large opaque inclusion of carbonaceous(?) material	9
5.	Sandstone, medium-gray, coarse-grained	6
6.	Sandstone, light-gray-green, fine-grained, massive; interbedded with shale; plant bearing mudstone, and thin coal seams. Colln. 54 AKe 16	15
7.	Basalt sill(?). Petrographic description (sample 54 AKe 15): Megascopically a dark dense aphanitic rock. Microscopically an intergranular holocrystalline rock. Plagioclase, predominantly labradorite, occurs as unoriented interfingering laths. Between the laths of plagioclase the interstitial augite(?) has altered to chlorite. Contains calcite, which probably represents an alteration product	13
8.	Siltstone	3
9.	Shale, dark-gray; plant fragments common	5
10.	Sandstone, dark-gray, crossbedded; with shale	4
11.	Sandstone, dark-gray, dense, fine-grained	8

		Thickness (feet)
12.	Sodic andesite flow. Petrographic description (sample 54 AKe 14): Megascopically a vesicular light-gray-green rock with some of the vesicles filled with quartz or calcite. Microscopically the rock is holocrystalline. The groundmass consists of lath-shaped microlites in a felty textured arrangement. The plagioclase has the approximate composition An_{30} (oligoclase-andesine). A few phenocrysts (0.5 to 1.0 mm diameter) of calcic plagioclase are present. The specimen is highly chloritized and the chlorite probably is an alteration product of former ferromagnesian minerals. Secondary quartz is abundant	5
13.	Sandstone and black silt shale, interbedded; nonlimy siltstone concretions	5
14.	Siltstone and carbonaceous shale, interbedded	4
15.	Covered interval	50
16.	Sandstone, interbedded, with platy, thin-bedded siltstone	6
17.	Sandstone, light- to medium-gray, fine- to coarse-grained, massive, with abundant wood and carbonaceous material	18
18.	Shale, black, with abundant leaf impressions. Colln. 54 AKe 13	18
19.	Sandstone, very light gray, dense, salt-and-pepper textured; massive unit; conglomerate lenses containing wood fragments near base	62
20.	Coal and platy carbonaceous shale, interbedded	4
21.	Sandstone, friable, crossbedded	2
22.	Coaly shale	2
23.	Sandstone, light-gray, very fine grained, friable	4
24.	Coal and silty sandstone, interbedded	2
	Total measured coal-bearing rocks at Geographic Harbor	280

Age and correlation.—Tertiary coal-bearing rocks of the Alaska Peninsula have been mentioned by many workers. Dall and Harris (1892, p. 234–249) mentioned lignite beds along the shores of the Alaska Peninsula and discussed them as part of the "Miocene of the Kenai group." Atwood (1911, p. 49) stated that "Cape Douglas, the northeastern extremity of the peninsula, is composed in part of Tertiary rocks, presumably of Kenai age." Fossil evidence cited by Atwood indicates that the rocks he describes are of Eocene age.

Smith (1939, p. 62–63), in speaking of coal-bearing Tertiary beds in southwestern Alaska, notes that they

> have been found in more or less discontinuous patches all the way from Cape Douglas * * * to and beyond Pavlof Bay * * *. Throughout this tract the lowest sedimentary beds appear to be in general closely comparable with the typical Kenai formation.

Since 1928 the name Kenai formation has been used only for Eocene rocks of the Kenai Peninsula. However, the coal-bearing rocks of

Tertiary age that are described in this report may be comparable with the Kenai formation of Eocene age.

The plant fossils collected from the formation by the authors were identified by Roland W. Brown. Collections 54 AKe 13 and 54 AKe 16 were obtained at Geographic Harbor (4, pls. 29 and 32). Collections 54 AKe 35 and 54 AKe 36 were obtained at Cape Nukshak (3, pls. 29 and 32).

Fossil collection	*Identification*
54 AKe 13	*Glyptostrobus dakotensis* (Brown); dicotyledonous leaves resembling *Alnus*, *Betula*, and *Corylus*.
54 AKe 16	?*Magnolia* sp.
54 AKe 35	*Metasequoia occidentalis* (Newberry) Chaney *Alnus alaskana* (Newberry)
54 AKe 36	*Metasequoia occidentalis* (Newberry) Chaney *Alnus alaskana* (Newberry)

Roland W. Brown (1954, written communication) states that although the material from the first two localities is fragmental, there seems to be enough to suggest early Tertiary age. He further states that "The last two localities are definitely Tertiary, probably Eocene."

In addition to the collections made by the authors at Cape Nukshak, collections were made at this locality by members of the Harriman Alaska Expedition of 1899. These excellent collections are listed by Atwood (1911, p. 52–54), who also quotes F. H. Knowlton's identification of them. Knowlton referred the collection to the upper Eocene.

VOLCANIC FLOWS AND ASSOCIATED ROCKS

Owing to the short time available for field studies, the authors made only a few observations of the volcanic flows and associated rocks in the area. Nevertheless, certain relationships, of the volcanic sequence are evident. Volcanism began at least as early as Eocene time and continued intermittently through the Tertiary and Quaternary periods. In addition, the volcanic-rock sequence includes a folded unit at least, in part, of Eocene age unconformably underlying younger undeformed flows. Because of the limited fieldwork it was not feasible for the authors to map this subdivision consistently, nor was it possible to determine the ages of all the intervals of volcanism. On the geologic map (pl. 29) the volcanic rocks have been subdivided into three units: a folded sequence, partly of Eocene age, which locally contains nonmarine sedimentary members; a younger generally massive undeformed sequence; and an undifferentiated sequence comprising both. In addition, the undifferentiated unit locally comprises

Kenai formation equivalents and Tertiary intrusive rock. The total thickness of the volcanic rocks is probably more than 6,000 feet.

The folded volcanic-rock sequence comprises interbedded andesite, basalt, and water-laid tuff with local lenses of agglomerate, sandstone, siltstone, and plant-bearing mudstone. In the northwestern part of the area the sequence is composed of several thousand feet of these rocks, which locally overlie rocks older than Middle Jurassic and Lower and (or) Middle Jurassic intrusive rocks. The volcanic sequence was deposited under much the same environmental conditions as its partial time equivalent, the coal-bearing rocks. The sedimentary lenses and interbeds of agglomerate consist of a volcanic matrix enclosing boulders of igneous rock and silicified wood. The igneous detritus is predominantly mafic in composition, although pebbles of granite occur locally. Interbedded in the volcanic rocks are mudflows, lenticular crossbedded coarse-grained green sandstone, thin-bedded to fissile coaly shale, and dense siltstone. Much carbonaceous material and many poorly preserved leaf impressions further characterize the formation. Fragments of leaves in one of the plant collections (54 ARr 1, Lake Grosvenor locality, pl. 29) were identified by Roland W. Brown (written communication) as belonging to *Metasequoia occidentalis* (Newberry) Chaney, *Cercidiphyllum ellipticum* (Newberry) Brown, and other dicotyledonous species. He states that, although the material was fragmental, there appeared to be enough to suggest an early Tertiary age assignment for the sequence characterized by this flora.

Other folded volcanic rocks, consisting predominantly of interbedded flows, are exposed along the Shelikof Strait coastline between Katmai Bay and Cape Nukshak, and may be present also from Cape Nukshak to the Douglas River. In the vicinity of Kukak Bay 1,960 feet of layered volcanic rocks dip very gently northward (stratigraphic section 5, pl. 29). The age of this sequence is unknown, although the fact that it is folded suggests that it was deposited before Quaternary time, and the authors believe that it is probably Eocene in age. Twelve samples were collected from this section. The basalt and andesite flows have been hydrothermally altered, and the samples collected from near the base of this measured section appear to have undergone the greatest alteration. Individual flows are generally less than 20 feet thick. Petrographic descriptions of the samples follow. The measurements in feet are the stratigraphic position of the sample above the base of the measured section.

Section 5: Layered volcanic rocks in the vicinity of Kukak Bay

[Location, pl. 29]

	Height above base of section (feet)
Volcanic flow rock. Petrographic description (sample 54 AKe 22): Megascopically a medium-gray aphanitic rock, containing abundant feldspar phenocrysts. In thin section the groundmass is seen to consist of a dense felty textured mass of microlites, cryptocrystalline quartz, and magnetite dust. Phenocrysts of partly altered plagioclase (including oligoclase and labradorite), averaging about 1.5 mm in length, are abundant. The ferromagnesian minerals are almost entirely replaced by chlorite, calcite, and talc(?). The groundmass is partly chloritized, and limonite staining is prevalent	1,960
Basalt. Petrographic description (sample 54 AKe 23): Megascopically a dense aphanitic brownish-gray rock. In thin section the rock seems to be equigranular and holocrystalline. The laths of plagioclase average 0.15 mm in length, are interfingering, and display a felty texture. In some areas of the slide a tendency toward subparallel flow-line orientation is apparent. Extinction angles indicate that the plagioclase has the approximate composition An_{60} (labradorite). The interstices are filled with augite grains in various stages of alteration. Larger grains, 0.4 mm in size, of former ferromagnesian minerals are entirely replaced by chlorite, epidote, calcite, and quartz. Magnetite grains are common and well dispersed throughout the groundmass	1,850
Highly altered flow rock. Petrographic description (sample 54 AKe 24): Megascopically a light-green-gray porphyritic rock. Microscopic examination indicates that the rock is an andesite vitrophyre that has been completely altered. The feldspar minerals are almost entirely destroyed; the glass has devitrified to a chloritized cryptocrystalline aggregate (quartz?). Two remnant lithophysae are still discernible in the thin section. The mafic minerals have been completely replaced by chlorite (penninite?). Several laths of calcite were probably also derived from the altered mafic minerals. Pyrite is fairly common and minor limonite staining is present	1,830
Porphyritic rock, greenish-gray, containing abundant phenocrysts 1 to 2 mm in diameter. Petrographic description (sample 54 AKe 25): Microscopically the groundmass of the rock appears as a cryptocrystalline mass containing myriads of small unoriented microlites. The groundmass is clouded with magnetite dust, and chlorite is abundant. The phenocrysts consist of euhedral to subhedral laths of plagioclase feldspar and augite crystals. The predominance of labradorite suggests that the rock solidified as vitrophyric basalt, which has since devitrified. The pyroxene crystals show varying stages of alteration; some are partly altered to uralite, others are completely replaced by chlorite	1,780

	Height above base of section (feet)
Intensely altered flow rock. Petrographic description (sample 54 AKe 26) : A porous light-gray porphyritic rock containing many light-colored feldspar phenocrysts as much as 2 mm in size. The groundmass comprises a cryptocrystalline mass of quartz(?) and secondary quartz. The feldspar phenocrysts are partly altered to sericite, and those that are identifiable are in the labradorite part (An_{70}) of the plagioclase series. Abundant chlorite (penninite?) and vein quartz fill many of the cavities and seams. Magnetite crystals are abundant. The rock may have solidified as andesite or, as is indicated by the plagioclase, vitrophyric basalt, but alteration makes positive identification impossible	1,450
Volcanic flow rock. Petrographic description (sample 54 AKe 27) Dense medium-gray porphyritic rock containing many small (1 to 2 mm) feldspar and pyribole phenocrysts. Microscopically the groundmass is seen to consist of a glassy base containing many needlelike microlites. Some of the microlites are arranged in subparallel flow patterns about the phenocrysts. The plagioclase phenocrysts, predominantly in the labradorite range of the plagioclase series, are relatively fresh and unaltered. Many of the plagioclase crystals are zoned. Euhedral to subhedral phenocrysts of pyroxene are abundant. These crystals have undergone varying degrees of alteration, with uralite and chlorite replacing the pyroxene. Magnetite grains and limonite staining are present throughout the rock, which is vitrophyric basalt	1,350
Altered flow rock. Petrographic description (sample 54 Aka 28) : Megascopically a dense light-gray-green porphyritic rock containing abundant white phenocrysts (1 to 3 mm). Microscopically the groundmass consists largely of cryptocrystalline quartz. Many former feldspar crystals are indicated by lathlike crystal outlines now enclosing cryptocrystalline quartz and calcite. One incompletely altered andesine phenocryst was seen in the thin section. Small amounts of epidote and chlorite, probably derived from pyroxene, are present. Approximately 20 percent of the rock consists of chlorite (penninite and ripidolite(?)) veins. A few pyrite cubes are also present	1,250
Altered extrusive rock. Petrographic description (sample 54 AKe 29): Mottled gray-green rock containing many small (0.1 to 1 mm) white phenocrysts. The groundmass consists of secondary crystalline and cryptocrystalline quartz, chlorite, and shreds of sericite. The original phenocryst minerals have been entirely replaced, with only partial crystal outlines (as much as 0.5 mm in size) remaining. Uralite, chlorite, and epidote represent former ferromagnesian minerals, and patches of sericite and calcite may be alteration products of former feldspar minerals	350
Altered extrusive rock. Petrographic description (sample 54 Ake 31): Very similar to sample 54 AKe 29. Alteration is more complete, with the groundmass composed entirely of secondary quartz and chlorite. No distinct crystal outlines are present, but aggregates of sericite, quartz, chlorite, and calcite probably are alteration products of former feldspar and ferromagnesian minerals	300

	Height above base of section (feet)
Altered extrusive rock. Petrographic description (sample 54 AKe 32): Dense mottled light- to dark-gray rock. The groundmass is a chloritized aggregate of cryptocrystalline quartz, sericite, and calcite. There are no distinct phenocrysts, but aggregates of sericite indicate the former presence of feldspar minerals. Chlorite, with vague but discernible boundaries, indicates the former presence of some mafic minerals. Vein quartz and calcite are common, and limonite is disseminated throughout the rock	220
Altered volcanic flow rock. Dense medium- to light-gray aphanitic rock. Petrographic description (sample 54 AKe 21): The groundmass has the appearance of cryptocrystalline devitrified glass containing many microlites which compose about 20 percent of the groundmass. Fractured and altered phenocrysts of plagioclase are common and average 0.4 to 0.6 mm in size. Those identified fall in the andesine-labradorite part of the plagioclase series. A few scattered phenocrysts of former ferromagnesian minerals are completely altered to chlorite. Magnetite dust and accessory pyrite are present	50
Altered volcanic flow rock. Petrographic description (sample 54 AKe 33): A dense brownish-gray rock containing many small dark elongate phenocrysts as much as 3 mm in length. The rock has been completely altered. The groundmass is composed of a fine mosaic of cryptocrystalline quartz with interspersed calcite aggregates. Phenocrysts of schorlite indicate the former presence of feldspar minerals that have been altered by hot acid solutions. Small amounts of vein quartz and chlorite are present, and pyrite and limonite are accessory minerals	0

The unit mapped as undeformed volcanic rocks (pl. 29) was not examined by the authors in the field. Differentiation of the unit is based in part upon examination of vertical photographs and in part upon the field notes of Werner Juhle and Ronald Kistler. The unit consists predominantly of flows of Quaternary age, but locally may include volcanic rocks of Tertiary age.

TUFF

Delineation of the tuff unit (pl. 29) is based on aerial reconnaissance of the area and examination of vertical aerial photographs. The emplacement of this thick tuff deposit prior to the 1912 eruption of Mount Katmai has been discussed in great detail by Griggs (1922) and Fenner (1923) as volcanic sandflow. In addition, summary statements concerning this tuff deposit are presented by Curtis, Williams, and Juhle (*in* Luntey and others, 1954, p. 55–59).

SURFICIAL DEPOSITS

Surficial deposits in the Katmai area are predominantly alluvial gravel and glacial moraine and gravel, but locally some ash and pumice deposits are exposed and a few small beach deposits may be seen along the shore. Individual lateral, terminal, and recessional moraines are shown on the geologic map (pl. 29); other surficial deposits, including alluvial and glacial gravel, ash and pumice deposits, and beach deposits, are shown on the map as undifferentiated surficial deposits.

INTRUSIVE ROCKS

JURASSIC AGE

Within the area mapped, intrusive rocks of Jurassic age crop out in a northeastward-trending belt 3 to 20 miles wide. The igneous body, which is of batholithic proportions, has been mapped in the Iliamna region to the north (Martin and Katz, 1912, pl. 2), and as far south as Becharof Lake (Smith, 1925, pl. 4). In the Katmai area the intrusive body abuts the Naknek formation in fault relationship, and northwest of the fault it is overlain by layered volcanic rocks that are, in part, of Eocene age. The intrusive rocks cut the rocks older than Middle Jurassic in the vicinity of Kulik Lake.

These intrusive rocks are variable in composition but consist predominantly of hornblende and biotite granite. Megoscopically the granite is light gray to pink. Along the southeast margin of the intrusive body the rock becomes darker and more mafic in composition.

The exact age of the intrusive rocks cannot be postulated on the basis of their relationships with sedimentary units in the Katmai area. They are probably older than the Naknek formation, inasmuch as boulders of hornblende granite, probably derived from these rocks, occur as detritus within the Chisik conglomerate member of the Naknek formation. In the area adjoining the Katmai area on the north, Mather (1925, p. 166–167) notes that the intrusive rocks probably cut the Tuxedni formation of Middle Jurassic age. He further states (1925, p. 167) that

> The granitic rocks in this and adjacent portions of the Alaska Peninsula are the results of several intrusions closely associated in time, but distributed at intervals throughout the Lower and Middle Jurassic epochs.

Mather's work is the basis for the age which the authors have assigned to these rocks.

TERTIARY AGE

In many localities in the area, dikes and sills of Tertiary and Tertiary (?) age have intruded the beds of the Naknek and Kaguyak formations, which generally have low dips. Smith (1925, p. 198), quoting notes of Fenner, reports "* * * many generally horizontal or gently inclined intrusions of hornblende andesite cutting the sedimentary rocks * * *" in the vicinity of Mount Katolinat. In addition, many dikes and sills, presumably of the same composition as those that intrude the sedimentary rocks at Katolinat, are present in the mountains at the headwaters of Gertrude and Takayoto Creeks and in the mountains northeast of Lake Grosvenor. In the latter area the upper several hundred feet of the mountain appears to be composed of sills. In addition, intrusive rocks of Tertiary age are known to be present in the vicinity of Geographic Harbor and Kukak Bay and along the fault south of Hallo Bay; and the crest of the Kamishak anticline is reported "* * * to be intruded by a quartz-diorite stock of post-Cretaceous age" (Hazzard, Bryan, and Borax, 1950, p. 2377).

Three samples of intrusive rocks of Tertiary age were collected by the authors; the descriptions follow:

Quartz gabbro intruding the fault at Cape Nukshak (sample 54 AKe 37). Megascopically a light-colored phaneritic rock. Crystals of quartz, feldspar, and pyribole minerals are easily distinguished with a hand lens. Microscopically the rock is hypautomorphic and equigranular. The crystals average about 2 mm in size. Free quartz constitutes more than 5 percent of the rock. The feldspar is predominantly labradorite. A few of the feldspar crystals are partly epidotized. Pyroxene (augite) is altering to amphibole and chlorite. Accessory minerals include sphene, zircon, apatite, and magnetite.

Quartz diorite collected on the southeast side of Kukak Bay (sample 54 AKe 18). A light-gray-green phaneritic rock very similar in appearance to sample 54 AKe 37. Microscopically the rock is hypautomorphic and equigranular; it has undergone some alteration. The feldspar crystals average 2.5 mm in diameter. More than 3 percent quartz is present, some as micrographic intergrowths with potash feldspar. These intergrowths surround some of the abundant plagioclase laths that crystallized earlier. The plagioclase minerals are mostly oligoclase and andesine. The mafic minerals have been almost entirely replaced by chlorite, although a few amphibole relicts remain. Sericite replacement occurs along the feldspar fractures. A few crystals of sphene and much pyrite occur throughout the rock as secondary minerals, together with secondary calcite and chlorite.

Quartz diorite collected on the southeast shore of Kukak Bay (sample 54 AKe 20). A light-gray phaneritic rock spotted with dark-green pyribole minerals. Microscopically, a hypautomorphic granular rock with grains averaging 1.5 mm in diameter. The feldspar grains are mostly alkalic. Crystals of hornblende are fairly common and are in various stages of alteration, from comparatively unaltered to completely chloritized. A few magnetite grains are present.

STRUCTURE

STRUCTURAL FEATURES

The major structural feature in the area is a northeastward-trending fault that extends from the Kamishak River to Contact Creek, and is particularly well exposed about 2 miles northeast of Lake Grosvenor. This fault of presumed Tertiary age, upthrown on the north side, juxtaposes intrusive rocks of Early and (or) Middle

Jurassic age with the sedimentary rocks of the Naknek formation. It is the southwestward extension of the Bruin Bay thrust of the Kamishak area (Hazzard, Bryan, and Borax, 1950, p. 2377), and it has been inferred (Gryc, Miller, and Payne, 1951, fig. 5) to extend northward beyond Chinitna Bay and at least as far south as Becharof Lake (Smith, 1925, pl. 4). Within the mapped area, the fault generally has a steep dip.

Northwest of the fault, volcanic rocks of Tertiary age dip gently and monoclinally toward Bristol Bay. Southeast of the fault the regional southeasterly dip is interrupted by reversals, and, locally, gentle folds have developed within the sedimentary and volcanic sequences. Seven anticlines, all of which trend northeastward and in general plunge southwest or northeast toward the central part of the area, were mapped. No marked asymmetry is evident in the anticlines, although the south flank of the Kamishak anticline is slightly steeper than the north flank. This anticline, the largest in the area, extends from the Savonoski River to the north margin of the map area and beyond, to Kamishak Bay, and plunges southwest where it apparently dies out at the Savonoski River.

Two small anticlines lie between Kejulik Pass and Kaguyak Crater. Most of the southwestern anticline is in volcanic rocks and lies along the trend of the chain of volcanoes between Martin Mountain and Mount Katmai. It is delineated by dips in the flanking Naknek formation. The northeastern anticline, southwest of Kaguyak Crater, has the same general alinement. The two anticlines apparently do not connect, although they trend toward each other. Another anticline lies south of Topographers Peak, and three are formed in the volcanic rocks along the shoreline of Shelikof Strait. All four of these structures plunge northeast.

The three synclines that have been mapped in the area have gentle flanks. The largest syncline extends from Gas Creek to Kukak Bay and is for the most part in volcanic rocks.

In addition to the fault that transects the area from Little Kamishak River to Contact Creek, smaller faults are present. The largest of these is a westward-trending fault, which extends from Cape Nukshak to the volcanic spine of the Aleutian Range. Direction of throw on this fault is questionable. If, as it appears on vertical photographs, the volcanic beds on the north side of the fault are correlative with the volcanic rocks that overlie the Kenai formation on the south side, then the south side is upthrown relative to the north side.

The volcanoes of the region, as already noted, are in northeasterly alinement. This alinement strongly suggests that the volcanic chain is structurally controlled. Surface outcrops, however, offer little evidence as to the nature of the control. The most reasonable assumption is that the two anticlines that are alined along the trend of the volcanoes are the manifestations of a deep-seated fault, and that the magma presumably followed zones of weakness not apparent in the surface outcrops of the Naknek formation.

AGE OF THE FOLDING AND FAULTING

It appears that there has been but one interval of major deformation since deposition of the Naknek formation, and the authors believe that this deformation probably occurred after Eocene and before Quaternary times. No angular unconformities are apparent between the formational units younger than Late Jurassic or older than Eocene. However, there is a definite angular break between the folded volcanic rocks that interfinger, at least in part, with the Eocene rocks equivalent to the Kenai formation and younger undeformed volcanic rocks that are at least in part Quaternary in age. The authors therefore suggest that only one interval of deformation occurred, and that this was between the deposition of these two volcanic sequences. More precise dating of the folding and faulting is not possible with the present limited information.

HISTORICAL GEOLOGY

Inasmuch as no rocks older than Early Jurassic were studied in the field by the authors, only those events in geologic time since emplacement of the intrusive rocks of Jurassic age are considered in this discussion. These events have been reconstructed on the basis of the lithologic character of the rock units, their depositional relationships, their ages as established by the identification of the fossil lots by Imlay and Brown, and the structure in the map area.

The emplacement of a batholith in Early and (or) Middle Jurassic time and subsequent uplift apparently created a positive land mass from which the arkosic conglomerate and feldspathic sandstone of the Naknek formation were derived. The Naknek formation changes very little anywhere along its strike in the area mapped, and its rocks seem typical of shelf deposits. The high percentage of feldspathic detritus within the formation suggests that the rock unit was deposited fairly close to its source, and the thick conglomerate beds and disseminated plant remains in the upper part of the formation are evidence of minor regressions of the sea in late Naknek time.

A major hiatus, from Neocomian to Santonian time (fig. 45), separates the Naknek and Kaguyak formations, and during the hiatus the Mount Katmai area was probably at base level. There is no apparent angular discordance between the Naknek and Kaguyak formations, and it is therefore unlikely that folding or faulting occurred between them.

During Campanian time the seas transgressed the Mount Katmai area, and the marine lower member of the Kaguyak formation was deposited. The transgression was apparently followed by a gradual regression, and the more littoral middle and upper members of the Kaguyak formation were deposited. Locally, volcanic rocks, in part of Eocene age, directly overlie the Naknek formation, and it therefore appears either that part of the Mount Katmai area was completely emergent during the deposition of the Kaguyak formation or that the Upper Cretaceous rocks were eroded before the Eocene epoch.

By Eocene time part of the Mount Katmai area was completely emergent. The coal-bearing rocks that are equivalent to the Kenai formation are typical of those deposited in lagoons, marshes, or along beaches, and the conglomerate lenses and beds may represent, in part, channel fillings along distributary stream courses. Early Eocene time was also one of volcanic activity, as indicated by the interbedded flows in the sedimentary sequence; it appears that environmental conditions during this period were not very different from those in the Mount Katmai area at the present time. The volcanic activity probably continued intermittently through Tertiary time, and the rocks of the map area were deformed between the Eocene epoch and the Quaternary period. Dikes, sills, and at least one stock were intruded into the sedimentary sequence during or following this deformation. Since the folding and faulting, the topography has been modified further by volcanic and fluviatile deposition and by glaciation and other types of erosion.

PETROLEUM POSSIBILITIES

The rocks of Mesozoic and Cenozoic age in the Mount Katmai area lie in the arcuate belt of the Matanuska geosyncline (Payne, 1955). This geosynclinal belt extends northeastward almost to the Canadian border, and southwest of the Mount Katmai area it parallels the south side of the Alaska Peninsula. Since the early 1900's a number of wells have been drilled in this geosyncline, mainly in the older Jurassic rocks. The closest of these wells to the map area is located about 25 miles south of Katmai National Monument. Up to the time of writing of this report (1956), oil had not been found in commercial quantity, although oil shows had been found in most of the wells.

Petroleum may be present in the map area, for oil and gas seeps have been reported. Martin (1905, p. 138) states that "Seepages have been reported from the shores of Kamishak Bay, especially at Douglas

River," and Smith (1925, p. 206), states that "gas seepages on Gas Creek [at the headwaters of the Kejulik River] * * * occur for about 200 yards along the stream and issue from the loose boulders in its bed." To the knowledge of the authors, the Douglas River seeps have never been verified.

STRATIGRAPHIC RELATIONS

In the Mount Katmai area, 6,000 to 9,000 feet of Upper Jurassic marine fossiliferous rock, comprising arkose, siltstone, and shale, is exposed. The Upper Cretaceous rocks of the map area include 4,500+ feet of marine shale, siltstone, and nearshore sandstone; above this is 830+ feet of predominantly nonmarine sedimentary rocks of Eocene age. The rocks of Late Jurassic age could be both a source of, and reservoir for, petroleum, although in their belt of outcrop the sandstone units of the Naknek formation are tight and generally impermeable. The sandstone units in the middle and upper members of the Kaguyak formation cannot be dismissed as possible petroleum reservoirs. Furthermore the porous permeable sandstone of Eocene age may also, under special conditions, contain petroleum.

Variables are such that it is not possible for the authors to predict the nature and thickness of the sedimentary rocks that might underlie the Naknek formation in the Mount Katmai area. These variables include unconformities as well as possible lateral variations in the rocks older than the Naknek formation. In addition, the southeast extent of the batholith emplaced in Early and (or) Middle Jurassic time can be determined only by geophysical work or by drilling. However, some idea of the sedimentary sequence older than the Naknek formation can be gained by a study of the literature dealing with localities north and south of the Mount Katmai area.

About 30 miles south of the Mount Katmai area, at Puale Bay, rocks of Triassic as well as Early and Late Jurassic age are exposed below the Naknek formation. Kellum, Daviess, and Swinney (1944, fig. 2) mapped 2,250 feet of rocks of Late Triassic age at this locality; these rocks consist predominantly of thin-bedded limestone interbedded with sandstone and calcareous shale. Kellum, Daviess, and Swinney show a sequence of rocks of early Jurassic age that overlies the rocks of Triassic age and consists of about 1,050 feet of interbedded tuffaceous sandstone and limestone overlain by about 1,270 feet of rocks that are mostly shale. At Puale Bay, rocks of Middle Jurassic age are missing (Imlay, 1952, chart 8–C), and at least 5,000 feet of conglomerate, sandstone, and shale (Smith, 1925, p. 196–197) of the Shelikof formation of late Jurassic age overlies the rocks of

Early Jurassic age and underlies the Naknek formation. Smith (p. 196) states that "the formation apparently decreases in thickness toward the east from the head of Cold Bay [now Puale Bay], and some of the massive sandstone beds change laterally into shale."

At Ursus Cove, about 30 miles north of the Mount Katmai area, Martin and Katz (1912) mapped a sequence of Late Triassic age (the Kamishak formation) which is probably correlative with the Triassic sequence at Puale Bay, and they stated (p. 48) that it "probably exceeds 2,000 feet and may be much greater." They described the sequence as consisting of chert interstratified with thinner beds of limestone, shale, and sandstone. About 70 miles north of the Mount Katmai area, west of the peninsula between Iniskin and Chinitna Bays, Hartsock (1954) mapped a thick sequence of volcanic breccia, lava, and andesitic tuff of Early Jurassic age, which overlies Triassic rocks. At this same locality the volcanic rocks are overlain by the Tuxedni formation of Middle Jurassic age; this includes 8,000 feet or more of generally tight sandstone, siltstone, and shale (Kirschner, and Minard, 1949; Imlay, 1952; and Hartsock 1954). Overlying the Tuxedni and underlying the Naknek formation is the Chinitna formation, which Kirschner and Minard (1949) state "consists of approximately 2,000 feet of arenaceous siltstone" and which Imlay (1952) believes is correlative with the Shelikof formation at Puale Bay.

The comparison of the rocks south and north of the Mount Katmai area is shown on figure 46. The occurrence of petroleum in these older rock units appears to be most likely in the rocks of Late Triassic age; these may lie as deep as 15,000 feet below the base of the Naknek formation in the Mount Katmai area, if judged by the thicknesses of the older rock units to the south and to the north.

STRUCTURAL RELATIONS

The authors do not rule out the possibility of producing oil from structural and stratigraphic traps in the Mount Katmai area, but believe that in general the area is not very promising. The area has been subjected to intense igneous activity, and it is unlikely that favorable petroleum strata can be reached at practical drilling depths on most of the structures that could be drilled.

Seven anticlines and one major reverse fault are present in the map area. The largest anticline is the Kamishak, which the authors believe to be a closed structure on the basis of Mather's map (1925, pl. 3) and their fieldwork. However, there are two drawbacks to drilling this anticline. It has been intruded at the crest by a quartz diorite stock (Hazzard, Bryan, and Borax, 1950), and the depth to

System	Series	Puale Bay After Imlay (1952), Kellum, Daviess, and Swinney (1944), and Smith (1952)	Ursus Cove and Iniskin Peninsula After Hartsock (1954), Imlay (1952), Kirscher and Minard (1949), and Martin and Katz (1912)
Jurassic	Upper	Naknek formation	Naknek formation
		Shelikof formation 5000 feet Conglomerate, sandstone and shale	Chinitna formation 2000 feet Arenaceous siltstone
	Middle	Not represented	Tuxedni formation 8000+ feet Impermeable sandstone, siltstone, and shale
	Lower	Unnamed formation 1270 feet shale 1050 feet tuffaceous sandstone and limestone	Unnamed formation Thickness unknown Volcanic breccia, lava, and andesitic tuff
Triassic	Upper	Unnamed formation 2250+ feet Thin-bedded limestone, sandstone, and calcareous shale	Kamishak formation 2000+ feet Chert, limestone, shale, and sandstone

FIGURE 46.—Comparison of Naknek and older formations south and north of the Mount Katmai area.

a potentially favorable stratum may be beyond the limits of a practical drilling test.

The two anticlines that transect the central part of the map area are closely related to the alinement of the volcanic chain, and are probably a reflection of the deep-seated structural control of this alinement. If they are, the chances of producing oil from either of the two are not good.

The anticline south of Topographers Peak, the one that cuts Dakavak Lake, and the one between Katmai Bay and Geographic Harbor, all plunge northeast. The authors have not studied these anticlines in detail, but it is their opinion that none are closed structures.

The authors are not prepared to say whether the anticline that lies between Kinak Bay and Kaflia Bay is a closed structure. It is formed in dense volcanic rocks that may overlie rocks of Cretaceous age as well as Jurassic age, and although the thickness of the volcanic sequence is not known, the older rocks, which cannot be ruled out as possible oil reservoirs, may be within drilling depth. However, the fieldwork of the authors was not detailed enough to rule out the possibility that the anticline has been intruded by igneous rock.

The reverse fault that extends from the Little Kamishak River to Contact Creek is the largest structural feature in the area. No potential drilling sites are readily apparent along this fault, although the strikes of the Naknek formation south of Yori Pass, south of Angle Creek, and west of Kejulik Pass, indicate that there may be closure against the southeast side of the fault along Contact Creek. The intrusive body that lies along the northwest side of the fault is presumed to be of Lower and (or) Middle Jurassic age, and if it is, it may underlie the Naknek formation on the southeast side of the fault. If it does, the chances of striking a petroleum bearing zone in a drill test near Contact Creek are not good.

As already noted, Smith (1925, p. 206) reported gas seeps "along a fault at Gas creek." The seeps were not visited by the authors, and their source and nature are not known. Possible drilling sites could not be delineated from vertical photographs of this vicinity.

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