MINERAL RESOURCES OF THE KAMISHAK BAY REGION

By Kirtley F. Mather

INTRODUCTION

Kamishak Bay is a broad indentation at the north end of the Alaska Peninsula, near the mouth of Cook Inlet, at the northeast end of Shelikof Strait. The area surveyed in the exploration upon which this report is based includes the entire shore of the bay, except its extreme southeastern portion, and extends westward about halfway across the peninsula. It includes much of the previously unmapped country south of Lake Iliamna and north of the Katmai National Monument.

As thus defined, the Kamishak Bay region lies between latitude 58° 20′ and 59° 20′ north and longitude 153° 35′ and 154° 45′ west. It includes about 2,500 square miles, as indicated on the accompanying map (Pl. III). A more complete report with topographic and geologic maps will be published later.

Field studies in this region were made during the summer of 1923 by a party consisting of R. H. Sargent, topographic engineer in charge; K. F. Mather, geologist; and four assistants and camp hands. The party landed at Iliamna Bay on June 16. Geologic and topographic mapping of the area was completed on August 28, when a junction with another party in charge of R. K. Lynt, topographic engineer, and W. R. Smith, geologist, was effected near the mouth of Savonski River. The two parties reached Kanatak on September 9 and sailed from Kodiak on September 23. The primary aim of the expedition was to make a reconnaissance map of previously unexplored territory. The short time available and the necessities of travel through a region whose major geographic features were unknown made it impossible to extend the geologic work to certain localities where essential data might have been obtained. For this reason most of the geologic boundary lines indicated on the accompanying map are generalized.

Although not far removed from customary routes of travel, the Kamishak Bay region is really very inaccessible. There are no docks or regular ports of call within or near the mapped area. The several bays are notably poor harbors, unprotected from the fierce winds that accompany the numerous storms along this coast, and many of them are so situated that entry or exit is safe only during times of comparative calm. As a rule, the large passenger boats that ply between Seattle and the head of Cook Inlet and Kodiak Island will put in at Iliamna Bay to discharge and take on passengers. Here they drop anchor a mile or more from shore, and the transfer must be made in small boats. The journey between Seattle and Iliamna Bay occupies about 10 days.

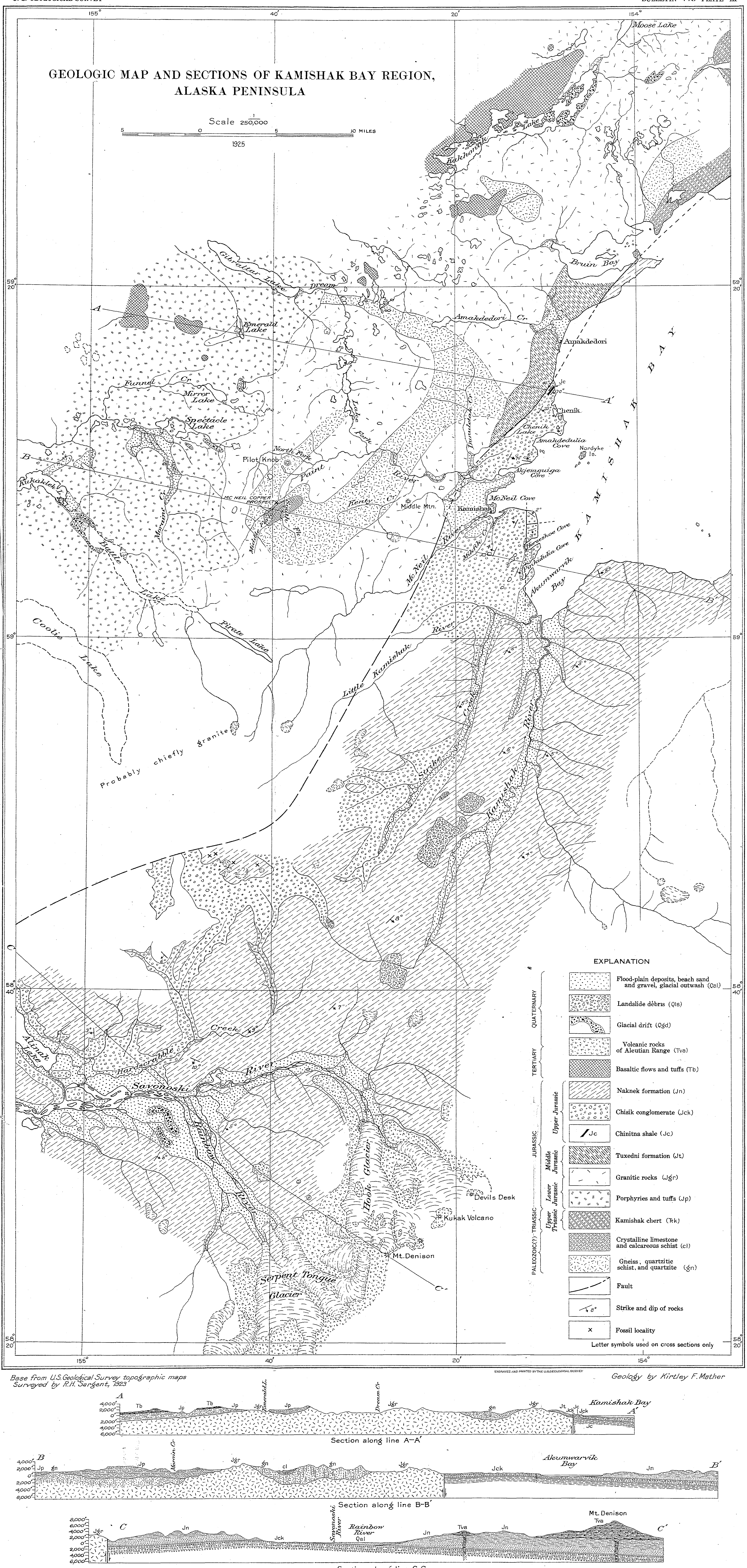
Kamishak Bay has never been adequately charted, and none of the larger passenger ships will enter, although it is stated that there is good anchorage in the lee of the Nordyke Islands. Small gasoline-propelled launches are accustomed on occasion to cross the inlet from Seldovia and at high tide enter McNeil Cove, near the head of Kamishak Bay. Seldovia is 90 miles from McNeil Cove and is a regular port of call for all steamers entering Cook Inlet. About seven or eight days is required for the journey from Seattle to Seldovia. It is also possible to obtain motor-boat transportation from Kodiak, about 100 miles from Kamishak Bay and 10 or 12 days' journey from Seattle.

The region under discussion is almost entirely uninhabited. Charles McNeil occupies a comfortable log cabin near the mouth of McNeil River. No other white man lives within the area shown on the accompanying map, although there are white residents a few miles north of its boundary, at the head of Cottonwood Bay and at Iliamna village. One family of Aleut natives lives at Chenik, and two families occupy cabins at Amakdedori.

PHYSIOGRAPHY

Topography.—The coast of this portion of the Pacific Ocean is deeply embayed and very irregular. Ursus Cove and Bruin Bay are fiords from whose shores the land rises steeply to mountainous heights. Although made irregular by many coves and other indentations, the southwest shore line of Kamishak Bay fringes lower and less rugged land. The mountains there are distant 2 or 3 miles from the strand.

The half of the Alaska Peninsula that is nearer the Pacific Ocean than Bering Sea consists of rugged mountains rising to altitudes of 3,500 to 4,500 feet near the south end of the Chigmit Range. These mountains are maturely dissected by numerous streams and everywhere display the results of strong glacial action. The multitude of lakes and ponds west and northwest from Kamishak Bay constitute the most obvious result of glaciation but are no more impressive than the many U-shaped valleys in which the intertributary spurs have been truncated by ice.


GEOLOGIC MAP AND SECTIONS OF KAMISHAK BAY REGION, ALASKA PENINSULA
Scale 1/250,000
5 0 5 10 MILES
1925
EXPLANATION
QUATERNARY
Flood-plain deposits, beach sand and gravel, glacial outwash (Qal)
Landslide débris (Qls)
Glacial drift (Qgd)
TERTIARY
Volcanic rocks of Aleutian Range (Tva)
Basaltic flows and tuffs (Tb)
JURASSIC
Upper Jurassic
Naknek formation (Jn)
Chisik conglomerate (Jck)
Chinitna shale (Jc)
Middle Jurassic
Tuxedni formation (Jt)
Lower Jurassic
Granitic rocks (Jgr)
Porphyries and tuffs (Jp)
TRIASSIC
Upper Triassic
Kamishak chert (Ѣk)
PALEOZOIC(?)
Crystalline limestone and calcareous schist (cl)
Gneiss, quartzitic schist, and quartzite (gn)
Fault
Strike and dip of rocks
Fossil locality
Letter symbols used on cross sections only
Kamishak Bay
Bruin Bay
Amakdedori
Chenik
Nordyke Is.
McNeil Cove
Kamishak
Horseshoe Cove
Akumwarvik Bay
Gibraltar Lake
Emerald Lake
Mirror Lake
Spectacle Lake
Kukaklek L.
Battle Lake
Pirate Lake
Coolie Lake
Moose Lake
Kakhonak Lake
Pilot Knob
Middle Mtn.
MC NEIL COPPER PROSPECT
Paint River
McNeil River
Little Kamishak River
Kamishak River
Strike Creek
Probably chiefly granite
Hardscrabble Creek
Savonoski River
Rainbow River
Hook Glacier
Serpent Tongue Glacier
Devils Desk
Kukak Volcano
Mt. Denison
Base from U.S. Geological Survey topographic maps
Surveyed by R.H. Sargent, 1923
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY
Geology by Kirtley F. Mather
Section along line A–A'
Section along line B–B'
Section along line C–C

West and northwest from the long belt of mountainous country the surface drops abruptly away to the lowlands that border Bristol Bay. Here the relief is slight, and there are few hills more than 400 feet in altitude. Several large lakes occupy the deeper depressions of the undulating plain. Among these Kukaklek Lake is the only one within the area surveyed by this expedition, although Iliamna Lake borders the area on the north.

The southeast margin of the Kamishak region encroaches upon the northwest flanks of the Aleutian Mountains, which extend in a broad arc as a line of snow-capped and glacier-clad peaks from the Katmai National Monument northeastward to Cape Douglas, at the southeast corner of Kamishak Bay. This line of extinct or recently active volcanoes includes Mount Douglas, at the north, with an altitude of 7,000 feet; Four Peaked Mountain, next in line, 6,800 feet; Kukak Volcano, 6,600 feet, still emitting a slender plume of steam from a vent near its summit; Mount Steller, 7,450 feet; and Mount Denison, 7,560 feet, near the extreme south margin of the area.

The largest stream in this region is Savonoski River, which has its sources among the glaciers on the flanks of the Aleutian Range near the south margin of the area and empties into Naknek Lake and thus is eventually tributary to Bering Sea. Next in size is Kamishak River, which flows northward and receives the water of the Little Kamishak just before it debouches into Akumwarvik Bay, at the extreme southwest corner of Kamishak Bay. The only other streams of sufficient size to cause the traveler to worry concerning fords are McNeil River and Paint River, both of which flow in a general easterly direction and enter Kamishak Bay along the west shore.

Climate.—The climate of the region adjacent to Kamishak Bay is not severe, although it is by no means uniformly pleasant. There is abundant precipitation of snow during the winter and of rain during the summer. Except at the higher altitudes frosts are rare between June and September. During the growing season an extremely heavy stand of grass develops, so that meadows and hillsides have a luxuriant mantle of grass 3 to 6 feet tall by the later part of August. Along the shore the beach grass continues to grow even during the winter, so that it is reported to be possible to winter horses and other stock at a few sheltered localities.

The region is almost devoid of trees. Cottonwoods are confined to the valley flats of such rivers as the Savonoski and the Kamishak, and spruce trees grow only near the shores of Lakes Kahkonak and Naknek. Nearly everywhere there is an abundant growth of alders, which form dense thickets on many hillsides. Above an altitude of about 2,500 feet the only vegetation is reindeer moss and similar elements of the tundra flora.

The alders and scanty groves of spruce and cottonwood are sufficient to supply fuel only for preliminary exploratory development. Mine timbers would have to be transported many miles. Fuel for use during a drilling campaign in opening new oil fields must also be imported from other regions. In this connection the presence of coal along the shores of Kachemak Bay near Seldovia is worthy of note.

GEOLOGY

The Kamishak Bay region embraces two sharply defined geologic provinces, separated by a line that follows the major fault plane indicated on the accompanying map (Pl. III) as extending in a general southwesterly direction from a point near the mouth of Bruin Bay to a point near the middle of Alinak Lake. Because of the sharp contrast between these two provinces each will be described as a geologic unit.

NORTHWESTERN AREA

That portion of the Kamishak Bay region to the northwest of the major fault plane reveals geologic features practically identical to those in the Iliamna region,[1] at the north. There are considerable areas of metamorphosed sediments, probably of Paleozoic age, that were intruded by great masses of molten magma, which now appear at the surface over large areas as coarsely crystalline gray granite. The same granite batholiths intrude a thick series of volcanic beds—tuffs, agglomerates, and lava flows—of early Mesozoic age. All these older rocks are cut by a number of dikes, most of which are basaltic. Resting unconformably upon the eroded surface of these older formations there are at many localities patches of bedded volcanic rocks of Tertiary age. These include basaltic lavas and tuffs. Stream alluvium, glacial moraines, and landslide débris are the most abundant products of Quaternary time.

Gneiss, quartzitic schist, and quartzite.—The oldest rocks of this region are highly metamorphosed sediments, which now appear as gneiss, mica schist, and quartzite. They are identical in appearance and composition to similar rocks described by Martin and Katz in their report on the adjacent area at the north. These rocks are admirably exposed in the drainage basin of Paint River near the center of the mapped area. They are likewise crossed by Dream Creek a short distance west of Lake Gibraltar. At that locality

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

they appear at the surface throughout a long, narrow belt of territory which has a general easterly trend and probably curves southward to coalesce with the Paint River area, as indicated on the accompanying geologic map. Another mass of similar quartz-rich metamorphic rock forms the foundation beneath the volcanic ridge which culminates in the Seven Sisters, 7 miles northwest of Bruin Bay. Still another area of similar rocks was noted near the center of the peninsula, between Ursus Cove and Bruin Bay.

These rocks vary greatly in texture and composition from place to place. The coarse-grained varieties are generally light in color and show rather definite gneissoid banding. They are composed of quartz, feldspar, biotite, and hornblende, with minor amounts of various accessory minerals. The banding of these gneisses shows great variability in width, direction, and intensity, with no definite trend.

The finer-textured members of this series are quartzitic and chloritic schists, carrying a minor amount of dark-colored hornblende and feldspar. At places they show a strong resemblance to bedded rocks, and everywhere the schistosity is well displayed. Where crossed by Paint River a short distance above the mouth of Kenty Creek, these schists have a northeasterly strike and a dip of 20°–50° NW. In many places they are cut by stringers, dikes, or irregular intrusive bodies of granite, which is differentiated from the gneiss and schist on the map only where it occurs in large bodies.

The only evidence available concerning the age of these metamorphic rocks is their degree of metamorphism. As stated by Martin and Katz,[2] the evidence seems to indicate that these rocks must belong well down in the Paleozoic or possibly in part below it. They display many characteristics closely comparable to those of the metamorphic rocks of pre-Cambrian age in the Laurentian region of Canada.

Crystalline limestone and calcareous schist.—There is a single area of lime-rich metamorphic rocks near the head of Paint River which is of especial interest because of its relation to the copper properties described below. These rocks are intimately associated with the gneiss and quartzitic schist that surround them. It is possible that they represent merely the higher members of the same series, preserved at this locality because it is approximately in the trough of a great synclinal fold. The series as exposed along the forks of Paint River includes thin-bedded black quartzitic schist, much fractured and with many seams and veins of calcite, which has healed most of the fractures; thin-bedded quartzite of light flesh tint or milky appearance; white crystalline limestone or marble,

[2] Op. cit., p. 32.

which weathers to a yellowish red; and a red calcareous conglomerate, lime indurated and considerably altered by pressure and heat.

These calcareous rocks are so intimately associated with the quartzitic schist and gneiss described above that there can be little doubt as to the accuracy of their reference to the same general terrane. They are therefore presumably of Paleozoic age.

Kamishak chert.—The Kamishak chert, of Upper Triassic age, is typically exposed on the west shore of Kamishak Bay in a long, irregular belt extending northeastward from the southeastern shore of Bruin Bay. This occurrence has been described in detail by Martin and Katz.[3] The formation is in intrusive contact with granitic rocks along the northwest margin of the belt of outcrop. This belt is terminated along the southeast by the major fault plane above referred to.

Porphyries and tuffs.—The western foothills of the mountains west of Kamishak Bay and at least part of the adjacent lowlands are composed of bedded volcanic rocks which are probably the equivalent of the formation described by Martin and Katz[4] as Lower Jurassic (?) porphyries and tuffs. These rocks embrace a great variety of tuffs and flows and include many intrusive sills and dikes. Most of the beds weather to a light-gray or pinkish-gray surface. Characteristically, close inspection shows numerous phenocrysts of lath-shaped white feldspar and irregular grains of greasy or glassy quartz, set in a dense matrix of dark-greenish material. The matrix in some of the rock appears to be chiefly glass but in most of it is an andesitic or basaltic rock. Other beds show abundant crystals of hornblende and a few of biotite occurring as phenocrysts with quartz and feldspar. Most of the beds of this volcanic series are tuffs rather than flows, if the powdery appearance of the matrix gives a correct idea of their origin.

The entire series is distinctly silicic, and most of the porphyries would fall within the range of a latite. There are, however, especially in the upper part of the series, some flows and tuffs that approximate andesite and basalt in composition.

The varying resistance of these flows and tuffs results in the development of slopes composed of successive ledges rising steplike from valley floor to hilltop. The beds display dips of varying amount and direction but rarely pitch at steeper angles than 10°. In general they have a northeast strike and a regional dip toward the northwest. The series of silicic volcanic rocks must be at least 2,500 feet in total thickness. Between Gibraltar Lake and Funnel Creek, where this terrane controls the topographic development, the land is a submaturely dissected plateau. Broad, flat-topped mesas

[3] Op. cit., pp. 47–50.

[4] Idem, pp. 50–59.

are separated by steep-walled canyons. The mesa and plateau summits at many places coincide with the surface of a resistant lava flow.

The relations between this volcanic series and the granite that borders it on the east and southeast are well displayed in the cliff overlooking the landslide mass a mile northeast of Mirror Lake, as well as in the valley of the stream flowing westward from the pass at the head of North Fork of Paint River. At each of these two localities it is clear that the granite is intruded into the volcanic rocks.

The volcanic series appears to rest unconformably upon the eroded surface of the gneiss and schist, which crop out in a small area near the upper end of Kukaklek Lake. The reference of these rocks to the Lower Jurassic is in perfect keeping with all the facts observable in this area.

Tuxedni formation.—The rocks here identified as representing the Tuxedni sandstone consist of a variable series of sediments and extrusive volcanic rocks that forms the shore of Kamishak Bay in the vicinity of Amakdedori, a short distance north of Chenik. As exposed in the cliffs both north and south of the alluvial flat at the mouth of Amakdedori Creek, these rocks include a series of sediments about 500 feet thick, which comprises dark carbonaceous shale, sandstone, grit, and volcanic tuff. Both above and below these clastic beds there are lava flows composed of dense basic rock.

The conglomerates in this formation are generally only a few inches thick and occur at wide intervals among the sandy beds. Most of the pebbles are small, not over 1 or 2 inches in diameter. There is, however, one conglomeratic zone 10 to 20 feet thick in which the boulders are from 4 inches to a foot in diameter. These particular beds appear to be water-laid volcanic agglomerates. The pebbles and boulders scattered throughout this variable formation are chiefly basic volcanic rocks or porphyries; no granite boulders were noted.

Some of the more calcareous beds are crowded with fragments of shells, chiefly pelecypods, with a few belemnites. Most of these shells were mashed and jammed together by the waves while the sediments were being accumulated. At many places throughout the thickness of this formation there are sills and dikes of granodiorite, which in the smaller bodies is somewhat porphyritic.

Where exposed along the shore near Amakdedori these beds dip 40°–60° SW. and in general strike approximately N. 25° W. The exposure in the sea cliff is terminated both north and south of Amakdedori by the major fault plane, which here is inclined at an angle of about 45° NW., so that the beds of the Tuxedni formation with the included intrusive rocks are thrust forward from the northwest upon the younger formations, which form the tip of the peninsula south of Bruin Bay and the shore of Kamishak Bay near Chenik.

The fossils collected from this formation about 2 miles north of Amakdedori have been examined by T. W. Stanton, who has submitted the statement given below. His correlation would place the beds in the Middle Jurassic.

12101. About 2 miles north of Amakdedori, on west shore of Kamishak Bay; collected by K. F. Mather, 1923:

Inoceramus ambiguus Eichwald. Three small specimens.
Grammatodon? sp.
Trigonia sp.
Astarte sp., large form.
Elongate pelecypod resembling a solenid.

This small assemblage of fossils seems to belong to the fauna of the Tuxedni sandstone.

Granitic rocks.—The greater part of that portion of the Kamishak Bay region situated northwest of the major fault plane above referred to is underlain by granitic rocks of considerable diversity. Granite of varied texture and composition, granodiorite, and quartz diorite have not been differentiated on the accompanying map. Their occurrence is an extension of the outcrop area of similar rocks in the south margin of the Iliamna region, between Iliamna Lake and Cook Inlet. The variety of granites and associated rocks falls within the range of the "granitic rocks" described by Martin and Katz.[5]

In general, these rocks are characterized by a light to dark gray color and a wide variety of texture. In the coarse-textured varieties crystals of white feldspar and dark mica as much as half an inch in length are common. Irregular grains of greasy or glassy quartz fill the interstices between the feldspar laths. The coarse-grained granite is generally deeply weathered, and surfaces that not long ago were ice smoothed are now rough and irregular.

Elsewhere the granite is of much finer texture, displaying few crystals more than 2 millimeters in greatest dimension. The mineral composition of the rock is, however, much the same, regardless of the dimensions of individual crystal grains.

These rocks are obviously intrusive into the older formations described above. At some localities the contact between granite and schist is a zone 100 yards or more in width in which the schist is impregnated with stringers and lenses of granite, for the most part in the form of narrow dikes oriented parallel to the planes of schistosity. Ordinarily, such contact zones are places of weakness, marked by gulches or sharp topographic change.

[5] Op. cit., pp. 74–77.

As pointed out by Martin and Katz in their report on the adjacent Iliamna region, these granitic rocks must be in large degree if not entirely of Lower or Middle Jurassic age. It can not be definitely affirmed that the granodiorite sills intruded into the Tuxedni formation are offshoots from the main granite batholith, but that conclusion is a very reasonable one. The large number of huge granite boulders in the Chisik conglomerate, of the Upper Jurassic, may be interpreted to mean that the granitic intrusions had ceased before the end of Middle Jurassic time. In all probability the granitic rocks in this and adjacent portions of the Alaska Peninsula are the result of several intrusions closely associated in time but distributed at intervals throughout the Lower and Middle Jurassic epochs.

Tertiary volcanic rocks.—The western slopes of the Chigmit Mountains north of Kukaklek Lake display a number of isolated remnants of a once very widespread series of basaltic flows and tuffs. Erosion remnants cap the summits of several of the plateaus in the general vicinity of Gibraltar Lake. The jagged ridge west of Bruin Bay, which culminates in the Seven Sisters, is another outlying patch of the same series. The north and west shores of Lake Khakonak are formed in part of similar rocks, which extend thence to the west and northwest for many miles.

These basaltic rocks are in many places porphyritic, with tiny phenocrysts of plagioclase feldspar, augite, and magnetite embedded in a matrix which is generally either microcrystalline or a devitrified glass. On the ridge west of the north end of Lake Khakonak the basaltic flows are underlain by tuffs and thin calcareous sediments, which are evidently the basal members of the Tertiary volcanic series. Everywhere these rocks rest unconformably upon the eroded surfaces of the older terranes.

No fossils were obtained from the basal beds above referred to, but in the neighboring region to the north small collections of fossil plants were found in two localities. As reported by Martin and Katz,[6] these fossils indicate the Tertiary age of the containing beds. Doubtless the basalts of the Kamishak Bay region were contemporaneous with those of similar nature that occur near Iliamna Lake.

SOUTHEASTERN AREA

That portion of the Kamishak Bay region which lies between the major fault plane and the northwestern flank of the Aleutian Range is underlain by sedimentary rocks of Upper Jurassic age. Although these rocks amount to at least 6,000 feet in total thickness, only two formations could be differentiated in the reconnaissance mapping that

[6] Op. cit., pp. 81, 82.

served as a basis for this report. These represent the Chisik conglomerate and the Naknek formation, which are widespread throughout the northeastern part of the Alaska Peninsula and have been described repeatedly by earlier workers in neighboring localities. Strata that appear to underlie the Chisik conglomerate crop out at one locality on the shore of Kamishak Bay, and these beds are tentatively identified as a part of the Chinitna shale.

Chinitna shale.—Rocks that are believed to be the oldest now exposed in the southeastern part of the Kamishak Bay region were observed on the shore of Kamishak Bay 2 miles north of Chenik. At that locality there is a closely compressed anticlinal fold, along the crest of which these rocks are elevated above sea level and in consequence appear in the sea cliff and wave-cut tidal flat.

The strata thus exposed are thin-bedded dark argillaceous shale, including a few thin layers of light-colored limestone. These thin calcareous beds are composed almost entirely of very much elongated lenses, which may be in large part of concretionary origin. They have a distinctly yellowish tinge on weathered surfaces. The inclosing beds of shale reveal no fossils but are evidently very rich in carbonaceous matter. They are generally dark gray or almost black and display fairly regular and closely spaced bedding planes.

The lithologic character of these rocks is apparently identical to that of the upper portion of the Chinitna shale in the Iniskin Bay district, a few miles to the northeast of Kamishak Bay, as described by Moffit.[7] Their relations to the coarse conglomerate of the Chisik formation make it clear that these beds are either beneath the Chisik or included in its basal portion. Somewhat similar beds of shale are known to occur as lenses in the lower part of the Chisik conglomerate near Horseshoe Cove, but the shale at that locality does not contain included beds of lenticular limestone. Again, the thickness of the shale at the locality north of Chenik is much greater than that of any of the shales known to occur within the Chisik conglomerate. All available evidence, therefore, is in harmony with the conclusion that the beds exposed at the crest of the anticline near Chenik are the uppermost layers of the Chinitna shale.

As noted by Moffit, the Chinitna shale is of Upper Jurassic age. It is known to be several hundred feet in thickness and at one locality reaches a maximum of 2,300 feet, but less than 200 feet is exposed on the shore of Kamishak Bay.

Chisik conglomerate.—The west shore of Kamishak Bay from a point 2 miles north of Chenik southward to the mouth of Kamishak River is formed of comparatively flat-lying beds of Chisik conglomerate. The same formation extends far up the valley of Little

[7] Moffit, F. H., The Iniskin Bay district: U. S. Geol. Survey Bull. 739, pp. 123–124, 1923.

Kamishak River and reappears along the upper courses of Strike Creek and other streams that drain the region east and northeast of Alinak Lake.

The Chisik conglomerate is well displayed in the remarkable cliffs that rise sheer from the water's edge to heights of several hundred feet along the shore of the peninsula between McNeil and Horseshoe coves. The rocks here exposed are practically all conglomerate of varying texture and composition. Among the boulders there are specimens of all the various kinds of granitic and metamorphic rocks that now form the mountains west of Kamishak Bay. Some of the boulders and blocks of granite are as large as 8 by 10 by 15 feet. Some are angular and little rounded; others are considerably waterworn. In general the bedding is extremely irregular, and many lenses of sandstone or shale are intercalated with the thicker beds of conglomerate. Two zones of fine-grained thin-bedded blue-black clay shale from 25 to 50 feet in thickness were noted in the headland. These zones are several hundred feet below the top of the formation; each is underlain by coarse conglomerate. One seam of lignite, 2 or 3 inches thick, is exposed in the points on either side of Horseshoe Bay in the midst of the conglomerate beds.

There is abundant evidence that this formation was accumulated in a piedmont coastal strip not unlike that present at the same place to-day. At certain points the shale lenses are much contorted or fill hollows between reefs of conglomeratic débris. In all probability much of the coarser material was supplied by glacial streams issuing from rugged mountains not far distant from the shore. No glacial markings were found upon any of the boulders, but their huge size and angular appearance suggest transportation by other agencies than running water and swift currents.

The entire formation approximates 1,000 feet in thickness. At its top there is a transition zone between it and the overlying Naknek formation. These conglomerates are beyond doubt the equivalent of the beds in the Iliamna region described under this same name by Martin and Katz.[8] These rocks have also been more recently studied by Moffit,[9] who described their occurrence on the peninsula between Iniskin Bay and Oil Bay, about 35 miles northeast of Chenik.

Naknek formation.—Flat-lying beds of the Naknek formation are widespread throughout the drainage basins of Kamishak and Savonoski rivers. This formation was named by Spurr[10] from its occur-

[8] Op. cit., pp. 68–69.

[9] Moffit, F. H., The Iniskin Bay district: U. S. Geol. Survey Bull. 739, pp. 117–132, 1923.

[10] Spurr, J. E., A reconnaissance of southwestern Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 169–171, 1900.

rence in the vicinity of Naknek Lake, a short distance southwest of the area now under consideration. Exposures of the same formation in the Cold Bay district, 120 miles to the southwest, along the Pacific shore of the peninsula, have recently been described by Capps.[11]

Near the mouth of Kamishak River the conglomeratic beds of the Chisik formation blend upward into the basal sandstones of the Naknek, without a marked plane of separation. Successively higher beds in the series show progressively smaller pebbles until the whole displays the texture of a sandstone rather than a conglomerate. These basal Naknek sandstones aggregate 250 to 400 feet in thickness and are grayish-brown arkosic sands, generally poorly cemented in irregular beds of varying thickness, ranging from less than an inch to 1 or 2 feet. They are much cross-bedded, and there are many lenses or laminae containing scattered pebbles, some of which are an inch or more in diameter.

These basal sandstones are overlain by 1,200 to 2,000 feet of brown and gray sandstone of much finer texture, interbedded at short intervals with sandy, nonfissile shale. A characteristically dirty greenish tint is displayed on freshly broken surfaces of the sandstone, but the shale is more commonly grayish drab, much of it with a greenish cast. In the midst of this part of the formation in the Kamishak Valley there are two or three beds, 1 to 3 feet thick, of loose pebbly conglomerate carrying a great variety of pebbles similar in composition to those in the Chisik conglomerate. At similar horizons, as well as higher in the Naknek formation, thick lenses of fairly coarse conglomerate, similar to the basal Chisik beds, were noted in the lower part of the Savonoski Valley. Presumably the thick conglomerates in Mount Katolinat, a short distance southwest of the mouth of Savonoski River, represent the recurrence of similar or equivalent conditions not unlike those which produced the subjacent Chisik conglomerate.

About 2,000 feet above the base of the Naknek formation there are scattered layers of dark bluish-gray limestone which weathers to a rusty yellowish brown. These layers are more or less lenticular and rarely attain greater thickness than a foot or so. The sandstones at about the same level as these beds of limestone are commonly concretionary, certain layers being crowded with calcareous concretions of about the same composition as the limestone beds.

Higher members of the Naknek formation form the divide between the Kamishak and Savonoski drainage basins and make many of the rugged hills in the vicinity of that divide. The great

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[11] Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 739, pp. 101–105, 1923.

variability of the beds is in keeping with the arkosic nature of the sands and the presence of numerous lenses of grit and pebbles. About 4,000 feet above the base of the Naknek formation there is a rather uniform change in composition. Rocks aggregating between 1,000 and 2,000 feet in thickness and occurring above that plane may be described as essentially dark-gray to black nonfissile shale carrying many thin layers of gray sandy shale and many nodules or lenses of very dark limestone. These strata are likewise included within the Naknek formation, which thus attains a thickness of 5,000 or 6,000 feet in this region.

All the beds of the Naknek formation, except possibly the arkosic basal sandstones, carry an abundance of fossils, most of which are shells of a single species of pelecypod, which belongs to the genus *Aucella.* Other pelecypods, as well as belemnites, are, however, not lacking. These fossils indicate the Upper Jurassic age of the formation.

Cenozoic volcanic rocks.—The peaks forming the portion of the Aleutian Range that traverses the southeast corner of the Kamishak Bay region are composed of volcanic rocks. Basaltic lava flows and tuffs of varied composition rest unconformably upon the eroded surface of the Naknek formation. Apparently this locality during Tertiary time was the site of great eruptive activity. Lavas welled up through vents and poured out on the surface. Explosive débris was hurled upward and contributed to the building of volcanic cones. The transfer of lava from its subterranean reservoirs to the surface seems to have been accomplished without notable deformation of the Naknek strata. Numerous dikes cut these sedimentary beds at several localities in and near the line of volcanoes and have altered the older rocks in a narrow zone closely adjacent to the fissures through which the lava moved.

Since the construction of Kukak Volcano, Mount Steller, and Mount Denison these volcanic cones have been deeply sculptured by streams and glaciers. At present the base-level of erosion in this part of the region is several hundred feet below the surface on which the lavas and tuffs were piled. In consequence the upper reaches of Savonoski River and its tributaries expose a considerable thickness of Naknek beds beneath the Tertiary volcanic rocks. While erosion was thus biting deep into the foundations of these mountains volcanic activity was frequently renewed. The later eruptions have occurred at no remote date in Quaternary time. About 12 miles northwest of Kukak Volcano there are volcanic rocks extruded within the valley of Savonoski River, and their base is only slightly above the modern flood plain of that stream. Kukak Volcano itself is still emitting gases that form a slender plume of smoke issuing from a vent near the summit of the mountain.

METALLIFEROUS DEPOSITS

So far as known, deposits of the metalliferous ores in the Kamishak Bay region are confined to the northwestern part of the area mapped. Here the igneous activity has been so intense as to justify expectations of workable deposits of such metals as gold, silver, and copper. On the other hand, the volcanic activity in the southeastern part of the area has evidently been so superficial as to give slight warrant for the hope that any workable deposits of precious or semiprecious metals have been formed there.

At numerous localities near the contact between the granitic batholiths of the Chigmit Mountains and the invaded country rock there is evidence of slight mineralization. Iron and copper sulphide minerals have been noted in sufficient quantity to lead to the opening of several prospect pits. In the basin occupied in part by Mirror Lake there are two or three places from which specimens impregnated with sulphide ores have been collected. The andesitic and latitic lavas exposed in the high cliff overlooking the landslide mass 1½ miles northeast of Mirror Lake are locally shattered and twisted near their contact with the granodiorite, which forms the divide at the head of Funnel Creek. Near that contact the volcanic beds are cut by countless veins of quartz, most of which are very thin but some of which attain a thickness of a few inches. Some of these quartz veins carry considerable pyrite, but nothing was noted that would justify the hope of finding a workable ore body there. Nearer to the shores of Mirror Lake there is a fissure zone extending for at least half a mile from northwest to southeast. It is crossed by several small streams flowing toward the lake. Pyrite and chalcopyrite are abundant in the quartz veins of this fissure zone. The copper content of this mass is, however, very low, and the total volume of copper-bearing rock is probably small.

Metallic sulphides have been introduced near the contact between the Mesozoic volcanic rocks and the granitic intrusions in the area between Battle Lake and Lake Gibraltar in sufficient quantity to raise the hope that a workable ore body may exist somewhere in this part of the Kamishak Bay district. Careful prospecting in that contact zone seems justified. At the same time, experience with such evidences of mineralization indicates that the chances of rich ores are by no means great.

A somewhat similar introduction of sulphide minerals was noted at several localities where the Paleozoic sediments, now gneiss and schist, are invaded by the same granitic intrusions. The quartzitic schist exposed in the basin of Paint River, for example, contains much pyrite. At only one locality, however, did the mineralization appear extensive enough to justify prospecting. That locality is near the head of Paint River and deserves special consideration. It is described below.

The west margin of the mass of calcareous schist and marble near the mouth of Crevice Creek and extending thence northeastward across the south fork of Paint River is cut by many dikes of basalt and granite or granodiorite. The metamorphosed sediments strike N. 40°–75° E. and dip 70°–80° SE. A number of mining claims were located here in 1911. When the locality was visited in 1923 application for patent on five claims had been filed by C. H. McNeil, E. H. Holly, and others. These claims cover an irregular area along Crevice Creek and Paint River and include most of the showings of mineralized rock along the northwest margin of the calcareous sediments. There are a number of prospect pits and one tunnel about 60 feet long from which some ore has been extracted. Most of the workings are badly caved, and many are mere pits in the gossan. The ore occurs in pockets in the metamorphosed sediments in close proximity to the acidic intrusive rocks. Some of these pockets are filled with an irregular mass of very coarse calcite, many crystals of which are 3 to 5 inches in length. Several of these masses of calcite are surrounded by so-called "garnet rock." Generally a belt of rich chalcopyrite ore, a few inches thick, lies near the "garnet rock," with another belt of coarsely crystallized amphibole, possibly actinolite, also a few inches thick, between. The tunnel follows what appears to have been a bed of limestone, now almost completely replaced and altered to schist and ore. It is not very far from a dike of quartz-feldspar porphyry, the widest dike noted in this locality. The dike is about 20 feet wide and extends in a general north-south direction for at least half a mile. Other intrusives in the vicinity consist of more or less irregular masses of diorite, granodiorite, and granite. A ton of ore from this drift was shipped to the smelter at Tacoma, Wash., where it yielded $6.08 in gold, 10.93 ounces of silver, and 18.19 per cent of copper. Unfortunately the workings are not sufficiently extensive to permit any estimate of the size of this ore body. Where exposed in the tunnel and at the surface it is only a few feet in width. Presumably it continues downward along the almost vertical beds of calcareous schist.

Numerous assays from the many scattered workings on these five claims have yielded varying but in general satisfactory amounts of gold, silver, and copper. About 10½ tons of ore sacked from different openings and representing the best material from each has been shipped to the smelter and gave returns of $2.50 in gold and 15 ounces of silver to the ton and 17.55 per cent of copper.

The expense of transportation is prohibitive, even for ore of the high grade indicated by these samples. Much more prospecting must be done before any adequate knowledge concerning the size of the ore body can be gained. Unless there is a much larger ore body than is now apparent, the large investment necessary to reduce transportation costs would scarcely be justified. These workings are 17 miles from the shore of Kamishak Bay. A wagon road 6 miles long has been constructed from the head of McNeil Cove to the mouth of Kenty Creek. Thence a fairly good horse trail leads to a camp site on Paint River a short distance below the month of Crevice Creek. There are no buildings or cabins, nor is timber available for the mine workings. The nearest sources of supply for mine timber are driftwood on the beach, the cottonwoods along Kamishak River, and the spruce timber on the shore of Lake Kakonak.

PETROLEUM

RELATION TO OTHER OIL FIELDS

Search for petroleum is justified in the area of Jurassic sediments throughout much of the southeastern portion of the Kamishak Bay region. This area is midway between the "oil fields" near Iniskin Bay, 50 miles to the northeast, and the Cold Bay district, 120 miles to the southwest. Several years ago attention was called to the possibilities of this area,[12] and in 1922 a large number of claims were staked along the southwest shore of Kamishak Bay and up the valley of Kamishak River for a distance of about 10 miles. No development has been attempted, however, and, so far as known, no detailed geologic work has been done in the area.

OCCURRENCE OF OIL ON ALASKA PENINSULA

Observations made by numerous geologists at many places along the Alaska Peninsula from Chinitna Bay, on the west shore of Cook Inlet, to Chignik Bay, 300 miles to the southwest, make clear the general conditions surrounding the occurrence of oil throughout that area. The sedimentary formations comprise a great thickness of shale, sandstone, conglomerate, and limestone, ranging from Triassic to Upper Jurassic in age. The sequence of these formations on the land bordering the three principal indentations of this part of the Alaskan coast is indicated in the following table:

[12] Martin, G. C., Notes on the petroleum fields of Alaska: U. S. Geol. Survey Bull. 259, p. 138, 1905; Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, pp. 42, 68, 1921.

Mesozoic sediments on north shore of Shelikof Strait and Cook Inlet

Age	Cold Bay district	Kamishak Bay district	Iniskin Bay district
Upper Jurassic.	Naknek formation; sandy shale overlying conglomerate and arkose; 5,000+ feet.	Naknek formation; sandy shale overlying sandstone and arkose; 4,000–6,000± feet.	Naknek formation; sandstone, arkose, and tuff, 3,000 feet; gray shale with sandstone beds, 1,500 feet.
		Chisik conglomerate, 1,000± feet.	Chisik conglomerate, 290 feet.
	Shelikof formation; black shale with limestone lenses, overlying sandstone, conglomerate, and sandy shale; 5,000–7,000 feet.	Chinitna shale; only uppermost 200 feet exposed. Maximum probably 7,000 feet.	Chinitna shale, 2,300 feet.
Middle Jurassic.	Kialagvik formation; sandstone and sandy shale; 500+ feet.	Tuxedni formation; shale, sandstone, grit, and tuff; 500+ feet.	Tuxedni sandstone; sandstone, shale, arkose, and conglomerate; 7,000 feet.
Lower Jurassic.	Calcareous sandstone and sandy shale; 2,300± feet.	Volcanic rocks, porphyritic lavas and tuffs.	Volcanic rocks, porphyritic lavas and tuffs.
Upper Triassic.	Thin-bedded limestone and calcareous shale; 1,000+ feet.	Kamishak chert; calcareous shale and limestone.	

In the vicinity of Iniskin Bay there are a number of oil seepages and showings of oil in test wells, all of which probably come from beds within the Tuxedni sandstone. That formation displays all the prime requisites of beds suitable to serve as a source of petroleum and includes a number of beds that are eminently adapted for reservoirs of oil and gas. The slight thickness of the beds referred to this formation and exposed on the shores of Kamishak Bay presents no striking indications that they, like the typical Tuxedni, may include both mother beds and reservoir rocks for oil. There is, however, nothing known concerning the Tuxedni in the Kamishak Bay region to show that it or closely associated formations could not include such beds. More than likely the southeastern portion of the Kamishak Bay region is generally underlain by Middle Jurassic strata comparable to those in which oil is known to occur near Iniskin Bay. Where exposed on the east shore of Kamishak Bay such strata are in too intimate contact with intrusive rocks to permit any hope that oil may ever be recovered from them. Elsewhere throughout the Kamishak and Savonoski valleys the Tuxedni formation is almost certainly so deeply buried that it is beyond the reach of ordinary drilling operations. Its top is probably between 4,000 and 6,000 feet below the top of the Chisik conglomerate. Horizons equivalent to those which yield oil in the Iniskin Bay district could therefore be reached by ordinary drilling methods only where the drilling could begin at a horizon close to or below the bottom of the Chisik conglomerate.

In the Cold Bay district the Shelikof formation probably contains both mother beds and reservoir rocks. Numerous seepages indicate the presence of oil in commercial quantities at several horizons within the thick series of clastic sediments constituting that formation. Apparently the most favorable conditions are present in the upper 1,000 to 2,000 feet of those beds. This portion of the Shelikof formation is the equivalent of the Chinitna shale of the Iniskin Bay district and is presumably present throughout that part of the Kamishak Bay region which lies on the southeast side of the major fault plane previously described. It is quite probable that certain beds of shale exposed on the apex of a compressed anticline along the shore of Kamishak Bay between Chenik and Amakdedori represent the uppermost strata of this same formation. There is no reason to doubt that it underlies the Chisik conglomerate throughout the Kamishak and Savonoski valleys.

Reservoir beds from which oil may be obtained in commercial quantities may be expected to occur at several stratigraphic horizons ranging from a few feet to many hundreds of feet below the base of the Chisik conglomerate. Such beds would be within 3,000 feet of the surface under considerable parts of the drainage basins of Kamishak and Savonoski rivers.

Oil may be concentrated in commercial pools within these reservoir beds under at least two conditions. Wherever such beds are flexed into doubly plunging anticlinal folds or domes, oil would be expected at or near the highest points of such folds. Again, where these beds are monoclinal, dipping downward in one direction, suitable traps for petroleum migrating through the reservoir rocks might be provided if the sandstones are lenticular. In that case an oil pool might form at the upper margin of a regularly dipping sandstone lens. Obviously, an oil pool localized in that way could not be foretold from surface indications alone. In the present state of the petroleum industry search for oil in the Kamishak Bay region should be confined to those areas in which the rocks are so flexed as to make structural traps for the upward-migrating hydrocarbons. Any doubly plunging anticlinal fold or dome in which the Chisik conglomerate is either exposed at the surface or is known to be present within a few hundred feet of the surface is worthy of prospecting for oil, unless there are unexpected differences between conditions in the Kamishak Bay region and those near Iniskin Bay, toward the northeast, and Cold Bay, at the southwest.

OIL SEEPAGES

During the progress of the field work on which this report is based no seepages of oil were observed in the Kamishak Bay region, but reliable reports were received concerning an oil seepage near Bruin Bay, within the area mapped.

According to C. H. McNeil, there is a small oil seepage about 50 yards off the point at the south side of the entrance to Bruin Bay. Reefs and a wave-cut flat are exposed here at extremely low tides. Mr. McNeil saw the seepage when there was 4 or 5 feet of perfectly still water over the spot. Bubbles of gas came up from the clean sand and, breaking at the water surface, spread a film of oil over a considerable area. The odor of gas and oil was very distinct, and the film of oil, when broken by an oar, quickly came together again. Reference to the accompanying map indicates that the locality referred to by Mr. McNeil is approximately on the crest of the Chenik anticline, if that anticline extends northeastward from the locality at which it disappears beneath the water of Kamishak Bay.

In an earlier publication [13] there have been references to a seepage of oil near the mouth of Douglas River, which empties into Kamishak Bay near Cape Douglas, 15 miles east of the mouth of Kamishak River. No opportunity was afforded for observations in that locality during the field season of 1923. Mr. McNeil states that he searched for this seepage during the preceding summer but was unable to find it. The reports concerning it, nevertheless, seem to be authentic, and it is extremely likely that oil from the strata beneath the Chisik conglomerate reaches the surface at that point.

GEOLOGIC STRUCTURE

Regional structure.—The greater part of the drainage basins of Kamishak and Savonoski rivers is underlain by comparatively flat-lying sediments, described as belonging to the Chisik conglomerate and the overlying Naknek formation. These Jurassic beds occupy nearly all of that portion of the Kamishak Bay region lying southeast of the great overthrust fault. In close proximity to the fault plane the Jurassic strata are crumpled and display varying strikes and dips. Elsewhere these beds dip 4°–8° SE. The major fault, extending from the north shore of Kamishak Bay southwestward to Lake Alinak, has not been studied throughout its length. Near Bruin Bay it is an overthrust from the northwest, and the fault plane is inclined about 45° NW. South of Amakdedori the fault plane is apparently almost vertical. Near Alinak Lake the only observations which the necessities of travel would permit were made from a considerable distance. They gave the impression, however, that the fault plane was there approximately vertical. The first displacement along this fault plane could not have occurred before

[13] Martin, G. C., Notes on the petroleum fields of Alaska: U. S. Geol. Survey Bull. 259, p. 138, 1905.

the end of the Jurassic period and probably took place not long thereafter. Possibly there has been recurrence of this movement in later Tertiary time, although no satisfactory data were obtained concerning that matter.

Anticlinal folds.—The most pronounced anticlinal fold that was noted in the southeastern portion of the Kamishak Bay region may be called the Chenik anticline. It extends in a general northeasterly direction parallel to and in close proximity to the major fault plane. The sea cliff 2½ miles north of Chenik crosses the anticlinal fold obliquely and exposes the strata on both limbs. The anticline is tightly compressed, so that the beds are approximately vertical throughout a width of 100 yards on the very summit of the fold at that point. On either side of the crest of this anticline the dip decreases rapidly, and a few hundred yards to the northwest it has been reduced to 40°. A short distance farther northwest the structure is terminated abruptly against the major fault plane. Similarly toward the southeast the dip decreases, and throughout a zone a quarter of a mile in width the beds plunge downward toward the southeast at angles varying from 50° to 75°. About half a mile from the crest of the fold the strata appear practically undisturbed, although in the vicinity of Chenik it was not possible to determine with accuracy their exact attitude, because of the notably irregular bedding of the conglomerates that crop out there.

The summit of the Chenik anticline brings a series of shales to a position which has permitted them to be exposed in the sea cliff. As indicated on page 168, it is probable that these are the uppermost beds of the Chinitna formation. The limbs and in places the summit of the Chenik anticline are composed of the massively bedded Chisik conglomerate. Where steeply inclined these beds are considerably shattered by numerous small displacements. Many bedding planes show slickensides.

The trend of the Chenik anticline at this locality north of Chenik is N. 35° E. The wave-cut flat exposed at low tide displays the fold continuing in the same direction until it disappears beneath the deeper water east of Amakdedori. If the anticlinal trend were extended northward it would pass just offshore from the point separating Bruin Bay and Kamishak Bay. It is at this locality that an active seepage of oil has been reported. In all probability this seepage represents the leakage from the Chinitna shale, which may be exposed by the truncation of the anticlinal fold by wave erosion at that place.

A second anticlinal fold that may be of great economic importance was observed between McNeil Cove and Akumwarvik Bay and may extend for many miles toward the southwest between the valley of McNeil River and that of Strike Creek. The observed strikes and dips in this locality are indicated on the accompanying map. To this uplift the name Kamishak dome may well be applied. Mikfik Creek is overlooked on the east and south by a long hogback ridge with a dip slope rising from the creek bed to the summit, about 600 feet above and 2 miles distant from the stream. In this dip slope the massive resistant beds of Chisik conglomerate strike N. 25° E. and dip 4° NW. This hogback ridge is abruptly terminated by the vertical cliffs forming the wave-cut headland between McNeil and Horseshoe coves. At the farthest point of this headland the strata appear to dip gently downward toward the northeast, but near Horseshoe Cove there is a gentle dip in a direction a few degrees east of south. Farther south, near the head of Pinkidulia Cove and elsewhere along the valley of Strike Creek, the rocks display the normal regional dip toward the southeast. There is, therefore, a well-defined anticlinal axis trending about N. 25° E. through the rugged hills between Mikfik Creek and Pinkidulia Cove. This anticlinal fold plunges slightly at the tip of the headland near the south side of the entrance to McNeil Cove.

As indicated on the accompanying map, there are two fault planes which cut the Chisik conglomerate in this headland. Each makes a conspicuous linear gulch, eroded along the shattered zone. The beds of Chisik conglomerate do not match across the fault planes, but the variations of these beds are so numerous that it is impossible to tell how much vertical displacement is involved. Presumably these faults are only superficial breaks in the competent and brittle Chisik conglomerate where it was stretched on the crest of the anticlinal fold, and probably they do not continue downward more than a short distance into the underlying incompetent shale.

A few scattered observations on the geologic structure of the region drained by Hardscrabble Creek north of Savonoski River were made, for the most part from a considerable distance. These indicate, however, that there is notable departure from the regional dip at that locality. Apparently there must be a broad anticlinal flexure with its apex somewhere near a point about 12 miles north of the confluence of Rainbow and Savonoski rivers. As indicated on the accompanying map, the strata west of that point dip gently toward the southwest, and those east of it dip gently toward the southeast. It is possible that this structure is not closed on the north, but no observations were made in the considerable strip of territory that intervenes before the major fault plane terminates the Jurassic strata.

Mr. McNeil reports the presence of a broad, gently folded anticline near the mouth of Douglas River, but details concerning it are not now available.

RECOMMENDATIONS

From the facts above set forth it is apparent that much of the southeastern portion of the Kamishak Bay region is underlain by beds that may be reasonably expected to contain oil in commercial quantities. In at least two localities the structure is such as to favor the localization of oil in commercial pools, and at each of these localities the horizons at which the oil would be expected to occur are within reasonable drilling distance of the surface. None of the structural features thus far known are so well adapted to serve as a trap for oil as the Pearl Creek dome, in the Cold Bay district. The Chenik anticline is more closely folded, and the Kamishak dome is much more open than the Pearl Creek dome. Nevertheless, each of these two folds is worthy of careful consideration. Further detailed studies may well reveal localities along the summits of these anticlinal folds where conditions are much better than those already observed. Such detailed study, by competent geologists, ought certainly to precede the selection of any drilling sites in the Kamishak Bay district.

The steep inclination of the limbs of the Chenik anticline is not believed to indicate a sufficient intensity of regional stress to have destroyed the hydrocarbon content of the underlying rocks. Rather, the most unfavorable feature of this closely crumpled fold is that the territory from which the oil might migrate to its crest is thereby reduced to a comparatively slight area. On the other hand, the gentle slopes on the flanks of the Kamishak dome permit the gathering of oil in subterranean reservoirs from a considerable area, extending westward nearly or quite to the major fault plane and eastward far beyond the Kamishak Valley. These gentle dips are obviously very much greater than the minimum required for the concentration of oil in many other oil fields, but it is not yet known that they are adequate to cause oil migration in these particular Jurassic rocks. In all probability, experience in and near the Pearl Creek field of the Cold Bay district will ere long provide data from which definite conclusions may be drawn as to the efficiency of the Kamishak dome in this regard.

It would seem advisable at present to delay the drilling of any test wells in the Kamishak Bay region until the practically ideal structure in similar rocks in the Cold Bay district has been adequately tested. Should the drilling operations in that district reveal the presence of considerable quantities of oil, the conditions under which the oil occurs there may soon be deduced. A knowledge of those conditions ought greatly to reduce the chances of failure in the Kamishak Bay region. Should the Cold Bay district prove to contain valuable oil fields, the drilling of test wells in the Kamishak Bay region would certainly be justified and may confidently be expected.

Before drilling sites are finally selected, there should be careful detailed geologic studies to determine with accuracy the limits and conditions of the anticlinal folds to which attention has above been called. From present knowledge it may be expected that favorable drilling sites will be found on the summit of the Chenik anticline north or west of Chenik and on the apex of the Kamishak dome between Mikfik Creek and Horseshoe Cove.

THE COLD BAY-KATMAI DISTRICT

By Walter R. Smith

INTRODUCTION

Location and area.—The following report is a brief account of the general geologic and geographic features of the country extending from the north side of Cold Bay to a point a few miles east of Naknek along Savonoski River, Alaska Peninsula. The district is bounded on the southeast by Shelikof Strait between Cape Kekurnoi and Kashvik Bay; inland toward the west investigation was carried as far as Becharof and Naknek lakes, including the northwest half of the Katmai National Monument. The maximum north-south extent of the district is 60 miles, and the greatest width is about 40 miles. The area mapped during the field season of 1923 is approximately 1,200 square miles and lies between meridians 154° 50′ and 156° west and parallels 57° 40′ and 58° 35′ north, except the Severnson Peninsula in Becharof Lake. The district is in about the same latitude as Juneau, Alaska.

Previous surveys.—Parts of the district as outlined above had been surveyed and were rather well known prior to 1923. However, since Alaska came into the possession of the United States, in 1867, little surveying had been done in this district until 1921. The shore line between Cape Kekurnoi and Kashvik Bay is still uncharted, although some of the bays along the southeast side of the Alaska Peninsula have been charted in recent years by the United States Coast and Geodetic Survey.

General descriptions of the physiography of the Alaska Peninsula with reference to the Katmai district are given by Petrof,[1] Atwood,[2] and others. Geologic observations were made by Spurr[3] in 1898 along the trail from Naknek Lake to Katmai Bay. The report of this trip across Katmai Pass contains the first information regarding the geology of the district. During the summer of 1904

[1] Petrof, Ivan, Report of the population, industries, and resources of Alaska: Tenth Census, vol. 2, 1884.

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

[3] Spurr. J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 59, 1900.

Stanton and Martin[4] made a geologic survey along the southeastern coast of the Alaska Peninsula, from Cook Inlet to Unga Island, with observations along the shore line of the district herein considered.

Renewed interest in the district was caused in 1912 by the great volcanic activity of Mount Katmai and vicinity. However, the volcanic area was not entered until 1915, when a party sent out by the National Geographic Society to study the effect of the ash fall upon vegetation discovered the Valley of Ten Thousand Smokes. Since that time four other expeditions sent out by the National Geographic Society and also investigators from the Geophysical Laboratory have gone into the region. The results of these expeditions, including a topographic map of the Katmai National Monument, have been published in various magazines, scientific papers, and a book, "The Valley of Ten Thousand Smokes," to which reference is made elsewhere in this report.

A stratigraphic section was measured along the north shore of Cold Bay by Capps[5] in 1921, and the following year a United States Geological Survey party[6] extended topographic and geologic mapping farther north into the Kejulik River valley. Independent examinations of possible oil lands have been made during the last four years in the country adjacent to Cold Bay, including the lower Kejulik River valley, by geologists representing western oil companies. Very little was known of the character of the country between the upper part of Kejulik Valley and Naknek Lake prior to 1923.

Present investigation.—The expedition of 1923 in the Cold Bay-Katmai district, in charge of R. K. Lynt, topographic engineer, was one of a series begun by the United States Geological Survey in 1921 to make a topographic map and to investigate the mineral resources of Alaska Peninsula. During the field season of 1922 the work was carried southwest from Wide Bay to Chignik and north from Portage Bay to Kejulik River. In 1923 the investigation began at Cold Bay and was extended north by Mr. Lynt's party until met by a party conducted by R. H. Sargent, topographic engineer, working southwest from Iliamna Lake. The party traveling north consisted of R. K. Lynt, chief of party; C. S. Franklin, recorder; the writer, geologist; and three camp hands. C. N. Fenner, of the Geophysical Laboratory, and Charles Yori accompanied the party as far as Cold Bay and also on the return trip from the Valley of

[4] Stanton, T. W., and Martin, G. C., The Mesozoic section on Cook Inlet and Alaska Peninsula; Geol. Soc. America Bull., vol. 16, pp. 391–410, 1905.

[5] Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 739, pp. 90–91, fig. 5, 1923.

[6] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924.

Ten Thousand Smokes. Transportation in the field was supplied by 15 pack horses.

The party sailed from Seattle on board the steamer *Admiral Evans* May 24 and arrived at Kanatak, Portage Bay, June 5. The horses were taken overland while the field equipment and provisions were taken by power boat to the head of Cold Bay. From this point Mr. Fenner and the packers set out immediately for the Valley of Ten Thousand Smokes, traveling up the east side of Kejulik Valley. A pass was found across the Kejulik Mountains, and the Katmai district was entered from the west. Upon the return of the packers to Cold Bay, Mr. Lynt's party started north, mapping the country along the route taken by Mr. Fenner as far as Angle Creek. Thence the party traveled west around the mountains near the large lake south of Naknek Lake and entered the Valley of Ten Thousand Smokes from the northwest. A week of unfavorable weather was spent in the valley, and then the party continued to map the country along Savonoski River until Mr. Sargent's party was met August 27. The return trip of both parties to Kanatak, ending September 11, was made most of the way over the same route taken going into the country. After a delay of nearly a week at Kanatak transportation was obtained to Kodiak on the Coast and Geodetic Survey boat *Discoverer*. Both parties sailed from Kodiak September 23 on the *Admiral Evans* and arrived at Seattle October 6.

The writer received valuable assistance from C. N. Fenner in mapping the areal geology in the Katmai district. Especial acknowledgment is due to the officers and men of the *Discoverer*, who supplied a much desired means of transportation from Kanatak to Kodiak and who showed the greatest courtesy in offering the best accommodations the boat could afford.

GEOGRAPHY

TOPOGRAPHY

The coastal mountains between Cold Bay and Katmai Bay reach inland about 18 miles, to the Kejulik and Savanoski valleys, and rise to altitudes of 3,000 to 4,000 feet. These mountains are part of the Aleutian Range, which extends along the south coast of Alaska Peninsula. Near the coast northeast of Cold Bay several sharp peaks, especially on Cape Kubugakli, rise above the neighboring mountains, but farther inland the crests are generally rounded. The range is deeply dissected and is characterized by steep slopes which in places form nearly vertical cliffs. The coast is irregularly indented by many small bays, most of which have broad, low valleys stretching inland a short distance. The Kejulik Valley, about 8 miles wide near the mouth of the river, trends northeast from Becharof Lake and separates the Kejulik Mountains on the northwest from the coastal range. The Kejulik Mountains, a spur of the main Aleutian Range, extend from Mount Mageik to Becharof Lake and are exceedingly rugged, being pinnacled by fantastic spires and castles weathered from volcanic rocks. The contrast between this range, many peaks of which reach altitudes of 5,000 feet, and the coastal mountains is very conspicuous. Another range, separated by Yori Pass from the mountains on the east, rises along the south shore of the lake south of Naknek Lake. These mountains are sharp peaked and are composed almost entirely of coarsely crystalline granite. Within the Katmai National Monument and in the northeastern part of the district visited in 1923 a group of one extinct and five active volcanoes form the most prominent topographic feature in the region. Of these, Knife Peak, situated on the north side of the Valley of Ten Thousand Smokes, is regularly conical in outline and rises to an altitude of nearly 8,000 feet, being thus the highest point in this part of the peninsula. It was considered to be an extinct volcano until 1923, when it was found to be slightly active. Several of the volcanoes constantly send columns of white fumes many hundreds of feet in the air. On a clear day this activity may be observed from any part of the district. The Valley of Ten Thousand Smokes includes an area of about 40 square miles, which is nearly level. In this area there are many hot springs and thousands of active fumaroles. The Valley of Ten Thousand Smokes and the volcanoes of the Katmai region have been described in some detail by Griggs [7] and others, and it is beyond the purpose of this report to discuss them at length.

West of the mountains the country is less than 100 feet above sea level and contains many lakes and marshes which make travel difficult in summer except by small boats. Very little of this broad lowland has been surveyed.

In the latitude of Naknek Lake the Alaska Peninsula is about 90 miles wide, and more than half of it consists of the lowland that borders Bristol Bay. The divide between the Pacific Ocean and Bering Sea drainage lies along the main crest of the coastal range, which is relatively close to the south side of the peninsula. The larger streams of the district between Cold Bay and Naknek Lake have their sources in the vicinity of Mageik Volcano, from which they flow radially. Mageik Creek rises among the glaciers on the east side of the volcano and contributes a large volume of water to Katmai River, the largest stream in the region that flows into the Pacific Ocean. Several tributaries of Kejulik River head in the country southwest of the volcano and flow west into Becharof Lake.

[7] Griggs, R. F., The Valley of Ten Thousand Smokes, Nat. Geographic Soc., 1922.

Kejulik River is the principal stream of the Becharof Lake drainage basin and is rather broad and deep and too swift to be crossed on foot in its lower reaches. Other streams, some of considerable size, flow northwest from the vicinity of Mount Mageik either into Naknek Lake or directly into Bristol Bay. The westward-flowing streams are rather sluggish, except near their heads, and have eroded broad, marshy valleys that are difficult to cross during the summer. In contrast the Pacific drainage is characterized by short, turbulent mountain streams flowing through narrow V-shaped valleys in which there are many beautiful falls.

Savonoski River, flowing into Naknek Lake, drains the central part of the mountainous area northeast of the lake. The lower 15 miles of the Savonoski Valley is swampy and is traversed by several river channels. All the streams are supplied by melting snow and glaciers that persist throughout the summer along the crests of the mountains. However, some of the larger glaciers on the west side of the range, especially in the volcanic area, descend to the heads of broad valleys. The glaciers of Mageik and Katmai volcanoes are from 2 to 4 miles long and reach down to the head of Angle Creek valley and also to the Valley of Ten Thousand Smokes, where the ice water from the glaciers mingles with the hot water from the volcanic ash in the River Lethe and Knife Creek. These two streams unite with Windy Creek at Three Forks, in the lower end of the valley, to form Ukak River, which flows north into Naknek Lake. Knife Peak, although higher than the other volcanoes, has less vigorous glaciers on its flanks.

A series of large lakes occurs along the central part of the peninsula west of the mountains. Two of these lakes, Becharof and Naknek, form the western boundary of the Cold Bay-Katmai district. Becharof Lake has an area of about 450 square miles and is the largest of the series. Lake Alinak and a smaller lake just west of it are situated a few miles north of Naknek Lake. Another lake of considerable size lies south of Naknek Lake. Egegik and Naknek rivers are the respective outlets of Becharof and Naknek lakes. These rivers are navigable by small boats and, together with the lakes, furnish the best routes of travel through the Bering Sea coastal plain.

CLIMATE

In discussing the climate of the country north of Cold Bay only the observations made during the field work in the district are available, as no systematic weather records have been kept. Temperature and rainfall in this region are greatly influenced by local geographic features, so that the meteorologic data for Kodiak, 100 miles southeast, and Ugashik, on Bristol Bay, are of little value for comparison. The summer weather of the Alaska Peninsula is characterized by high winds and wet, driving fogs. This condition is especially true of Cold Bay and the country immediately northwest of it. The prevalent high winds sweep across the relatively narrow strip of land either from the Pacific Ocean or from Bering Sea, their direction depending upon the difference in barometric pressure over these bodies of water. A change in atmospheric conditions either east or west of the land results in a sudden change in the direction of the wind, usually a complete reversal. The heavy moisture content of these sea winds is condensed upon striking the snow fields and glaciers of the mountains, causing dense, driving fogs. As a rule the weather is more favorable when the wind is from the west. Any low passes in the mountains, such as Katmai Pass and the low area between Cold Bay and Becharof Lake, form wind gaps through which the wind blows with velocities so high that at times travel against it is almost impossible. Severe storms that endanger navigation along the coast usually occur about the middle of September but are by no means limited to that time. Heavy rains are not frequent, but the nearly continual drizzle from the oversaturated fogs results in a moderately high annual precipitation that amounts to about 50 inches on Unga Island.

During the summer of 1923, from June 5 to September 12 there were 28 clear or partly clear days in the country between Cold Bay and Naknek Lake. The best weather occurred during the later part of June, the last week in August, and the first week in September. The maximum temperature recorded, August 16, was 90°, which is unusually high for this part of Alaska. The average temperature in the summer is probably about 60°. The amount of snowfall varies from year to year, but it is generally light until the 1st of January. The snow disappears from the lower elevations by the 1st of July. A raincoat and moderately heavy clothing are essential for comfort during the summer on the Alaska Peninsula.

VEGETATION

Although the area under consideration is small, the vegetation of the southwestern part differs greatly from that of the northeastern part. The difference is apparent in the absence of trees near Cold Bay and along the coast between Cape Kekurnoi and Cape Kubugakli, whereas in the vicinity of Naknek Lake the valleys are covered with forests of spruce, birch, and poplar. Two small patches of poplar trees grow in the central part of the Kejulik River valley, and farther east in the valley of Kashvik Creek a few birch and poplar were seen. These localities mark the southwest extent of the forests on the Alaska Peninsula, with the exception of a small isolated area found in 1922 in the vicinity of Mother Goose Lake, 75 miles southwest of Cold Bay. The spruce forest extends southwestward to the upper end of the lake south of Naknek Lake. A single spruce tree was seen on Cape Kubugakli, many miles from its nearest neighbor. The largest trees were found growing in the Savonoski Valley, where spruce trees nearly 3 feet in diameter and 40 to 50 feet in height were frequently seen.

Between the lower end of the Valley of Ten Thousand Smokes and Naknek Lake nearly all the trees, as well as the lower forms of vegetation, were killed by the ash fall and probable acid rains during the Katmai eruption. Farther to the west, in Angle Creek valley, the vegetation was also injured, and for distances of 20 miles or more from the volcano mosses and grasses were destroyed. However, in 1923 several varieties of grass, principally horsetail and redtop, had gained a footing where the covering of ash is not too thick. A few seedlings of poplar were seen, but spruce and birch have not yet started to reforest the devastated area.

The largest forms of plant life in the vicinity of Cold Bay are willow and alder bushes, which are unevenly distributed in nearly all the valleys and at places on the lower slopes of the mountains. In exceptionally protected spots the alders attain a height of 15 feet, but usually they are only a few feet tall and so crooked that they can not be used as tent poles, yet they are a valuable source of fuel for the camper. Camp sites are chosen in the midst of alder thickets for protection against the wind.

The dominant and most conspicuous forms of vegetation in the district are grasses, flowering plants, and mosses, which grow rapidly during the summer and clothe the entire country, except the barren crests and cliffs where soil has not accumulated. Of the grasses the so-called redtop is the most common and grows to a height of over 4 feet. It furnishes excellent grazing during the growing season but is not nutritious after it is killed by frost. Mosses and lichens are abundant, except in the northwestern part of the area, where they were destroyed by volcanic ash. Berries are not plentiful, although occasionally fruitful patches of low-bush cranberries, blueberries, or salmonberries are found. The red, sour berries commonly known as high-bush cranberries grow profusely in the forests of Savonoski Valley.

ANIMAL LIFE

As the greater part of the Cold Bay-Katmai district is not forested, game is not so plentiful there as in many other parts of Alaska. The most numerous of the larger animals is the Kodiak bear, tracks of which are seen nearly every day in all sorts of places.

Usually these bears are very shy, and very few of them have been seen by Geological Survey parties. In the area covered by ashes the food of the bear, consisting principally of grass and fish, has been decreased. However, several trails made by bears cross the region. The timbered area is the westward limit of the range of moose, although a stray one is reported to have been killed recently south of Becharof Lake. Many tracks and a single large moose were seen in the Savonoski Valley by members of the party of 1923. Caribou were fairly plentiful on the Alaska Peninsula 30 or 40 years ago, but during recent years very few have been seen. About 20 were seen in 1922 by members of a United States Geological Survey party southwest of Wide Bay, but only a few tracks were noticed in 1923 in the Katmai region.

Many fur-bearing animals live in the district. The red fox is most abundant, and mink, marten, land otter, wolverine, and lynx are also taken by trappers. Lynx are not found farther south than the upper Kejulik Valley and are rather few there except during certain years, although they are apparently plentiful in the Savonoski Valley. The large Arctic hare is found in the vicinity of Cold Bay; farther northwest it was not seen, but small rabbits are very numerous. Grouse find a suitable environment in the spruce forest, and several varieties of ptarmigan are plentiful on the mountains and tundra. In the forested area around the lakes in the northeastern part of the district small birds are common and include robins, jays, crossbills, and woodpeckers. These birds were not seen near Cold Bay, but golden-crested sparrows, water wrens, magpies, snipe, ravens, and a small yellow-plumed bird belonging to the canary family are numerous. An abundance of waterfowl, including many species of ducks as well as geese and swans, find favorable breeding places in the lakes and swampy areas west of the mountains. Thousands of sea fowl—gulls, shags, and sea parrots—breed in the cliffs and on the rocky islands along the Pacific coast and are often seen flying across the peninsula.

The lakes and streams that drain to Bering Sea are the spawning grounds of the Alaska red salmon. Each year countless thousands of salmon migrate from salt water to the bodies of fresh water in which they were hatched to spawn and die. Along the larger rivers flowing from the lakes into Bristol Bay an extensive canning industry has been established. Several valuable species of salmon occur on the Pacific side, but the red or sockeye salmon is not as plentiful as on the Bristol Bay coast. Large trout are found in nearly every stream in the district, and grayling were caught in a few streams.

POPULATION

The country between Cold Bay and Naknek Lake, a distance of about 60 miles, is not inhabited except by one white man living on Cape Kubugakli. Formerly Katmai village, near the head of Katmai Bay, was one of the largest native villages along the southern coast of the peninsula, but it is now entirely abandoned. Other villages close to Naknek Lake have also been abandoned since the Katmai eruption in 1912. Savonoski, near the mouth of Savonoski River, was the largest of the inland villages.

Several substantial frame buildings were constructed on the west shore of Cold Bay near its entrance in 1902, when the first oil developments were under way. These buildings are still in good condition and formed the principal trading post for many years but were unoccupied in 1923. A trapper's cabin at the head of the bay is the base of several trappers during the winter. The lone white inhabitant of Cape Kubugakli operates several trap lines during the fur season; otherwise the district has not been visited by trappers since the natives were driven out in 1912. Many of the natives have settled on Bristol Bay near the large salmon canneries. The transient population at the canneries during the canning season amounts to several thousand people. A few tourists visit the Katmai National Monument each year, but until the region is made more accessible by roads and roadhouses, few travelers will brave the hardships of the trip.

The nearest white settlement to the district is Kanatak, on Portage Bay, 30 miles south of Cold Bay. This town is the base of supplies and center of activity of the present oil developments on the Alaska Peninsula.

ROUTES OF TRAVEL

Parts of the Cold Bay-Katmai district are rather inaccessible at present. This is especially true of the Valley of Ten Thousand Smokes, which lies about 25 miles inland from the Pacific coast. No provision has yet been made to facilitate the trip over the rough country that lies between the coast and the valley. Formerly Katmai Pass, across the mountains between Katmai Bay and Naknek Lake, afforded an important means of going from the Pacific coast to Bristol Bay. This trail was a tribal highway for centuries before the arrival of white men. Petrof[8] gives the following account of Katmai village and the pass:

> The settlement of Katmai, in this vicinity, was once the central point of transit for travel and traffic across the peninsula. Three different routes converged here and made the station a point of some importance; now

[8] Petrof, Ivan, Report on the population, industries, and resources of Alaska in the Tenth Census, reprinted in Compilations of narratives of explorations in Alaska, 1869–1900, p. 84, Committee on Military Affairs, U. S. Congress, 1900.

Katmai's commercial glory has departed, and its population, consisting of less than 200 Creoles and Innuits, depend upon the sea otter alone for existence.

The people of two villages across the divide, in the vicinity of Lake Walker (Naknek Lake), come down to Katmai to do their shopping and to dispose of their furs, undertaking a very fatiguing tramp over mountains and glaciers and across deep and dangerous streams in preference to the canoe journey to the Bristol Bay stations. On the eastern side of the peninsula the mountains rise abruptly from the sea, a short day's climbing transplanting the traveler from tidewater into the midst of glaciers and eternal snows and scenes of alpine grandeur and solitude.

During the gold excitement at Nome Katmai again became an important point in the long and weary journey to the site of the new discovery. Hundreds of prospectors preferred the rough trail and the fury of the winds in the pass to the long and hazardous ocean trip of 300 miles around the end of the peninsula. A bunk house was constructed at Katmai, and small boats plied Naknek Lake and Naknek River to accommodate the travelers. During the winter the Nome mail was carried over this route by dog sled for many years. A very low divide exists between the head of Cold Bay and Becharof Lake. The route by this divide was never extensively used, however, probably on account of the difficulty of landing and the swampy areas along the way. In the period from 1902 to 1904 a wagon road was constructed from Cold Bay to the headwaters of Becharof Creek. The road is in poor condition at present but was used for several years by the Bristol Bay mail carriers. Although there are many bays along the coast protected harbors are not plentiful, and for this reason the problem of constructing a road into the Valley of Ten Thousand Smokes is more difficult. Three possible routes into the valley could be used. The route that has received the most consideration is by way of Geographic Harbor, the upper part of Katmai Valley and Katmai Pass. Although Geographic Harbor affords good anchorage, it is surrounded by lofty mountains which must be crossed in order to reach the Valley of Ten Thousand Smokes. The construction of a road or even a trail over these mountains would require a considerable expenditure of money. Nevertheless it is the shortest route into the valley, although by no means the easiest. Another possible way of entering the valley is by Cold Bay and the Kejulik River valley. The Kejulik Mountains would have to be crossed near the head of the valley, and this can be accomplished only by pack train. The traveler would enter the valley at its west end by taking this route. A third route is by Kanatak, Becharof Lake, and Yori Pass to the west of the valley. A wagon road has been built from Kanatak to the upper arm of Becharof Lake. Thence a four hours' boat ride would land the traveler on the north side of the lake, west of the Kejulik Mountains. From this point a journey of 35 miles over moderately level country would place him at the west entrance of the valley. This route, although indirect, presents the fewest difficulties and is probably the most feasible of the three ways of entering the valley from the Pacific side of the peninsula. The most serious objection to it is the lack of a safe harbor at Kanatak.

GEOLOGY

GENERAL FEATURES

The investigation of the area between Cold Bay and Naknek Lake was a reconnaissance survey, and only the principal geologic features were noted. (See Pl. IV.) The time spent in any one locality did not permit a detailed study of the geology, and frequently the inclemency of the weather interfered with work. The district is occupied chiefly by sedimentary rocks, which are gently folded, faulted in places, and intruded by igneous rocks. All the sedimentary rocks, except the unconsolidated alluvium and glacial débris, are of Mesozoic age, and the greater part are Upper Jurassic. Therefore, aside from several faulted areas and the problems concerning the volcanoes, the geology of the district is not complicated.

The oldest sedimentary rocks exposed in the district are of Upper Triassic age and occur on Cape Kekurnoi. Above the Upper Triassic beds are several thousand feet of sandstone, shale, and conglomerate, which have been referred to the Lower (?) and Middle Jurassic. Upon these beds a great thickness of Upper Jurassic strata rests unconformably. The Upper Jurassic sequence is divided into the Shelikof and Naknek formations. The Naknek forms the surface rock over the greater part of the district.

Igneous rocks occur in several areas and vary greatly in character. The largest mass extends southwestward from Naknek Lake and consists of coarsely crystalline granite and gabbro. The rugged crest of the Kejulik Mountains is formed by lava flows over the Naknek formation. Andesite intrusions occur in a number of mountains north and south of the Valley of Ten Thousand Smokes, and the valley itself is filled with andesitic volcanic ash and pumice to a depth of 100 feet or more. Thick sills and dikes are exposed on Mount Kubugakli, and older flows and intrusive rocks are interbedded with the Triassic limestone on Cape Kekurnoi.

All the larger valleys, the lowlands at the heads of bays, and the broad area west of the mountains are covered with alluvium or glacial detritus. The most extensive areas covered by glacial moraines are the valley of Angle Creek and adjacent area and the immediate vicinity of Naknek Lake. Active glaciers on the flanks of Mageik and several other volcanoes in the district are depositing considerable amounts of material at their terminals.

The structure of the rocks in the region is rather simple. From the coast to the west side of Kejulik Valley the structure is monoclinal, the beds dipping 4°–30° W. and in general striking N. 60° E. Locally the strata are nearly horizontal, especially along the Kejulik Mountains and in the vicinity of the Valley of Ten Thousand Smokes. An extensive fault probably exists at the contact of the granitic mass and the sedimentary rocks in the western part of the district. Other major faults and several minor faults were noted.

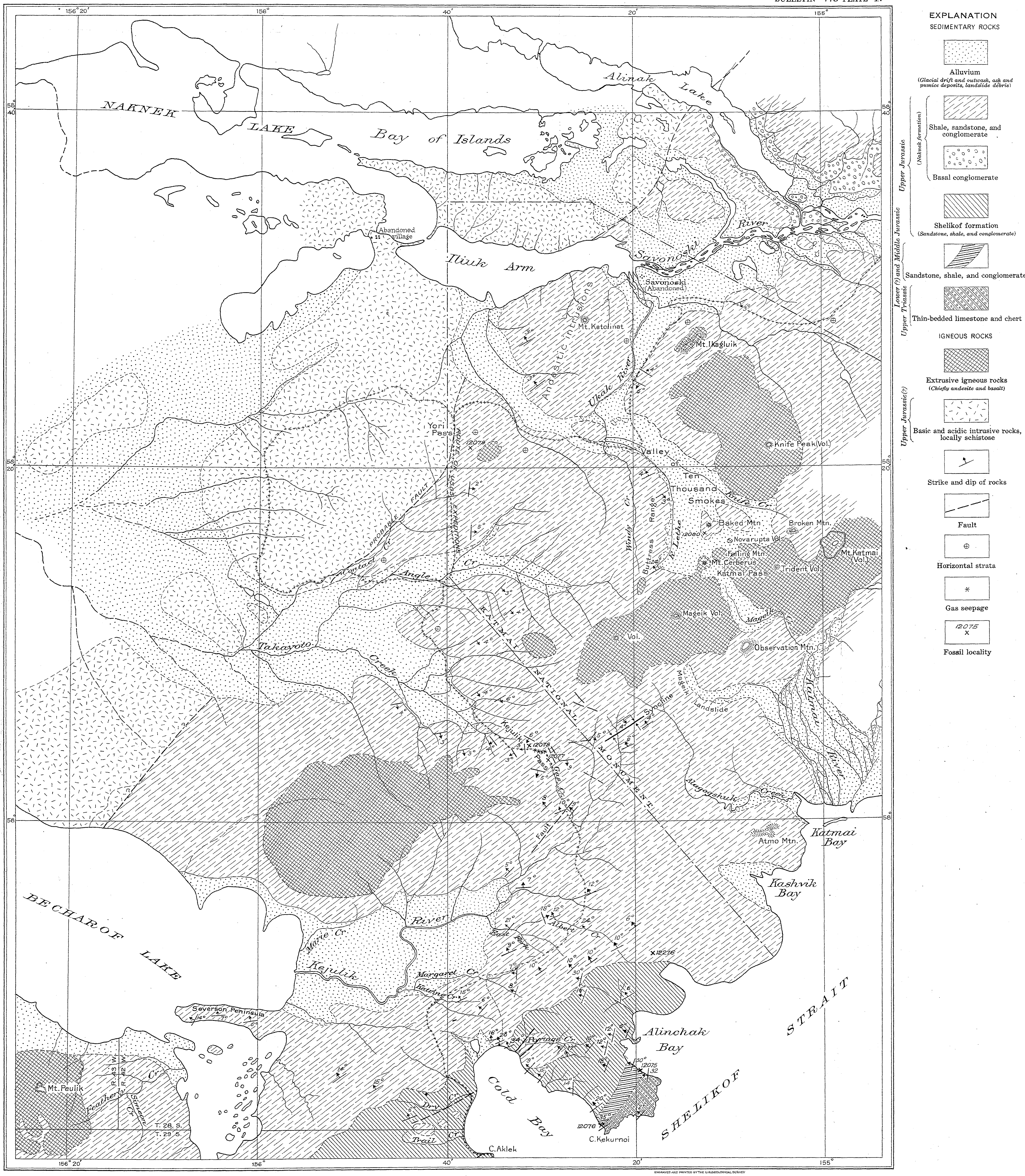
SEDIMENTARY ROCKS

TRIASSIC ROCKS

Little additional information was gained in 1923 regarding the small area of Triassic rocks exposed on Cape Kekurnoi. The rocks are equivalent in age to the Upper Noric of Europe and are the oldest sedimentary beds that crop out in the district. These beds, so far as known, have been described in several publications,[9] although a detailed study of them has not been made. The rather indefinite contact with the overlying Jurassic rocks has not been followed across the cape.

The formation consists chiefly of thin-bedded limestone, interbedded with sills or flows of basalt. However, the lowest beds exposed in the cliffs between Cold Bay and Alinchak Bay consist of very massive buff limestone about 85 feet thick which strike in general N. 75° E. and dip 20°–35° SW., although locally the dip is reversed and the strike is not constant. The cliffs are continuous along the beach between the two bays for nearly 5 miles and average about 80 feet in height. They are nearly vertical for the entire distance; at places they even overhang. About half the rock exposed in the cliffs and in the stream canyons back of the cliffs is basaltic and tuffaceous material containing veinlets of calcite and pyrite. The upper part of this series of rocks, also intercalated with igneous material, is exposed along the southeast shore of Alinchak Bay. Several hundred feet above the lowest bed of sedimentary rocks exposed a widely distributed Upper Triassic fossil, *Pseudomonotis subcircularis* Gabb, occurs abundantly at both Cold Bay and Alinchak Bay. The thickness of the beds of undoubted Triassic age is probably between 600 and 800 feet, but a careful measurement has not been made. The upper part of the limestone yields fossils which are believed by T. W. Stanton to be Jurassic.

[9] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, pp. 393–396, 1904. Martin, G. C., Triassic rocks of Alaska: Idem, vol. 27, pp. 685–718, 1916; Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, p. 58, 1921. Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 755, pp. 92–93, 1922. Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924.



Base largely from U.S. Geological Survey topographic maps.
Surveyed by R. K. Lynt.

Scale $\frac{1}{250,000}$

2 1 0 2 4 6 8 10 12 14 MILES

1925

Geology by W. R. Smith

GEOLOGIC MAP OF COLD BAY-KATMAI REGION, ALASKA PENINSULA

A gradual transition takes place from the limestone to a massive sandstone that is undoubtedly Jurassic, and no evidence of an unconformity has been noted between the limestone and the sandstone.

JURASSIC ROCKS

LOWER (?) AND MIDDLE JURASSIC ROCKS

The oldest Jurassic sedimentary rocks in the district and, so far as known, the oldest in the Alaska Peninsula rest conformably upon the Triassic rocks at Cape Kekurnoi. They are at least 2,000 feet thick and comprise limestone, massive calcareous sandstone, shale, and conglomerate. They extend across the cape from Cold Bay to Alinchak Bay. The beds are cut by several dikes and contain layers of fossiliferous tuff. On the shore at Cold Bay less than 100 feet above the highest zone of *Pseudomonotis* and apparently in the same stratigraphic unit a collection of fossils was made that has been determined by T. W. Stanton as follows:

12076. No. 2. South side of Cape Kekurnoi above Pseudomonotis zone:
Trigonia? sp.
Solemya sp.
Stephanoceras?, crushed fragment.
This lot is believed to be Jurassic.

At Alinchak Bay 200 feet or more above the highest observed *Pseudomonotis* zone a collection of fossils was made from sandy limestone and interbedded layers of tuff that has been identified as follows by Mr. Stanton:

12075. No. 1. Southwest shore of Alinchak Bay:
Lima sp. related to L. gigantea Sowerby.
Leda sp.
Pleuromya? sp.
Undetermined pelecypods, three species.
Phylloceras? sp.
Aegoceras?? sp.
Other undetermined ammonite fragments.
Sagenopteris sp. (determined by F. H. Knowlton).
This lot is believed to be Jurassic, as old as the Tuxedni sandstone (Middle Jurassic) or older.

The beds tentatively included in this assemblage were measured by Capps[10] and are approximately as follows:

Section of Lower (?) and Middle Jurassic beds at Cape Kekurnoi

	Feet
Conglomerate (top of section)	75
Mainly black to rusty weathered shale with some thin beds of limestone	800
Prevailingly massive sandstone	800
Prevailingly limy sandstone and limestone	700

[10] Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 739, p. 94, 1922.

The conglomerate was arbitrarily chosen as the top of the section and was thought to mark an unconformity at the base of the Upper Jurassic. The section at Alinchak Bay is very similar in sequence and in lithologic character, except at the top, where the conglomerate is absent. The brown iron-stained shale at the top of the Alinchak Bay section is overlain unconformably by a coarse massive sandstone that is believed to be Upper Jurassic. The total thickness is estimated to be less than at Cold Bay. The unconformity was not traced across the cape.

The beds dip 10°–25° NW. and conform in general to the monoclinal structure of the thick series of overlying Upper Jurassic beds.

UPPER JURASSIC ROCKS

SHELIKOF FORMATION

Probably the thickest section of Upper Jurassic marine sedimentary rocks in North America is found on the Alaska Peninsula. The total thickness of the beds of this series as developed west of Wide Bay is at least 10,000 feet. The lower beds, which are from 5,000 to 7,000 feet thick, consist chiefly of massive sandstone and carbonaceous shale and have been called the Shelikof formation, from their occurrence along the west side of Shelikof Strait. The formation as now known will probably be subdivided into smaller and more distinct lithologic units. The Naknek formation, consisting of thick beds of conglomerate, arkose, and sandy shale with a total thickness of at least 5,000 feet but probably much more, constitutes the upper part of the Jurassic rocks on the Alaska Peninsula. The faunas of the two formations are quite distinct, the Shelikof being characterized by various species of the ammonite *Cadoceras*, whereas the most abundant and characteristic fossil of the Naknek is the widely distributed *Aucella*.

In the area east and northeast of Cold Bay the Shelikof is apparently not so well developed or the exposures are relatively poor except along the northeast shore of Cold Bay. A section made at this locality by Capps shows a thickness of about 5,000 feet. These beds are monoclinal; they strike prevailingly northeast and dip 8°–40° NW. At 10 miles east from the head of the bay the beds flatten, and at Kashvik Bay are concealed by the overlying Naknek. The Shelikof formation is not exposed along the coast, so far as known, north of the upper arm of Alinchak Bay. Although only estimates of the thickness were made, the formation apparently decreases in thickness toward the east from the head of Cold Bay, and some of the massive sandstone beds change laterally into shale.

Section of uppermost beds of the Shelikof formation just north of the head of Cold Bay

	Feet
Thin-bedded bluish shale with thin layers of light-colored fine-grained sandstone	220
Shale and light-colored to dark-brown sandstone	340
Massive sandstone weathering nearly white, light red at base	680
Very massive dark to light brown sandstone	620

The above section and part of the overlying Naknek is duplicated along the northeast side of Cold Bay, having been displaced by two faults, one on each side of and parallel with the lower part of Portage Creek. The relative movement was downward on the southeast side, with a displacement of at least 2,000 feet. In the cliffs at the southwest end of the bay the displacement is greater and the fault is known as the Dry Creek fault. Northeast of the forks of Portage Creek evidence of the faults was not observed, but they probably extend some distance and may account for the apparent thinning of the Shelikof beds.

The base of the Shelikof, as exposed along the north shore of Cold Bay, is composed of a massive conglomerate about 75 feet thick in which some of the boulders are 2 feet in diameter. The conglomerate was not recognized farther east toward Alinchak Bay. A great thickness of massive brown sandstone, some of which is concretionary, with minor amounts of conglomerate and shale, overlies the basal conglomerate at Cold Bay. The sandstone is about 4,000 feet thick and forms the middle and most prominent member of the Shelikof formation. The upper member consists of 500 to 1,000 feet of black shale with some sandstone and limy shale. At places the shale is concretionary, the concretions consisting either of shale or of blue limestone that weathers dark yellow. The amount and thickness of the sandstone beds within the shale vary greatly from place to place, but the shale is always found beneath the conglomerate at the base of the Naknek formation.

Collections of fossils were not made from the Shelikof formation northeast of Cold Bay, but several lots were collected southwest of Cold Bay by Capps in 1921. These fossils, chiefly *Cadoceras*, are also characteristic of the Chinitna shale at its type locality at Chinitna Bay, on Cook Inlet. The thickness and lithology of the two formations differ considerably, but the similarity of the fossils makes the correlation of at least part of the Shelikof with the Chinitna formation rather definite. The upper shale member of the Shelikof yields very few fossils, but its position below the basal conglomerate of the Naknek places it within the Shelikof formation.

NAKNEK FORMATION

The Naknek is the most extensive areal formation in the district north of Cold Bay, as well as in many other parts of the Alaska Peninsula. All the known consolidated sedimentary rocks west of Kashvik and Katmai bays belong to this formation. Lithologically the sequence of beds is rather constant over wide areas, but the individual members vary greatly in thickness from one locality to another. The base of the Naknek is composed of a series of fine to very coarse conglomerate and arkosic sandstone 1,000 feet thick at Cold Bay but attaining a maximum thickness of 2,000 feet or more west of Wide Bay. At most localities a basal conglomerate forms a distinct unit; northeast of Cold Bay, however, the conglomerate is absent or occurs in thin lenses. In this locality coarse pebbly and arkosic sandstone rests upon the upper shale of the Shelikof formation. Above the conglomerate and arkose thick beds of sandy *Aucella*-bearing shale and thin beds of sandstone form the upper part of the Naknek formation southwest and northeast of Cold Bay except in Mount Katolinat, south of Iliuk Arm of Naknek Lake, where about 2,000 feet of sandstone and conglomerate rest upon the fossiliferous shale. This condition could result from a thrust fault, but it more probably represents a near-shore phase of deposition. The higher slopes of Mount Katolinat, which is one of the largest mountain masses in the district, were not visited by the writer. The data are taken from the unpublished notes of C. N. Fenner, who reports many generally horizontal or gently inclined intrusions of hornblende andesite cutting the sedimentary rocks in the mountain. Similar intrusions were noted in neighboring mountains, but the thick beds of conglomerate do not occur.

The westward extent of the Naknek, so far as known, north of Cold Bay is limited by a large granitic mass occurring along the central part of the peninsula southwestward as far as Becharof Lake. The contact of the granitic mass and the Naknek formation was not seen west of Naknek Lake, but a short distance from the granite the sedimentary rocks are broken and discolored, indicating a fault. A fault contact is reported farther northeast near Kamishak Bay. The strata exposed in the Kejulik River valley and the Kejulik Mountains are entirely of Naknek age and consist predominantly of bluish to black sandy shale. Relatively thin beds of sandstone and layers of limy concretions are irregularly interbedded. The thickness of the shale is apparently very great, but it is probable that there are many displacements within the valley that have not been observed. An estimate of the minimum thickness of the upper shaly member of the Naknek in the Kejulik Valley and Kejulik

Mountains is 4,500 feet. However, if there is no great repetition of beds caused by faults parallel to the Kejulik Valley and concealed beneath the alluvium, the thickness is probably twice the amount estimated. A few minor faults of 10 to 20 feet displacement were noted in the Kejulik Valley and Mountains. Considerable faulting has taken place near the base of the south side of the volcano locally known as Mount Martin. The faults apparently do not trend in any general direction, inasmuch as the strata appear to have been broken into large blocks that have been tilted. This faulted area was seen only from a distance, and the extent of the faults and the amount of displacement are not known. It is probable that a fault extends along the east side of the Kejulik Mountains near Becharof Lake, but this is not certainly known and is postulated from observations made on the structure from distant points of view.

The rugged crest of the Kejulik Mountains consists of andesite and very scoriaceous black and red lava that flowed out over the Naknek beds. The vent from which the lava was extruded has not been discovered.

The beds of the Naknek formation strike generally northeast and dip 4°–15° NW. in the Kejulik Valley and in the mountains east of the valley. The rocks in the Kejulik Mountains are nearly horizontal, but along the east side of the range there are slight dips toward the southeast, forming a shallow syncline along the upper northwest side of the valley. The syncline can be seen at the head of the valley east of the mountain locally called Mount Martin. Near the head of Tokayofo Creek, on the west side of the Kejulik Mountains, the beds strike N. 80° E. and dip about 4° SE., forming a broad structural terrace along the Kejulik Mountains that trends somewhat parallel to the crest of the range. The Naknek sandstone and shale exposed in the mountains on both sides of the Valley of Ten Thousand Smokes and also east and southeast of the lower Savonoski Valley are nearly horizontal. Locally, however, the beds dip 2° to 6°, but no well-defined anticlines or synclines were mapped.

Throughout the thickness of sandy shale beds of the Naknek formation *Aucella* is abundant and a few other fossils occur. Several collections were made by the writer and determined by T. W. Stanton, as follows:

12276. No. 3. Head of central and principal tributary of Bear Creek, flowing into north arm of Alinchak Bay, Alaska Peninsula:

Aucella sp. related to A. bronni.
Lima sp.
Artica sp.
Pleuromya sp.

These fossils belong to the Naknek fauna.

12077. No. 4. East side of Kejulik Pass, below Gas Creek:
Rhynchonella sp.
Pleuromya sp.
Turbo? sp.
Belemnites sp.
Phylloceras sp.
Bone fragment.
Jurassic, Naknek.

12078. No. 5. Upper part of Gas Creek. Lowest exposed beds:
Aucella sp.
Eumicrotis? sp.
Jurassic, Naknek.

12079. No. 6. Mountain top east of Yori Pass:
Aucella sp.
Astarte sp.
Pleuromya sp.
Jurassic, Naknek.

12080. No. 8. Baked Mountain, north side of Valley of Ten Thousand Smokes:
Aucella sp.
Lima sp.
Turbo? sp.
Belemnites sp.
Jurassic, Naknek.

12081. No. 9. Float in tributary of Savonoski River:
Aucella sp.
Eumicrotis sp.
Astarte sp.
Tancredia sp.
Jurassic, Naknek.

The rocks exposed on the Severson Peninsula, which projects into Becharof Lake from the east side, consist entirely of thick beds of conglomerate and coarse arkosic sandstone probably belonging to the basal part of the Naknek formation. The total thickness of the beds on the peninsula is probably 400 feet. The general strike is N. 75° E., nearly parallel to the direction of the peninsula. The dip ranges from 6° to 12° N., with local changes to the east and west. No fossils were found on the peninsula.

Fossils have not been found in the basal conglomerate and arkosic member of the Naknek except in some transitional beds near the top. The stratigraphic position of this conglomerate at Cold Bay corresponds rather closely to that of the Chisik conglomerate on the west side of Cook Inlet, where the conglomerate and arkose member rests upon beds yielding *Cadoceras* and is overlain by *Aucella*-bearing shale. At Cold Bay, however, the conglomerate lies about 800 feet above the highest known *Cadoceras* horizon, and the intervening shale may be in part equivalent in age to the Chisik conglomerate. On Cook Inlet and near Kamishak Bay (see pp. 168–169) the conglomerate is considered a distinct unit, but in the Cold Bay-Katmai district it has been included in the Naknek formation on account of the indefinite upper limit of the arkose. However, the conglomerate and arkose of Cold Bay are probably equivalent in part to the Chisik conglomerate of Cook Inlet.

QUATERNARY DEPOSITS

Deposits of alluvium composed chiefly of glacial material transported by streams occur in the lower parts of the valleys and the lowland on the northwest side of the peninsula. Glacial moraines formed by active and ancient glaciers are found in some of the larger valleys and along the margins of the principal lakes. The active glacier on the west side of the volcano at the head of Angle Creek has formed a rather prominent terminal moraine about 200 feet high. Farther down the valley the slopes of the hills adjacent to it are covered by glacial material in the form of irregular moraines roughly parallel to the valley. Many large striated boulders of andesite, probably from the volcano at the head of the valley, are scattered throughout the finer material of the moraines. Ponds and kettle holes are numerous in this area.

A very curious moraine extends unbroken for about 5 miles nearly parallel to the south shore of a lake west of Naknek Lake. The moraine is 2 miles from the shore of the lake; it is not wide but reaches a height of 150 to 200 feet and crosses a ridge several hundred feet above the lake. The area between the moraine and the lake is rather heavily timbered with spruce, but beyond the moraine toward the south there is scarcely a tree. A stream flowing north directly toward the lake is deflected northwestward by the moraine and forms part of the King Salmon River drainage system. A large part of the glacial material consists of hornblende andesite and fragments of shale containing *Aucella.* The mountains immediately south of the moraine, though apparently glaciated, are composed of coarsely crystalline granite, boulders of which could not be found in the débris at the locality examined. Across the lake toward the north andesite and the *Aucella*-bearing beds of the Naknek formation are not known to occur; hence the direction in which the glacier moved and the source of the material it deposited are problematic.

Large mounds of glacial débris were formed at the lower end of the Valley of Ten Thousand Smokes. Huge striated boulders of andesite from the mountains at the upper end of the valley, 12 miles away, are common in the heterogeneous morainal material. The valley is covered to a depth of 100 feet or more with volcanic ash and pumice. A detailed description containing a theory of the origin of the pumice has been published.[11] Detritus from stream and glacial erosion has accumulated in small deltas near the mouths of the larger streams entering Naknek and Becharof lakes. The numerous small islands in the upper part of Becharof Lake are made up entirely of alluvial material. The area of knolls or moraines forming the islands extends over the lowland east of the lake.

The coastal plain west of the mountains is low and contains many lakes, marshes, and areas of tundra. The only rock exposures are along streams and consist of more or less stratified alluvium. Spurr[12] gives the following description of the geology along Naknek River:

> There are no rock outcrops on Naknek River, the shores being always stratified clays and sands, undisturbed and horizontal, containing many boulders, which reach large size. These boulders are often striated and are chiefly mica diorite. At the coast the bluffs are from 40 to 60 feet high, but farther up the river they shrink to 20 feet and then increase again to the same height as those of the coast. At places there are well-marked terraces about halfway up to the top of the bluffs, which are level. At the upper end of the river, where it leaves the lake, there is no rock ridge, but only the same stratified drift as farther down.

IGNEOUS ROCKS

Several areas of igneous rocks, in which both intrusive and effusive types are represented, differing in age and composition, occur in the district under consideration. The largest area extends from the north shore of Becharof Lake, west of the Kejulik Mountains, to Naknek Lake and continues northwestward toward the Alaska Range. The width of the mass is not known; the contact with the Upper Jurassic sedimentary rocks on the east has been mapped, but the western contact is in many places covered with alluvium. The central part of a group of mountains southeast of Naknek Lake is composed of coarsely crystalline granitic and gabbroic rocks. The granites are light gray or pinkish; locally they show weak gneissoid banding. Masses of gabbro occur in close association with the granite but in much smaller amount. The east flank of the mountains is composed of finer-grained acidic and basic rocks, which may be either marginal facies of the coarsely crystalline mass or separate intrusions. The latter mode of origin is indicated by a rather sharp contact at one locality. Several quartz veins and considerable quantities of pyrite were noted on the east side of the range. The rocks containing the pyrite when exposed to the agents of weathering assume a reddish color and can be seen from distant points. Boulders occurring in the basal conglomerate of the Naknek

[11] Fenner, C. N., The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes: Katmai series No. 1, Nat. Geographic Soc., 1923.

[12] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 145, 1900.

formation are similar in texture and composition to the various kinds of igneous rocks found in place in the mountains southeast of Naknek Lake. No other source of the boulders and pebbles making up this conglomerate is known. Hence it is thought that the age of the coarsely crystalline rocks and probably the finer-textured marginal rocks is pre-Naknek.

Andesite of rather basic composition is found on the sides of the volcanoes and in the lower hills at the head of the Valley of Ten Thousand Smokes, and also near the summits of the mountains northwest of Knife Peak.

Mount Ikagluik, east of Ukak River, is made up of sedimentary rocks to a height of about 3,000 feet, but the upper 1,400 feet of the mountain is composed entirely of extrusive rocks. A depression on the summit of the mountain may be an extinct crater, the source of the igneous material. The rocks exposed in Knife Peak and near the tops of some of the mountains between Knife Peak and Mount Ikagluik are igneous, probably representing various types of andesite and basalt. Several mountains west of the lower part of Windy Creek appear to be composed of light-colored igneous rocks. Small dikes and sills cut the Naknek formation in the high mountains south of Yori Pass. The absence of sedimentary rocks more recent than the Naknek in this area makes the age determination of the andesitic rocks uncertain. However, they are very similar in character to rocks elsewhere on the Alaska Peninsula which are known to be Tertiary. The intrusive rocks of the Katmai district probably do not all belong to a single period of igneous activity, but some of them are undoubtedly of the same age as similar rocks southwest of Wide Bay.

The basaltic dikes and sills and interbedded tuffaceous material of the Triassic limestone of Cape Kekurnoi have already been mentioned (p. 195). Farther northeast along the coast, in the mountains on Cape Kubugakli, massive sills have been intruded into the sedimentary rocks, which are somewhat metamorphosed. Several dikes cut the sills and sedimentary rocks. One of the dikes, about 20 feet wide, exposed on the west side of Kubugakli Mountain, reaches from a point near the base to the summit. In the cliffs along the shore on the cape and in the banks of a small stream flowing from the mountain the country rock is impregnated by many small stringers of calcite and quartz. Some of the quartz stringers carry gold, magnetite, and the common sulphides.

Erratic boulders of igneous rocks—granite, diorite, greenstone, and many other types—are found at many places in the stream beds and scattered over the hills of the Cold Bay-Katmai district. Some of these boulders are angular, but most of them are rounded and are derived chiefly from the basal conglomerate of the Naknek formation.

Besides the pumice in the Valley of Ten Thousand Smokes, a small body of lava came to the surface in the crater of Novarupta during the volcanic activity in 1912. The lava is generally glassy, though slightly porous, and the greater part has the composition of a siliceous soda rhyolite, being much more siliceous than the older lavas in the vicinity. However, there are dark bands both in the lava of Novarupta and in the pumice of the valley which have the composition of a medium andesite. Several analyses [13] of Novarupta lava have been made.

MINERAL RESOURCES

INDICATIONS OF OIL

Oil seepages have been known for many years west of Cold Bay near the head of Oil Creek and to the southwest between Cold Bay and Portage Bay, also southeast of Mount Peulik about 15 miles inland from Portage Bay. Four wells were drilled near the seepages at the head of Oil Creek during the period 1902 to 1904, but the wells were not favorably located in respect to geologic structure, and oil was not found in commercial quantities. From 1920 to 1924 many claims were staked over wide areas from the Kejulik Valley to Chignik, but development did not begin until 1922, when two oil companies began to drill on the Pearl Creek dome, southeast of Mount Peulik. Observations on the geologic structure and the possibility of obtaining oil west and southwest of Cold Bay and in the Kejulik Valley have been recently published.[14] Favorable conditions of stratigraphy and geologic structure for oil accumulation are known to exist in the area termed the Cold Bay district. The expedition of 1923 from Cold Bay to Katmai was made partly for the purpose of finding out whether geologic conditions in this district are similar to those of the adjacent Cold Bay district.

Well-defined large anticlines and domes such as the Bear Creek-Salmon Creek anticline, between Cold and Portage bays, and the Pearl Creek dome, southeast of Mount Peulik, do not occur within at least 60 miles northeast of Cold Bay. In general the structure of the sedimentary rocks in this area is that of a monocline in which the beds dip away from the coast toward the northwest as far as the west side of Kejulik Valley. A few exceptions to this condition occur, especially in the northeastern part of the district, where the beds are nearly horizontal, but even here the slight local dips are

[13] Fenner, C. N., op. cit., p. 59.

[14] Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 739, pp. 77–116, 1922. Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924.

predominantly toward the northwest. On the flank of the monocline between the coast and the west side of Kejulik Valley there are many local changes in degree of dip, so that the beds become less inclined at places and form structural terraces or benches. Conditions similar to these have proved to be favorable for the accumulation of oil in other parts of the world. However, in the area northeast of Cold Bay the structural terraces so far as known are not well defined and do not extend for long distances. Furthermore, in most localities the stratigraphic sequence beneath the benches is not favorable for the discovery of oil at moderate drilling depth. A possible exception to this rule occurs along the east side of Kejulik Valley. At this locality the dip of the beds changes from a maximum of 23° W. in the high mountain east of the valley to 7° and 8° W. along the east side of the valley, becoming steeper farther west. The zone of relatively low dips is about a mile wide. The sandstone of the Shelikof formation, which, to judge from the occurrence of seepages in it west of Cold Bay, may be oil-bearing, should be within moderate drilling depth on the structural terrace extending along the east side of the valley. Whether the change in the degree of dip is sufficient to form a reservoir for oil is not known, but the best possibilities of reaching an oil-bearing bed in the Kejulik Valley are probably in the area of relatively low dips. However, special conditions such as local variations in cementation or porosity of beds and sandstone lenses inclosed in shale or other impervious rocks provide centers of concentration of oil and can not be foretold by surface observation. It is possible that such features exist within the Naknek formation in the Kejulik Valley. A more complete discussion of the occurrence of oil on monoclines is given in a previous paper [15] considering the same area.

A shallow syncline extends along the west side of the upper part of the Kejulik Valley. The dips for short distances on both sides of the syncline average about 4°. The beds on the east side of the Kejulik Mountains dip 4°–8° E. Along the crest of the range in the vicinity of Kejulik Pass (see Pl. IV) the beds are nearly horizontal. On the west side of the mountains the general dip is 2°–4° E., although locally the beds are horizontal or have a very slight dip toward the west. The position of the beds in the Kejulik Mountains forms a broad but not well-defined structural terrace near the pass. Farther northeast, near the volcanoes, the beds are faulted; the lower end of the range, near Becharof Lake, has not been examined. Southwest of the pass the crest of the mountains is very rugged and is composed of lava overlying the Naknek formation. Several minor faults were noted on the east side of Kejulik Pass.

[15] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 206–209, 1924.

Although numerous gas seepages were found along a fault at Gas Creek, on the east side of the pass, the Kejulik Mountains are not considered at present to be a favorable location for the discovery of oil at moderate depth. The Naknek formation, including the lower arkosic member and the *Aucella*-bearing shale, is at least 6,000 feet thick in the Kejulik Mountains, and there is scarcely any indication of oil occurring within these beds. Aside from the unfavorable lithologic and structural conditions the country is not easily accessible.

Small seepages of petroleum have been reported to occur in the Kejulik Valley, but they have not been seen by members of the Geological Survey. No traces of petroleum are authentically known in the region visited by the writer northwest of Cold Bay. An oil seepage was reported "near Katmai Bay" by Davidson[16] and Dall[17] in 1869, but it is quite probable that they referred to the seepages near Cold Bay. The gas seepages on Gas Creek occur for about 200 yards along the stream and issue from the loose boulders in its bed. The gas has a very faint odor, is colorless, and burns with a bright yellow flame. A small hole was made in the bottom of a lard can and the can inverted over one of the seepages. The gas escaping from the hole burned with a flame about 8 inches in length that was continuously maintained for three days. It furnished sufficient heat to boil water for laundering.

The country west of the Kejulik Mountains is chiefly lowland in which there are very few rock exposures. The observations made in this area show nearly horizontal beds of Naknek shale. A small, low anticlinal fold crosses the north end of the Buttress Range, west of the Valley of Ten Thousand Smokes. The dips on either flank do not exceed 4° and the axis of the fold is apparently very short. The area is almost inaccessible and should not be considered favorable for the discovery of oil until production is obtained at other localities.

The more favorable geologic structural features in the Cold Bay district should be thoroughly tested and the horizon of an oil-bearing bed definitely determined there before drilling is undertaken in any part of the area covered by this report.

CAPE KUBUGAKLI GOLD PLACER

The terrane northeast of Cold Bay is composed chiefly of sedimentary rocks with few large igneous intrusions except in the vicinity of Naknek Lake, and the area is very little mineralized. The only known mineral deposit of economic value occurs on Cape Kubugakli, a bold headland that extends slightly farther than the

[16] Davidson, George, Coast Pilot of Alaska, 1869, p. 36.
[17] Dall, W. H., idem, p. 199.

neighboring capes into Shelikof Strait. In 1915 placer gold was discovered by Fred and Jack Mason in a small stream about 2 miles in length rising in the snow fields of Mount Kubugakli and entering the strait at the point of the cape just west of the southwest boundary of the Katmai National Monument. Four claims were staked, and since 1915 a small amount of gold has been recovered each year. The total amount produced is about 160 ounces.

The valley of the stream is narrow and has steep banks; the floor of the valley is about 100 feet wide. Glacial material, a considerable part of which consists of large boulders, occurs on the banks of the stream, indicating that a small glacier once occupied the valley.

The gold is seemingly confined to one creek, as the area around the mountain has been prospected without success. The source of the gold is evidently the dikes in Mount Kubugakli and the numerous small quartz stringers in the fine-grained igneous rock that forms the bedrock of the stream and the cliffs along the beach. The gold occurs in the creek bed along a sinuous strip 8 to 10 feet wide. The best-paying material is usually found just below quartz stringers, which are a quarter of an inch or less in width. The bedrock is about 2 feet below a covering of gravel and large boulders, and the boulders are so numerous as to make mining unprofitable. Besides gold, small hand specimens of stibnite, molybdenite, galena, and tetrahedrite have been found in some of the stringers. Pieces of magnetite often remain in the sluice boxes.

THE OUTLOOK FOR PETROLEUM NEAR CHIGNIK

By George C. Martin

INTRODUCTION

The Chignik district has attracted considerable attention as a possible oil field ever since the enactment of the oil-leasing law. A large number of oil claims have been staked, some of the township and claim boundaries have been surveyed, and private geologic investigations in behalf of claim holders or oil companies have been made. No wells have yet been drilled, and no active preparations for drilling had been begun in August, 1923. As far as the writer knows, no oil seepages, residues, gas springs, or structural conditions that are especially favorable for the occurrence of petroleum have been found. The causes that led to the staking of most of the oil claims apparently were (1) a general but erroneous popular opinion that much, if not all, of the Alaska Peninsula is probable oil land; (2) the belief that the supposed oil-bearing strata of the Cold Bay and Cook Inlet fields underlie the Chignik district; (3) the presence on a geologic map (U. S. Geol. Survey Bull. 467, Pl. VII) of a symbol indicating "main anticlinal axis of the Aleutian Range"; and (4) the relatively easy accessibility of the Chignik district.

The information and opinions contained in this paper are based in part on a brief examination of the Chignik district which the writer made in August, 1923, and in part on earlier publications. The most comprehensive account of the geology of the Chignik region is that given by Atwood,[1] who described the geology and coal beds in considerable detail but gave no consideration to the possibility of the occurrence of oil near Chignik. Other descriptions, dealing chiefly with the coal, have been written by Dall,[2] Stone,[3] and Smith and Baker.[4]

[1] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, 137 pp., 1911.

[2] Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 801–804, 1896.

[3] Stone, R. W., Coal resources of southwestern Alaska: U. S. Geol. Survey Bull. 259, pp. 163–166, 170, 1905.

[4] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924.

The present paper includes a brief and very general account of the stratigraphy and structure, some detailed observations concerning the rocks at the localities which the writer visited, and a statement that in the writer's opinion the geologic conditions in the Chignik district are not favorable for the occurrence of oil.

GEOLOGY

STRATIGRAPHY

The rocks exposed in the Chignik district include the Upper Jurassic shale, sandstone, arkose, and conglomerate of the upper part of the Naknek formation; the Upper Cretaceous sandstone, shale, conglomerate, and coal beds of the Chignik formation; some early Tertiary (Eocene?) sandstone, shale, and conglomerate; some late Tertiary volcanic rocks; and Quaternary alluvial deposits. These rocks have been described in detail by Atwood.[5] A brief summary of their character, sequence, and thickness is given in the following table:

General sequence of rocks in Chignik district

	Feet
Quaternary:	
Alluvial, glacial, and beach deposits	100±
Tertiary:	
Andesitic and basaltic lava, agglomerate, tuff, and breccia	1,000±
Sandstone, shale, and conglomerate, with some thin beds of lignite	1,000
Upper Cretaceous:	
Chignik formation:	
Upper member—conglomerate, sandstone, and shale	300-500
Middle member—shale with many coal beds and some sandstone	300+
Lower member—shale	200±
Upper Jurassic:	
Naknek formation:	
Sandstone, conglomerate, arkose, and shale	1,000+

The base of the Naknek formation has not been recognized in the Chignik district, and it is believed that only the upper part of the formation is exposed. The supposed oil-bearing rocks of the Cold Bay and Cook Inlet fields, which lie in the lower part of the Upper Jurassic or in the Middle Jurassic, are not exposed in the Chignik district. They may not be present there, for they have not been recognized anywhere west of Wide Bay. If they are present beneath the Chignik district, they probably lie at great depths and may not be within the reach of the drill.

[5] Atwood, W. W., op. cit.

STRUCTURE

The structure of the Chignik district is not simple or especially favorable for the occurrence of oil. The rocks in some areas dip at low angles, but the general structure is not that of gentle folds or of flat rocks extending uninterruptedly throughout broad areas, but that of an intensely shattered mass in which the structural constituents consist of relatively small gently tilted blocks separated by faults or zones of shattering. Some of the broader structural features are indicated by the relations along the contacts of the major stratigraphic and structural units. These major rock masses (see Pl. V) include:

1. A large area of Upper Jurassic sedimentary rocks, which trend northeast along the main axis of the Aleutian Range west of Chignik Bay.
2. A belt of Upper Cretaceous sedimentary rocks, which trend northeast along the southeast flank of the Aleutian Range between the area occupied by the Jurassic rocks and the northwest shore of Chignik Bay and dip, in most places, southeast at low angles.
3. A belt of Upper Cretaceous and Tertiary sedimentary rocks, which trend northwest along the south shore of Chignik Bay and dip southwest.
4. A large area of Tertiary volcanic rocks south of the Upper Cretaceous and Tertiary sedimentary rocks south of Chignik Bay.
5. A large area of Tertiary and possibly Quaternary volcanic rocks in the peninsula northeast of Chignik Bay.
6. Broad areas of unconsolidated Quaternary deposits between the Aleutian Range and the shore of Bering Sea.

The southeast boundary of the large area of Upper Jurassic rocks in the mountains west of Chignik Bay is believed to be a fault. The contact between the Upper Jurassic and the Upper Cretaceous rocks on the unnamed creek next north of Whalers Creek is marked by a zone, several hundred feet wide, of brecciated shale cemented with calcite. This shattered zone is believed to lie on the extension of the fault which Atwood[6] represented as bounding the Upper Jurassic rocks south of Chignik Lake.

The writer believes that another fault, parallel to the one just mentioned, lies in the general position of the northwest shores of Chignik Bay and Chignik Lagoon. This fault is believed to form the southeast boundary of the Upper Cretaceous rocks west of Chignik Bay, separating these Upper Cretaceous rocks from the Tertiary rocks at the head of Chignik Lagoon, from the Upper Jurassic rocks near the spit at the entrance to the lagoon, and from the volcanic

[6] Atwood, W. W., op. cit., pl. 7.

rocks west of Hook Bay. It possibly, as Atwood[7] indicates, joins the fault that separates the Naknek formation from the Tertiary volcanic rocks south of Chignik Lake.

The Upper Cretaceous sediments, Tertiary sediments, and Tertiary volcanic rocks on the south shore of Chignik Bay lie in normal stratigraphic sequence, and all have a general northwest strike and southwest dip. There are some abnormal strikes and dips and some indications of faulting in this area, but their exact significance has not been determined.

The chief interest in the structure of the Chignik district is in the supposed oil-bearing Jurassic rocks of the mountains west of Chignik Bay. Such detailed information as is available concerning the structure of that area will therefore be given.

The Upper Jurassic rocks of the Aleutian Range have been described[8] as occurring in "a broad anticlinorium" or on the "main anticlinal axis of the Aleutian Range." The writer believes that the axis of the Aleutian Range in the Chignik district is anticlinal only in the sense that it exposes rocks older than those on the flanks. The range is regarded as a mosaic of uplifted fault blocks rather than an anticlinorium. The rocks may be arched in some places, as they seem to be on Chiaktuak Creek and as they are reported to be at other localities farther east, but such folding is believed to be local rather than typical of the broader structure.

On Chignik Lake the Upper Jurassic rocks dip gently, but their attitude indicates several fault blocks rather than simple folds. The rocks in the cliffs and hills bordering the western two-thirds of the lake strike northwest and dip 5°–25° NE. The rocks on the north shore about 2 miles above the outlet strike east and dip 15° S. The rocks on the southeast shore for 2 miles above the outlet strike northeast and dip 10°–12° SE. The writer believes that a fault crosses the lake at the narrow place about 2½ miles above the outlet and that there probably are one or more other faults between it and the outlet.

About a mile up the large creek that enters Chignik Lake from the west, about a third of the way down the lake, are good exposures of very dense and much shattered sandstone containing poorly preserved fragments of stems, bark, and grasslike leaves. These rocks are cut by a multitude of thin vertical veins of calcite. They are so intensely shattered that they probably could not hold oil. Beds of sandstone and black shale that are much shattered in places, probably on shear or fault zones, are exposed about 2 miles back from the lake. The rocks on this creek strike about N. 20° W. and dip 5°–8° NE.

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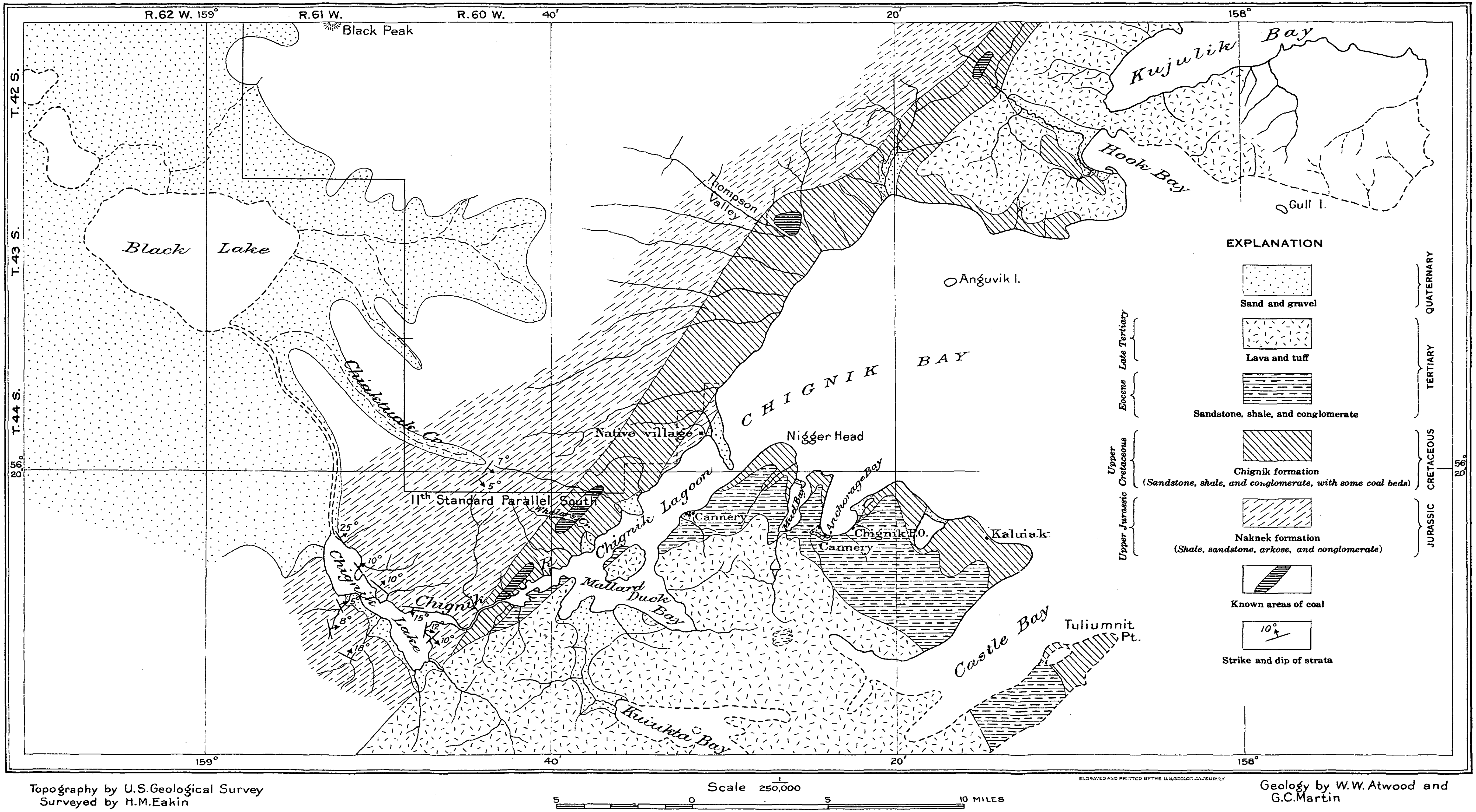
[7] Atwood, W. W., op. cit., pl. 7.

[8] Idem, pp. 28, 38, pl. 7.



GEOLOGIC SKETCH MAP OF CHIGNIK DISTRICT, ALASKA PENINSULA

The exposures on the upper half of the northeast shore of the lake consist of pebbly sandstone and conglomerate that strike N. 33°–53° W. and dip 10°–25° NE. At one locality the conglomerate is cut by sills of basalt. These beds are not as much shattered as those west of the lake.

An exposure on the north shore of the east arm of the lake about 1½ miles above the outlet shows dense "flinty" shale or fine-grained sandstone that strikes about N. 86° W., dips about 15° S., and is cut by a multitude of thin calcite veins.

The Upper Jurassic rocks exposed near the head of Chiaktuak Creek and thence southeast to the contact with the Upper Cretaceous rocks on the creek north of Whalers Creek dip 5°–7° SE. The rocks exposed west of a point about 2 miles below the head of Chiaktuak Creek have a gentle westward dip. The reversal of dip 2 miles below the head of the creek may be on an anticlinal axis, but some of the outcrops near this point apparently show that the rocks have been broken. The reversal of the dip may therefore be due to faulting, possibly along the fault that is believed to cross Chignik Lake.

CONCLUSIONS

No oil seepages, residues, or gas springs have been authentically reported from the Chignik district. The supposed oil-bearing beds of the Cold Bay and Cook Inlet fields apparently do not crop out near Chignik, and if present there probably lie at great depth, perhaps beyond the reach of the drill. The rocks of the Chignik district are cut by many faults and shattered zones, so that in many places they would not be likely to retain oil. No domes are known. It is doubtful if there are any unbroken anticlines. It is possible that oil pools may be found at localities which the writer has not seen or where the oil has been sealed in by variations in the porosity of the beds or by faults, but the available information indicates that the outlook for oil in the Chignik district is not hopeful.