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 indent&~~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.

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 greet 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 sf Paleozoic age.

Kamishak chert.—The Kamishak chert, of Upper Triassic age, is typically exposed on the west shore sf 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 a d *tuffs.*—The western foothills of the mouatains 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 accumulate& At many plqces 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 arb 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 them 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 these 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. Qne 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 end 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. 189-171, 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 cenglomerate. 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

[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 considerabk 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 simples. 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+ feat.	Tuxedni formation; shale, sandstone, grit, and tuff; 500+ feet.	Tuxedni sandstone; sandstone, shale, arkose, and conglomerate; 7,000 feat.
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 apes 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, ail 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 approxifnately 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 Karnishak 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 nbrth 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 anticliial 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 dose 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 anti- 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 khan 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 hag 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.