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A GEOLOGIC RECONNAISSANCE

OF THE

ILIAMNA REGION, ALASKA

BY

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PREFACE.

By Alfred H. Brooks.

Even during the Russian occupation of Alaska the journeys of traders and a few explorers had determined the position of the larger geographic features of the southern part of the region described in this volume. Since then this knowledge has been augmented by two expeditions organized for exploration and by the journeys of traders and prospectors. In this way a general knowledge of the relief and drainage of the province was obtained as well as some idea of its mineral resources. Previous to 1909, however, when the surveys whose results are here presented were made, accurate maps and knowledge of the geology and the distribution and occurrence of the mineral resources of the Iliamna region, except for the shores of Cook Inlet, were almost entirely lacking.

The Geological Survey's general plan for the investigation of the mineral resources of Alaska provides for reconnaissance geologic and topographic surveys of the Territory. Naturally the areas of proved economic importance have been taken up first, and this accounts for the long delay in surveying the Iliamna region, in which there has been no mineral production. Copper and gold lode prospects have been found within the district, some of which may prove to have commercial value. Relatively little work has been done on these prospects, so that it is not possible to give a definite opinion of the commercial importance of any of them.

The report is based on about four months of field work. During this time the two topographers of the party mapped 5,150 square miles, including the area of the lakes, and the two geologists 3,000 square miles. The topographic work is accurate to the scale, and much of the geologic mapping was done to a greater degree of refinement than has usually been possible in rapid reconnaissance surveys. Surveys made in 1903 and 1904 along the west shore of Cook Inlet were utilized to extend the mapped area to the east.

The matter presented in this volume is of importance not only because it describes a field new to the geologist, but also because it contributes many facts that will help elucidate the stratigraphy and structure of adjacent fields. The considerable detail in which the Mesozoic sequence has been determined is worthy of special note. Of importance to the miner are the facts set forth that the copper lodes occur in metamorphic limestones near the contacts of intrusive rocks and that the auriferous quartz veins thus far discovered occur either in greenstones or in granites.

This report covers an area lying between the Mount McKinley region on the north, which has already been described,[1] and the Alaska Peninsula, the general features of the geology and mineral resources of which have been summarized.[2] Some progress has been made in this volume in correlating the geology of these two regions, but much remains to be done before definite statements can be made concerning the stratigraphic equivalency of their geologic formations. There still remains a large area lying between Lake Clark on the south and the Rainy Pass region of the Alaska Range on the north which is almost entirely unexplored and which should, therefore, be surveyed.

Of possibly greater commercial importance would be a survey of the basin of Mulchatna River, lying west of the area here discussed. Auriferous gravels have been found within this basin, some of which are reported to carry sufficient gold to warrant exploitation, and a survey of this field will be undertaken as soon as circumstances permit.

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[1] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911.

[2] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: Bull. U. S. Geol. Survey No. 467, 1911.

A GEOLOGIC RECONNAISSANCE OF THE ILIAMNA REGION, ALASKA.

By G. C. Martin and F. J. Katz.

INTRODUCTION.

LOCATION.

The region described in this report covers an area of about 5,150 square miles. It is situated, as is shown on figure 1 (p. 12), in southwestern Alaska, west of the southern half of Cook Inlet and north of the Alaska Peninsula. It comprises the greater part of the drainage basins of Kvichak River, which is the outlet of Iliamna and Clark lakes flowing into Bristol Bay, and of the streams flowing into Cook Inlet from the west, south of and including Tuxedni Bay. The extreme limits of this area are bounded by parallels 59° and 60° 30′ N. and meridians 152° 30′ and 157° W. The nearest large town is Seward, which is about 150 miles to the east.

GEOGRAPHIC FEATURES.

TOPOGRAPHY.

Most of the northeastern part of this region lies within the Chigmit Mountains and consists of high, rugged mountain masses and narrow intervening valleys. The general elevation of these mountains is from 4,000 to 6,000 feet, although many peaks near the north end of Lake Clark are 7,000 feet high and the highest peak of the whole district is Mount Iliamna, which is about 10,000 feet high. (See Pl. VIII, *A*, p. 86.)

At Iliamna Bay the mountains extend eastward to the waters of Cook Inlet. Both north and south of this point a belt of foothills and lowlands, from 2 to 10 miles in width, reaches from the edge of the high mountains to the shore of the inlet. Much of the coast is deeply embayed, Tuxedni Bay, Iniskin Bay, and Iliamna Bay extending into the high mountains, and the other bays having their heads in the foothill belt. Iliamna and Bruin [1] bays head at well-known low passes

[1] Locally known as Bear Bay.

through the mountains, and Tuxedni Bay and the southwest arm of Kamishak Bay are reported to have passable routes from them

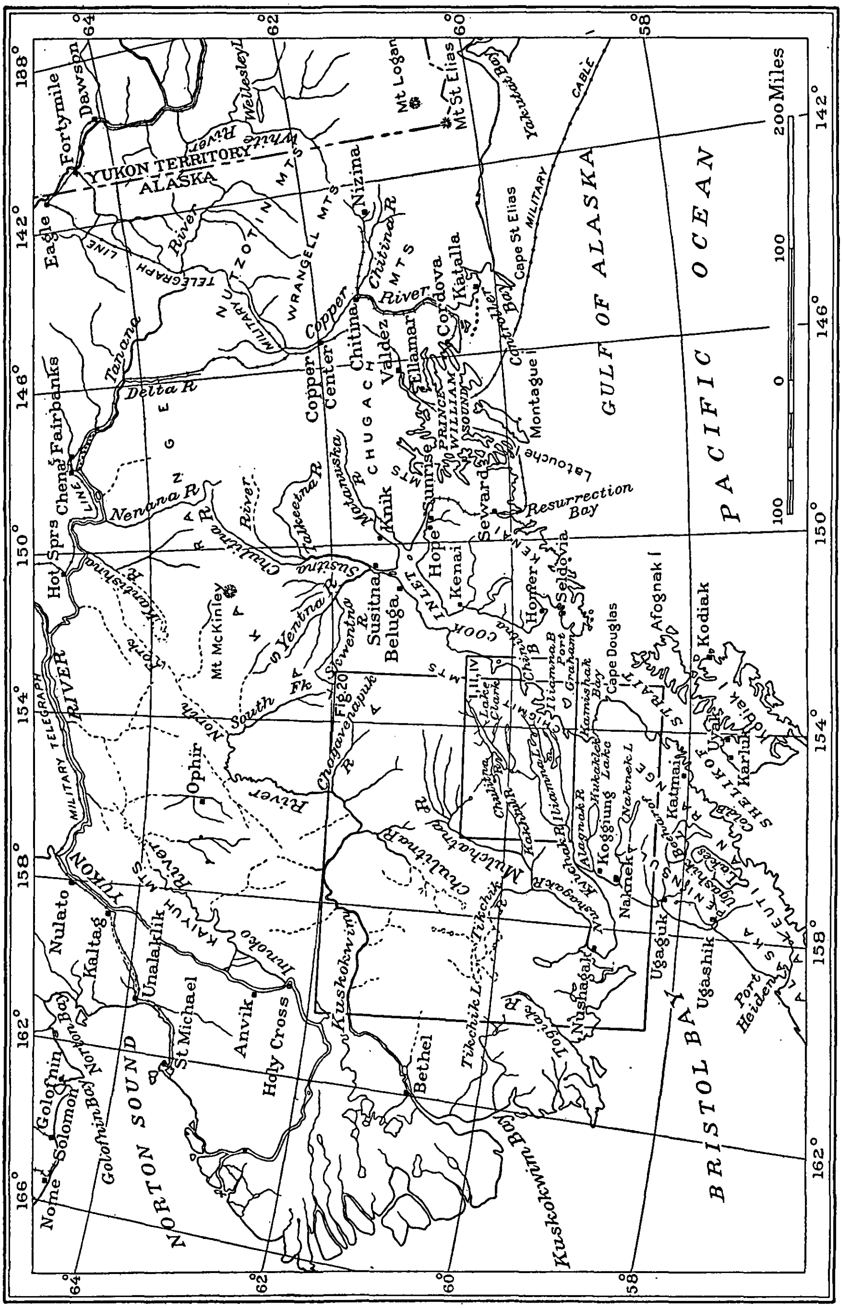


FIGURE 1.—Outline map of south-central Alaska, showing areas covered by the larger-scale maps.

FIGURE 1.—Outline map of Alaska, showing areas covered by the larger scale maps.

through the mountains. The topographic features of such parts of the region as have been surveyed are shown on Plate I (in pocket).

The western part of the region lies in the wide valleys of the lower ends of Iliamna and Clark lakes and consists of low gravel-covered flats with numerous isolated hills and groups of hills distributed irregularly through them. At the west end of Iliamna Lake the valley opens out into the wide coastal plain of Bering Sea. A broad low pass at the head of Chulitna River leads into the Mulchatna Valley, which is a region of flats and low rounded hills. The general position of the Mulchatna region is shown on figure 20 (p. 131).

LAKES.

Iliamna Lake lies in the south-central part of the region. It is about 80 miles long and in general is from 8 to 20 miles wide, being the largest body of fresh water in Alaska. It is about 50 feet above tide, and drains through Kvichak River into Bristol Bay. Reported soundings indicate a depth, at the east end, of many hundred feet. Lake Clark, in the northern part of the region, is about 52 miles long and from 1 to 4 miles wide. It is about 220 feet above tide or 170 feet above Iliamna Lake, to which it is tributary through Sixmile Lake and Newhalen River. The depth of Lake Clark "about 6 miles east of Cape Shishkin and about half a mile from the south shore of the lake" (probably not far from Tanalian Point) was determined by Schanz[1] to exceed 606 feet. Sixmile Lake is at practically the same elevation as Lake Clark, from which it is separated by a short strait. It flows out through Newhalen River into Iliamna Lake. Kontrashibuna Lake, tributary to Lake Clark from the east through Tanalian River, is 14 miles long and half a mile to a mile wide and lies about 560 feet above tide. Upper and Lower Tazimina lakes, which are about 650 feet above tide, drain through Tazimina River into Sixmile Lake. Many other smaller lakes lie on the various tributaries of Lake Clark. Meadow and Moose lakes lie about 600 feet above tide, on the headwaters of the river which enters Iliamna Lake at the head of Intricate Bay. Kakhonak Lake, about 260 feet above tide, and another unnamed lake above it, drain through Kakhonak River into Iliamna Lake at the head of Kakhonak Bay. Hundreds of smaller lakes are distributed over the whole western part of the region.

RIVERS.

The largest stream of this region is Kvichak River, which flows from Iliamna Lake into Bristol Bay. Its length from the outlet of the lake to Koggiung is about 62 miles. In the upper 17 miles of its course it has an average current of probably 6 miles an hour and is much broken up by islands and bars into narrow, shallow channels.

[1] Schanz, A. B., Frank Leslie's Ill. Mag., vol. 73, 1891, p. 224.

The greater part of its fall is in this part of its course. For the next 13 miles it is somewhat less swift, probably running 3 or 4 miles an hour, and is confined in a single deep channel. The lower 32 miles of its course is tidal, the water being of considerable depth even at low tide. The river is navigated by cannery steamers for about 22 miles above Koggiung, and by launches and Columbia River boats (when favored by strong west winds) for its entire length.

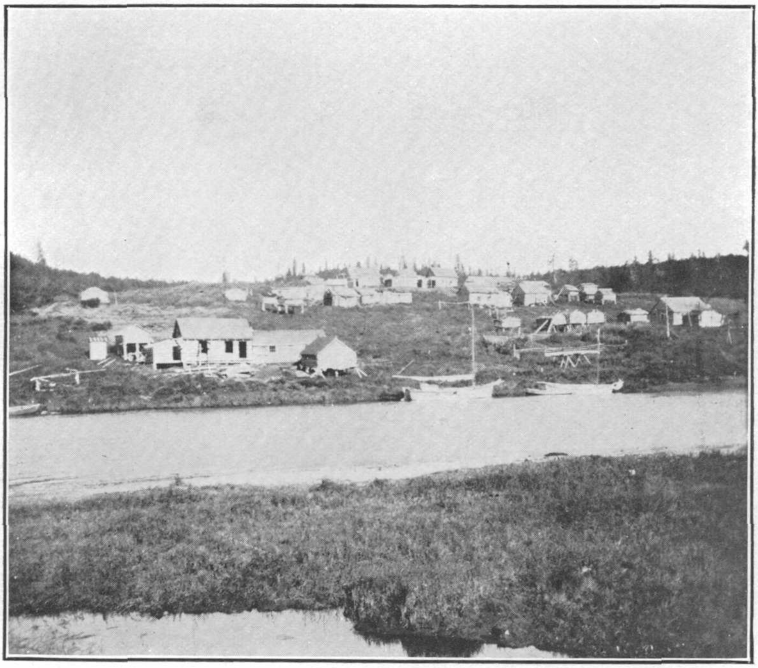
Newhalen River, the second stream of the area in size, is about half the volume of the Kvichak and about 23 miles in length. For the upper 11 miles of its course it can be navigated by canoes and poling boats. Rapids and reported falls make even canoe navigation impossible for the lower 12 miles. These rapids are avoided by a 5-mile portage.

The other large streams of the region are Pile, Iliamna, Kakhonak, Chekok, and other unnamed rivers tributary to Iliamna Lake; and Chulitna, Tlikakila, Chokotonk, and Tanalian rivers, and other streams tributary to Lake Clark. (See Pl. III.) Tazimina River, draining the lakes of the same name, enters Sixmile Lake just above its outlet. Large unnamed rivers enter Cook Inlet from the region here under discussion at the head of Tuxedni Bay and at the head of the southwesternmost arm of Kamishak Bay. The streams reaching Cook Inlet between these are all small.

Many of these streams may be used for water power whenever the development of the region creates a demand for it. One of the most promising water powers is on Tanalian River, which has a fall of 60 feet in a single drop at the outlet of Kontrashibuna Lake (Pl. III, *B*) and which descends about 340 feet in the 4½ miles between Kontrashibuna and Clark lakes. Tazimina River descends about 430 feet in about 8 miles from the lip of the hanging valley containing the Tazimina Lakes to Sixmile Lake, most of this fall being in a distance of 3 miles. Newhalen River descends nearly 170 feet in its lower rapids, which are distributed throughout a distance of about 6 miles. Meadow Lake lies about 550 feet above Iliamna Lake, and the stream draining it, which is about 20 miles long, may have available water power. Kakhonak Lake is about 210 feet above Iliamna Lake, and its water descends in a distance of about 5 miles. These streams are all large, and their flow is regulated by natural storage in lakes. Many of the smaller streams could also doubtless be used if local power should ever be needed.

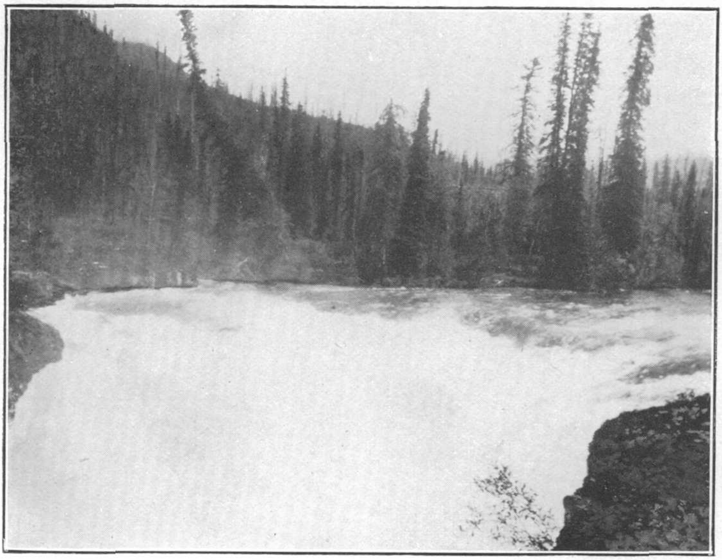
GLACIERS.

The existing glaciers of this region are neither numerous nor large. Only near Mounts Iliamna and Douglas, and outside of the area actually mapped, are there large unbroken areas above snow line



A. ILIAMNA VILLAGE AND RIVER.

Showing character of lowlands in valleys tributary to Iliamna Lake.



B. TANALIAN FALLS.

Showing water power and character of timber on Clark Lake.

which are competent to form the gathering grounds for extensive glaciers.

There are 18 small glaciers in the headwaters of the drainage tributary to Kontrashibuna Lake, and four on the streams coming into Lake Clark near its head from the east. These glaciers lie at altitudes of 3,400 to 5,800 feet in the Kontrashibuna drainage, and 2,000 to 6,000 feet at the head of Lake Clark.

The snow fields around Mount Iliamna send out several valley glaciers of fair size. Three of these go to the south and are tributary to streams entering Chinitna Bay. They are known as East, Middle, and West glaciers. Another good-sized valley tongue goes out to the north and is tributary to the unnamed stream at the head of Tuxedni Bay. Several other glaciers of this type must flow west from these snow fields, but nothing is known of their position nor size. The abundance of glacial silt in the waters of Iliamna and Pile rivers and of all the larger streams east of Lake Clark is conclusive evidence of the existence of many glaciers in that region.

The high country around Mount Douglas and the neighboring peaks at the north end of the Aleutian Range is a notable feeding ground for glaciers. Seven or eight large glaciers are known to radiate from these snow fields, several of which reach almost to tidewater.

CLIMATE.

The climate of this region has some features of both the coast and the interior climates of Alaska. The coast of Alaska is characterized by heavy precipitation and by mild winters and rather cool summers. The interior of the Territory has far less precipitation, the conditions verging in places on semiaridity, and has very cold winters and rather warm summers.

This region has abundant precipitation, though not as much as the ocean coast. The early summer months are frequently favored with long intervals of clear weather. Similar conditions are said to exist also during part of the winter. It was noticed during the summer of 1909 that cloudiness and precipitation were much greater in the high mountains at the upper ends of Iliamna and Clark lakes and in the Aleutian Range than in the broad valleys of the lower ends of the lakes. In the summers of 1903 and 1904, cloudiness and rain were far less at the head of Kamishak Bay than on the mountainous parts of the coast both north and south of that point.

This region is also believed to have a colder winter and a warmer summer temperature than the open coast, in this respect also being intermediate between the coast and the interior.

The following fragmentary weather observations have been made within the area described:

Temperature (° F.) at Millet's camp (north shore of Iliamna Lake) from Dec. 1, 1907, to May 31, 1908.

[Records by O. B. Millet.]

	8 a. m.			7 p. m.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
December	38	−13	9.9	34	−10	11.3
January	34	−10	15.3	36	− 5	16.1
February	28	−30	−8.0	31	−26	−3.8
March	32	−20	11.1	34	−15	14.8
April	40	−13	26.3	40	3	29.3
May	49	30	40.7	65	29	41.6

Miscellaneous observations.

December 31, 1905.—Ice began to form on Iliamna Lake.[1]
January 12, 1906.—Ice 16 or 18 inches thick on Iliamna Lake.[1]
February 12, 1906.—Ice in Iliamna Bay.[1]
March 16, 1906.—Ground began to become bare.[1]
January 17, 1908.—Iliamna Lake froze.[2]
May 28, 1908.—Iliamna Lake opened.[2]
June 2, 1909.—Ice out of upper end of Iliamna Lake.[3]
June 20, 1909.—Ice all gone from Iliamna Lake.[3]
September 13, 1909.—Snow at 2,000 feet.[3]
September 17, 1909.—Snow at 1,200 feet.[3]
September 20, 1909.—Severe freeze.[3]
September 27, 1909.—Snow at Iliamna Bay.[3]

VEGETATION.

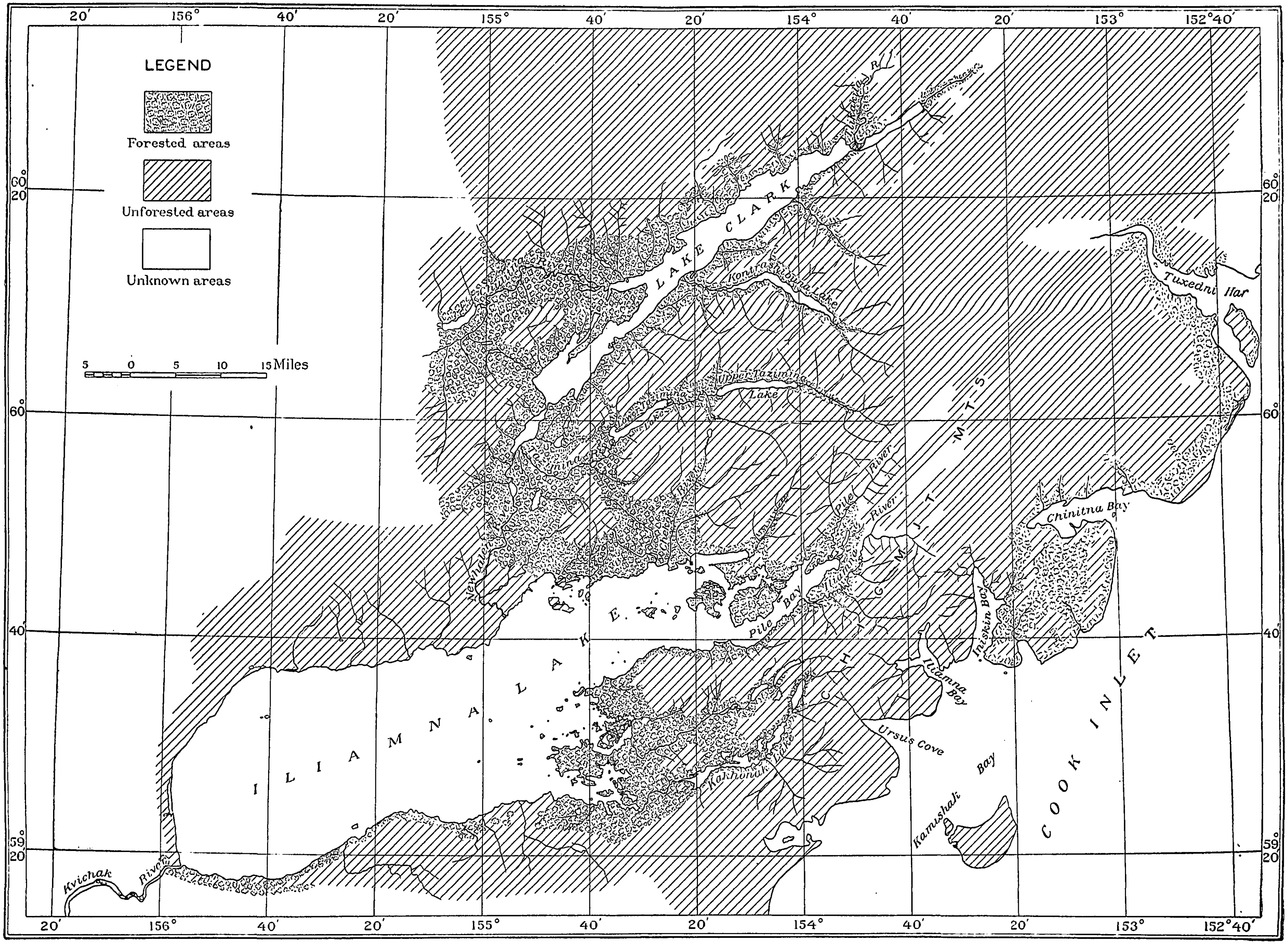
GENERAL FEATURES.

This region lies in the borderland between the densely forested coast of southeastern and south-central Alaska and the treeless coasts of the Alaska Peninsula and Bering Sea. Parts of it have the vegetation of the treeless tundras. Other parts have a vegetation rather closely akin to that of much of the lightly forested interior of Alaska and of much of northern Canada. Still other tracts are treeless because they are high and possess the universal features of the area above and near to snow line. The distribution of the forested and nonforested areas is shown on Plate IV.

FORESTS.

The forests extend throughout the lowland areas on the coast of Cook Inlet north of Iniskin Bay, in the valley of Lake Clark (Pl. III,

[1] Fifteenth annual report on the introduction of domestic reindeer into Alaska, 1906, pp. 168–172.
[2] Statement by O. B. Millet.
[3] Observations of U. S. Geological Survey.



MAP SHOWING DISTRIBUTION OF FORESTS IN THE ILIAMNA REGION.

B), and along the shores of Iliamna Lake east of longitude 155° W. The south shore of Iliamna Lake between longitude 155° W. and the outlet of the lake and most of the Kvichak Valley have only small scattered areas of forest. These forests consist chiefly of spruce with much birch intermingled with it or in separate groves. Birch is practically coextensive with the spruce throughout this region, except possibly on Cook Inlet. "Cottonwoods" also grow throughout the area of the spruce, but have a wider distribution, being present along many of the streams in the otherwise treeless areas.

The character of the vegetation at the mouth of Iliamna River has been described by Osgood [1] as follows:

> The timber in this vicinity is of the characteristic type found throughout the Hudsonian zone in northern Alaska. The white spruce (*Picea canadensis*) is the dominant tree, and with it are found its usual deciduous neighbors, the balsam poplar and the paper birch. Alders abound on the hillsides and willow thickets border the streams. Mosses, lichens, and small woody plants, chiefly Ericaceæ, cover the ground. A few small ponds near the river are bordered with grasses and sedges, and, where conditions favor, are filled with large yellow pond lilies (*Nymphæa*).

Concerning the timber on Lake Clark, Osgood [2] says:

> A good growth of timber surrounds the entire lake and runs up the mountain sides from 500 to about 1,500 feet. It is of much the same character as that at the head of Lake Iliamna. The black spruce (*Picea mariana*), which was not found about Lake Iliamna, however, is quite abundant on Lake Clark. This is particularly the case about the lower end of the lake, from the head of the Nogheling [Newhalen] River to Keejik, where there is more or less low, moist ground suited to the trees. The aspen (*Populus tremuloides*) is also found in a few places near the Nogheling and about Lake Clark. On the steep mountain sides south of the lake the white spruce is the principal tree, and in many places composes the entire forest. On the north side it is also abundant, but the deciduous poplars and birches are largely mixed with it. This difference in the timber of the two sides is doubtless due to slope exposure. Many of the small, low peninsulas projecting into the lake on the north side are almost entirely occupied by groves of poplars (*Populus balsamifera*), many individual trees slightly exceeding 12 inches in diameter. A beautiful open forest of birch and spruce is found in some localities, and much of the ground in some places produces tall grass (*Agrostis*) in great abundance. Devil's-club (*Echinopanax*) occurs in a few dark, sheltered places near the head of the lake, and perhaps reaches the northwestern limit of its range there. Willows and alders abound in their respective relative positions, while smaller shrubs and boreal plants are in characteristic profusion.

The spruce forests mentioned above contain good timber only locally. They are everywhere interspersed with open grassy meadows, bare ridges and hilltops, treeless swamps, and patches of alders and willows. (See Pl. III, *A*, p. 14.) Much of the spruce

[1] Osgood, W. H.,. A biological reconnaissance of the base of the Alaska Peninsula: North Am. Fauna, No. 24, 1904, p. 11.
[2] Idem, pp. 13–14.

is, moreover, very small and is worthless save for firewood. None of the forest can really be classed as commercial timberland. The best of it would supply good lumber for little more than the slight present local needs. The supply of material suitable for mine timber is, however, probably adequate to any local demands which can now be foreseen.

A rank growth of grass is present in all parts of the region, especially where the timber has been burned, and in the Cook Inlet lowlands. Abundant horse feed can be found throughout the greater part of the region, from about June 1 to October 1. Some hay is cut every year, especially near Iliamna village and the "Dutton prospects" and at the head of Cottonwood Bay. The areas of good grass are, however, not large and it is not probable that this could become a grazing country to more than a comparatively minor extent.

TREELESS AREAS.

The north shore of Iliamna Lake between Newhalen and Kvichak Rivers has no trees except "cottonwoods." The same condition holds on the west coast of Cook Inlet south of Iniskin Bay and over the greater part of the Alaska Peninsula. In the latter district spruce is known only on the shores of Iliamna Lake and on Kukak Bay.[1] It is definitely known to be absent on the southeast coast of the peninsula from Iliamna Bay to Cold Bay (except at Kukak Bay), along the route across the peninsula[2] from Naknek to Katmai, in the vicinity of Becharof Lake[3] and Ugashik Lakes,[4] and in the vicinity of Chignik Bay and Port Moller.[5]

The character of the vegetation in these nonforested areas at low altitudes is shown in the following description by Osgood[6] of the vegetation of the lower slopes around Iliamna Bay:

> They support no trees worthy of the name, but there are several groves of fair-sized balsam poplars (*Populus balsamifera*) in the narrow valley at the head of the bay and also on some low ground about a small indentation on the west side called Cottonwood Bay. On the mountain sides a few tiny spruces from 1 to 2 feet high proudly raise their heads above the matted mosses, lichens, and small shrubs. A few depauperate sprouts of the paper birch (*Betula papyrifera alaskana*) also occur. The characteristic shrubs are the alder (*Alnus viridis?*) and the dwarf birch (*Betula glandulosa rotundifolia*), which are found in great abundance.

Throughout this region the higher lands are bare of all vegetation except moss, grass, and small bushes. Timber line, the term being

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[1] Fernow, B. C., Forests of Alaska: Harriman Alaska Expedition, vol. 2, 1902, p. 244.

[2] Spurr, J. E., and Post, W. S., Report of the Kuskokwim Expedition: Maps and description of routes of exploration in Alaska in 1898, p. 33.

[3] Osgood, W. H., A biologic reconnaissance of the base of the Alaska Peninsula: North American Fauna, No. 24, 1904, pp. 19–22.

[4] Observations of A. G. Maddren.

[5] According to several members of the Geological Survey.

[6] Osgood, W. H., op. cit., pp. 10–11.

used to mean the upper limit in altitude of nonstunted spruce, and not the lateral limits of the forests where they abut on the low-altitude, nonforested areas, is in general at an altitude of 800 to 1,400 feet. Timber line was seen at its highest local altitudes near the heads of Clark, Kontrashibuna, and Upper Tazimina lakes, from which points it decreases to the south and west.

Altitude of upper limit of spruce.

	Feet.
Head of Lake Clark	1,200–1,400
Kontrashibuna Lake	1,100–1,200
Head of Upper Tazimina Lake	1,200–1,400
North side, Lower Tazimina Lake	1,100
South side, Lower Tazimina Lake	900–1,000
West of lower end of Lake Clark	1,000
West of Newhalen River	800–1,000
Head of Pile Bay	1,000
Knutson Bay	800
East of Reindeer Station	800– 900

Large areas of "reindeer moss" are found throughout the greater part of the region, both in the open areas within the forested belt and in the nonforested areas. The low hills south of Iliamna Lake have an especial abundance of it. This has led to the establishment of the Government reindeer station at the head of Kakhonak Bay.

CAUSE OF LIMITS OF FORESTS.

In the lowlands of southwestern Alaska densely forested and absolutely unforested districts lie in close proximity, in areas which are not known or believed to differ appreciably in any characteristic determining the presence or absence of trees. Several explanations of this fact have been offered, and as some of these are geologic they are presented here.

Becker[1] believes that there may have been recent uplift of this part of the Alaska coast, and that the absence of trees may be due to the former presence of salt-water straits with heavy tidal currents connecting Bristol Bay with Cook Inlet by way of Iliamna and Clark lakes, and to the submergence of the western part of Kodiak Island.

This explanation was accepted as probable by Spurr,[2] who believes that the recent submergence is an established fact, and that the subsequent uplift has been so rapid that the timber has been unable to migrate westward at a rate equal to the retreat of the shore line.

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[1] Becker, G. F., Reconnaissance of the gold fields of southwestern Alaska, with some notes on the general geology: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 19.

[2] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 68.

Gannett[1] believes that the cause of the absence of timber is an open question. He holds that in neither rainfall, temperature, nor winds do the treeless areas differ from the forested coasts farther east.

On the other hand, Fernow[2] claims that the spruce has in very recent time migrated westward, and may still be migrating, although the movement is retarded by the prevalence of moist winds from the southeast and south from September to May. He subsequently[3] elaborated this explanation, holding that the Alaska Peninsula and Aleutian Islands show evidence of recent and volcanic origin, that a forest could come to them only from the northeast, and that for this to take place it is essential that the winds should be dry and should blow from the north and east when the spruce releases its seed, from September to May.

According to Osgood[4] it hardly seems possible that there is even an appreciable difference in temperature between the timbered region around Lake Clark and the treeless region around Becharof Lake. He believes that all the causes determining the nonexistence of coniferous trees can hardly be ascertained until more work is done, but that the prevalence of wind and storm regardless of temperature would restrict arborescent vegetation in almost any latitude, though in spite of these adverse circumstances the timber may be advancing.

The observations of the Geological Survey party in 1909 show that there is no essential difference between the forested and nonforested areas in rainfall, temperature, intensity of winds, or in rocks and soils. They also support the conclusions of Fernow and of Osgood that the forests are now advancing into the treeless areas. The evidence for this lies chiefly in the scarcity of old dead trees throughout most of the forest areas and their complete absence on the margins of the forests. The earlier geologic explanation by assumed recent elevation following a period of submergence must be discarded, for proof of these recent movements is not at hand.

SETTLEMENTS.

The largest settlement and the chief trading point for this entire region is Iliamna village (Pl. III, *A*, p. 14), situated on Iliamna River, 4 miles above its mouth and 12 miles from Iliamna Bay. This village has a population of about 15 whites and 40 natives. It has

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[1] Gannett, Henry, General geography: Harriman Alaska Expedition, vol. 2, 1902, pp. 272–273.

[2] Fernow, B. E., Forests of Alaska: Harriman Alaska Expedition, vol. 2, 1902, pp. 244–246.

[3] Fernow, B. E., The forests of Alaska: Forestry and Irrigation, vol. 8, No. 2, 1902, p. 70.

[4] Osgood, W. H., A biologic reconnaissance of the base of the Alaska Peninsula: North Am. Fauna, No. 24, 1904, pp. 23–24.

a United States commissioner and a Government school. Three stores are located here. A Government reindeer station has been located at the head of Kakhonak Bay since the spring of 1905. The other villages, which are inhabited permanently only by natives, include Kakhonak, on the south shore of Iliamna Lake 12 miles west of the head of Kakhonak Bay; Newhalen, near the mouth of Newhalen River; Nondalton, on the west shore of Sixmile Lake; and Kaskanak, on Kvichak River, about 10 miles below Iliamna Lake. Iliamna and Nondalton are Kenai villages, the others being Eskimo. The former villages of Chekok and Nikhkak are now abandoned. There are several cabins belonging to prospectors and traders at Iliamna and Cottonwood bays, but these are occupied only when a steamer is expected or when freight is being moved from the coast. Numerous isolated camps and cabins are scattered throughout the district. Most of these were built by prospectors, who have been at work in a small way since 1898 over the greater part of this region and in the adjacent Mulchatna country. The most active of these operations were from 1903 to 1906; they are described under the heading of "Mineral resources."

Dutton post office, which was formerly situated at the head of Cottonwood Bay (the southern arm of Iliamna Bay), is now (1910) abandoned. The entire region is dependent for its summer mail on the accommodation of the postmasters east of Cook Inlet and of the mail clerks and other officers of the steamers calling at Iliamna Bay.[1] Winter mail is received by private delivery from points on the Cold Bay and Nushagak mail route.

The population of the local and neighboring villages according to census reports has been as follows:

Population of native villages.

	Tenth Census, 1880.	Eleventh Census, 1890.
"Chikak"	51	Not given.
Iliamna	49	76
Kakhonak	Not given.	28
Kaskanak	119	66
"Kichik"	91	Not given.
Koggiung	29	133
"Kivichakh"	Not given.	37
"Molchatna villages"	180	Not given.
"Nikhkak"	Not given.	42
"Noghelingamiut"	Not given.	16
	519	398

TRANSPORTATION ROUTES.

This region is accessible only by water, there being two well-traveled routes leading to it—one from the east by way of Iliamna Bay and the other from the west by way of Koggiung.

[1] Iliamna post office was established in 1910.

The steamers from Seattle to Prince William Sound and Cook Inlet and also the local steamers from Valdez westward and from Seldovia and Port Graham to the upper Cook Inlet ports will land at Iliamna Bay whenever weather permits and sufficient business warrants it. Iliamna Bay is about a day's sail from Seward or 6 to 12 days from Seattle. There is usually about a boat a month from May to October, inclusive, and occasional boats during the winter.

A good horse trail leads from the head of Iliamna Bay to Iliamna village, a distance of about 12 miles. This trail crosses a 900-foot summit 3 miles west of Iliamna Bay. Another trail leads from the head of Cottonwood Bay to Iliamna village, about 20 miles, crossing three summits at elevations of 1,700, 1,500, and 1,975 feet, at 4, 5½, and 15 miles from Cottonwood Bay, descending to 1,400 and 600 feet between the summits. A good wagon road has been built for the first 2 miles and from the fifth to the fourteenth mile, or as far as the Dutton copper prospects. These trails can usually be used by horses from June 1 to November 1. Dogs are used during the rest of the year.

From Iliamna village all parts of Iliamna Lake and Kvichak River can be reached in boats, there being several large sailboats and a gasoline launch at the village. Horses can also be taken from Iliamna village throughout the greater part of the region, except in the high mountains. The shores of Lake Clark are impassable for horses east of longitude 154° W.

Bristol Bay is visited by cannery vessels about May 1, and by a passenger steamer from Valdez once a month in June, July, August, and September. Part of the supplies for the stores at Iliamna village are brought in by this route, which has the advantage of being all water and avoiding the portage from Iliamna Bay to the village.

Iliamna Lake can also be reached by a portage from the head of Kamishak Bay to the head of Kakhonak Bay. This route is said to be easy, the pass being low. It is, however, not much used except by natives, because of the difficulty of having supplies landed on this uncharted part of the coast.

Many of the supplies for Lake Clark and the Mulchatna country west of it are taken in from Iliamna village by dogs in the winter. Summer transportation to Lake Clark may be accomplished either with horses or by boats to a point on the shore of Iliamna Lake 4 miles east of Newhalen River, by a 5-mile portage from that point to Newhalen River above the lower rapids, and thence by boat up the Newhalen. Native packers are usually available at this portage.

The Mulchatna region can be reached from Lake Clark by boats up Chulitna River to a short portage at the head of Swan River, or up Chulitna and Koksetna rivers to points near the headwaters of other of the eastern tributaries of the Mulchatna. (See fig. 20, p. 131.) It can also be reached by taking horses over this same general route.

Railroad surveys for the proposed Alaska Shortline Railway were made from 1902 to 1908 along a route leading from the head of Iliamna Bay westward along the trail to Iliamna village, around the north shore of Iliamna Lake to Chekok Bay, northwestward to the lower end of Lake Clark, up the Chulitna Valley and across the Mulchatna Valley to the Kuskokwim and Yukon. An attempt was made in 1902 to carry mail and passengers over this route by the Trans-Alaska Co. Several miles of trail and a few cabins were built, but the venture was not a success.

ACCOUNT OF INVESTIGATIONS.

The field work on which this report is based was a combined topographic and geologic reconnaissance by a party of 12 men in charge of D. C. Witherspoon, topographer. The party landed and began work at Iliamna Bay, May 16, 1909. After crossing the mountains to Iliamna village two subparties were organized. One of these, in charge of Mr. Witherspoon, consisted of six men and was equipped with a pack train of eight horses. This party traversed the area north of Iliamna Lake and east of Lake Clark. F. J. Katz accompanied this party as geologist. The other party, in charge of G. C. Martin, geologist, likewise consisted of six men and was equipped with three Peterborough canoes. This party traversed the shore lines of Iliamna and Clark lakes, mapping as much of the topography and geology as could be reached from the shore, and made an exploratory trip down Kvichak River to Koggiung. C. E. Giffin accompanied this party as topographer and Theodore Chapin served as geologic field assistant. Field work for both parties ended at Iliamna Bay on September 28.

The results here given include the hitherto partly unpublished results of a geologic and topographic reconnaissance of the supposed oil fields between Iniskin and Chinitna bays made by G. C. Martin[1] in 1903, and of a similar reconnaissance by T. W. Stanton and G. C. Martin[2] in 1904, of the west coast of Cook Inlet from Tuxedni Bay to Cape Douglas and on the southern coast of the Alaska Peninsula.

Comparatively little was known of either the geology or the general features of this region prior to these investigations. The earlier explorations are, however, of interest and are briefly described below.

[1] Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382; The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 37–49; Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139.

[2] Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 291–410.

The first exploration of parts of this region of which records are available was by Pinart,[1] who, in 1872, made extensive explorations on the coast of the Alaska Peninsula and Bering Sea, ascending Kvichak River to Iliamna Lake. The results of these explorations are still largely unpublished.

Schanz and Clark, early in the winter of 1891, ascended Nushagak and Mulchatna rivers and explored the lower ends of Clark and Iliamna lakes. This expedition brought back important geographic information, but no geologic data. The accounts of this exploration, written by Schanz,[2] made known the existence of Lake Clark definitely to the general public for the first time. The presence of a large lake in this general position had, however, been vaguely known for a long time. In fact it had been represented on some of the early Russian charts, and it is now known that it was visited by McKay about 1881.

Later and more detailed information, including some geologic data, was gained in an exploration made for the Biological Survey by Osgood[3] and Maddren in 1902.

Brief geologic notes dealing chiefly with the outlying parts of this district have been published by Dall,[4] Spurr,[5] and Brooks.[6] Dall is the only one of these who was personally familiar with any part of the area described in this report, having studied the Jurassic rocks at Tuxedni Bay in 1896.

The United States Coast and Geodetic Survey made a detailed chart (No. 8665) of Iliamna Bay in 1907, and has been engaged in primary triangulation on Cook Inlet in the succeeding seasons.

The results of the investigation on which the present report is based have already been published[7] in abstract.

Although this is strictly a joint publication it nevertheless seems desirable to indicate the individual responsibility for the opinions

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[1] Pinart, A. L., Voyage à la côte nord-ouest d'Amérique, d'Ounalashka à Kadiak (îles Aléoutiennes et péninsule d'Aliaska) : Bull. Géographie, 6th ser., vol. 6, Paris, 1873, pp. 561–580, map.

[2] Schanz, A. B., Frank Leslie's Ill. Mag., vol. 73, 1891, pp. 138, 240; The fourth or Nushagak district: Report on population and resources of Alaska at the Eleventh Census, 1890, pp. 91–97.

[3] Osgood, W. H., A biologic reconnaissance along the base of the Alaska Peninsula: North Am. Fauna No. 24, 1904, 86 pp.; Lake Clark, a little known Alaskan lake: Nat. Geog. Mag., vol. 15, 1904, pp. 326–331.

[4] Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 763–906.

[5] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898; Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 33–264; Lakes Iliamna and Clark: Maps and descriptions of routes of exploration in Alaska in 1898, with general information concerning the Territory, U. S. Geol. Survey, 1899, p. 129.

[6] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906.

[7] Martin, G. C., and Katz, F. J., Outline of the geology and mineral resources of the Iliamna and Clark lakes region: Bull. U. S. Geol. Survey No. 442, 1910, pp. 179–200. Katz, F. J., Gold placers of the Mulchatna: Bull. U. S. Geol. Survey No. 442, 1910, pp. 201–202.

here expressed by a brief statement as to the subdivision of the preparation of the manuscript.

The introduction (pp. 11–25) was written by the senior author, as were also the introductory pages (pp. 25–30) of the section on geology. In the description of the Paleozoic and Paleozoic or early Mesozoic rocks (pp. 30–41) the division of responsibility was as follows: The senior author wrote the discussions entitled "Areal distribution" and "Age," and the junior author wrote those entitled "Lithologic character" and "Petrographic description." The description of the Mesozoic and Tertiary rocks (pp. 41–82) was prepared by the senior author, with the exception of the sections on lithologic character of the porphyries and tuffs (pp. 51–58) and petrographic description of the granitic rocks (pp. 74–76) and of the basaltic flows and tuffs (pp. 79–81), which are the work of the junior author. In the section on the Qaternary (pp. 82–94) the junior author prepared the discussion of conditions of deposition of the glacial deposits (pp. 83–88) and the description of the high terrace gravels (pp. 91–92), the remainder of this section being the work of the senior author. The sections on structure and on historical geology (pp. 94–113) were prepared by the senior author. The junior author wrote the entire section on mineral resources (pp. 113–132), except pages 126–130 on petroleum.

GEOLOGY.

GENERAL FEATURES OF THE REGION.

The region here described covers the southern end and parts of the eastern and western sides of the Chigmit Mountains, the northern end of the Aleutian Range, an intermediate region lying between them, and parts of the Cook Inlet and Bristol Bay regions on the east and west sides. It consequently includes parts of several geographic and geologic subprovinces, the general features of which will be briefly reviewed before passing to the detailed description of the special area here under discussion.

The geologic subprovinces included in part by this area are the Cook Inlet basin on the east, the Chigmit Mountains west of it, the Alaska Peninsula in the southern part, the Bering Sea coastal plain in the western, and the Iliamna basin in a central portion between the last three. These subprovinces are each characterized by distinctive physiographic, stratigraphic, and structural features, and their boundaries according to any of these criteria not only are fairly distinct but are approximately concordant. The geologic map (Pl. II, in pocket) consequently shows approximately the local geographic limits of the subprovinces.

GEOLOGIC SUBPROVINCES.

COOK INLET BASIN.

The Cook Inlet basin is topographically a lowland area bounded by more or less linear-fronted mountain masses on the east and west sides. The waters of Cook Inlet occupy about half of the total area of the basin. The larger land areas are at the north end and on the east side. The bounding mountain masses are the Talkeetna, Chugach, and Kenai mountains on the east side of the basin and the Alaska, Chigmit, and Aleutian mountains on the west side. The mountain fronts are deeply embayed by the Matanuska and Turnagain Arm valleys, between the Talkeetna and Chugach and between the Chugach and Kenai mountains, respectively, and by valleys north of Mount Redoubt and at the head of Kamishak Bay, which separate the Chigmit Mountains from the Alaska and Aleutian ranges.

The rocks of the valley floor consist chiefly of Tertiary and Quaternary deposits. The former are only locally more than slightly folded, and are only partly consolidated. The latter consist chiefly of glacial outwash deposited in what are now a series of terraces, and underlain, in at least part of the region, by till.

The rocks of the bounding mountains are mostly granitic and metamorphic. Those of the Kenai and Chugach mountains are slaty sediments. The Talkeetna Mountains are largely quartz diorite, with some schists and other rocks. The Alaska Range consists chiefly of slightly metamorphosed Jurassic rocks. The Chigmit Mountains are largely granitic, although metamorphic and volcanic rocks also are present, as will be described below (pp. 27–28). The Aleutian Range is essentially volcanic, but considerable areas of granite rocks and of Mesozoic and Tertiary sediments are known to be present.

Intermediate in geographic position as well as in geologic character between the valley floor described above and the bounding mountains are locally developed belts of foothills. One of these borders the Cook Inlet basin along the eastern front of the Chigmit Mountains. These hills differ geologically from the floor of the basin and also from the bounding mountains in that they consist of unaltered Mesozoic sediments and volcanic rocks. Similar rocks are also present in the lowlands between the Chigmit and Aleutian ranges and in the foothills of the Kenai Mountains on the south shore of Kachemak Bay.

Only the western edge of the Cook Inlet basin is included within the area described in this report. It comprises the foothills and lowlands east of the Chigmit Mountains. The local rocks are unmetamorphosed Mesozoic sedimentary and volcanic beds with one or two small remnants of a former fringe of Tertiary rocks east of them. The structure is dominantly simple, the Jurassic and Tertiary rocks being but gently flexed and having a general dip eastward toward the center of the basin, the Triassic rocks alone being complexly folded.

CHIGMIT MOUNTAINS.

The Chigmit Mountains are that part of the Pacific mountain system which fronts on the west coast of Cook Inlet from Redoubt Bay to Bruin Bay. The neighboring parts of the Pacific mountain system are the Alaska Range, which is north of the Chigmit Mountains, and the Aleutian Range, which is south of them. The axes of these three ranges are parallel, but are offset progressively southeastward, so that the axis of the Chigmit Mountains occupies a position southeastward and coastward from that of the Alaska Range and northwestward and inland from that of the Aleutian Range. The northeastward continuation of the Chigmit Mountain belt is probably to be found in the Talkeetna Mountains, east of the Cook Inlet basin, with which it possesses many geologic features in common.

The eastern boundary of the Chigmit Mountains lies parallel to the coast of Cook Inlet. The northern termination is somewhere in the unexplored country northeast of Redoubt Bay. The southern end is at the head of Bruin Bay. The western boundaries are rather indefinite. The hills west and north of Kakhonak River and of Kakhonak Lake should not be included, but the mountains west of Lake Clark above Chulitna River and west of a line from Chekok Bay to the mouth of Currant Creek may be included or not, according to the point of view. These hills merge imperceptibly with the main mountain mass, which, in the writer's opinion, should include the mountains north of Chulitna River and east of Lake Clark and east of a line from the outlet of Lake Clark to the mouth of Iliamna River and thence to the head of Bruin Bay.

These mountains are a rugged mass, which has been mapped only within the area described in this report, and whose topographic detail is consequently largely unknown. The general height of the summits ranges from 4,000 to 6,000 feet, as is shown on the topographic map, Plate I (in pocket), and in the characteristic view shown on Plate VIII, *A* (p. 86). Many summits in the northern part of the mountain mass exceed 7,000 feet in height, and the isolated volcanic peaks, Iliamna and Redoubt, on the eastern front of the mountains rise to approximately 10,000 feet.

The Chigmit Mountains consist geologically of the granitic, metamorphic, and volcanic rocks described in the following pages. Their geology is not known outside of the area here described. Within this region they contain detached areas of gneisses and schists, probably of early Paleozoic age, overlain by limestones, slates, and greenstones, all considerably altered and severely folded, and probably chiefly of Paleozoic age. Some less altered Triassic limestone also is present. Large areas of porphyries and tuffs, probably of Lower Jurassic age, are found on the eastern and western flanks of the mountains. All these rocks are cut by great masses of granite which were intruded in early Jurassic time. The granite appears to occupy by far the greater part of the area of the mountains.

These mountains were formerly occupied by an extensive system of glaciers of the alpine type, which have left behind them the usual erosion features at all but the higher altitudes, which seem to have overtopped the ice, and are consequently of the ragged nonglacial form. Glacial deposits are in general scanty, doubtless because this was a region of vigorous glacial erosion rather than of glacial deposition. The character of the land surface from which these mountains were produced is not known.

ALASKA PENINSULA.

The southern border of the region here described is the north end of the Alaska Peninsula, which extends southwestward from Kamishak Bay between the waters of Iliamna Lake, Bristol Bay, and Bering Sea on the north and those of Shelikof Strait and the Pacific on the south.

The Alaska Peninsula consists of two parts, a mountain axis on the south and a coastal plain on the north. The mountains are the Aleutian Range, which consists of volcanic rocks, cutting Mesozoic and Tertiary sediments, and of granitic intrusives. The Aleutian Mountains extend from Cape Douglas to the western end of the peninsula, being broken by many low passes, of which the lowest and broadest is probably the one at the head of Becharof Lake. These mountains are separated from the Chigmit Mountains by a broad, low belt of rolling country which extends from the head of Kamishak Bay to the head of Kakhonak Bay on Iliamna Lake. The coastal plain forms the western part of the peninsula throughout the greater part of its length. It is covered with Quaternary gravel, sand, and clay, lying in a series of terraces.

ILIAMNA BASIN.

The Iliamna Basin constitutes a physiographic and geologic subprovince, here described for the first time. Its area is that of the greater part of the drainage basin of Iliamna and Clark lakes, including the broader reëntrants between the southern ends of the Chigmit Mountains on the north and the Aleutian Range on the south, but not the narrow fiord of Lake Clark above the mouth of Chulitna River nor the deep narrow upper ends of the valleys tributary to the east sides of Clark and Iliamna lakes, which belong to the Chigmit Mountains.

This subprovince possesses a physiographic unity characterized by the breadth of valleys and terracing of their sides, by the moderate height of the mountains, by their distribution as isolated individuals or groups, and by the rounded character of their tops and sides. These physiographic features accompany and were in large part caused by the geologic features described below, which likewise characterize this subprovince as a whole and distinguish it from the neighboring subprovinces.

The rocks of the Iliamna Basin consist chiefly of volcanic flows and tuffs, which are not metamorphosed nor closely folded, and are overlain at the lower altitudes by terrace gravels and by a small amount of glacial till. At two points within the area of the volcanic rocks are small patches of older rocks apparently protruding through the volcanic mantle. One of these is the limestone west of Chekok Bay, and the other is the greenstone near the head of Kakhonak Bay. The volcanic rocks include Mesozoic porphyries and tuffs and Tertiary basalts and tuffs. The former occur also on the western border of the Chigmit Mountains, as described above. The basaltic flows and tuffs are apparently restricted to this subprovince and give it some of its most striking geologic characteristics. Over large areas the basalts are horizontal or but gently tilted and are prominently exposed in the escarpments surrounding the mesas which they form. The greater part of the district has been scoured by the large ice sheets which formerly occupied the basin, and all the lower areas are mantled by the till and the terrace gravels left upon the retreat of the ice.

BERING SEA COASTAL PLAIN.

The Bering Sea coastal plain extends along the greater part of the shore line of Bering Sea, attaining its broadest development, except for the Yukon-Kuskokwim delta, on the shores of Bristol Bay, where it is from 20 to 50 miles in width. The part of it described in this report extends from the west shore of Iliamna Lake to the mouth of the Kvichak River. This is a terraced plain, at few points exceeding 200 feet in height, composed of stratified gravels, sands, and clays. The eastern end of the Kvichak Valley contains some till, which probably underlies part and may underlie all of the plain. Exposures of hard rock are not known in this district and are not believed to exist.

This subprovince merges eastward into the Iliamna Basin, the western part of which contains the same gravel-covered terraces, and overlaps southward upon the Alaska Peninsula.

STRATIGRAPHIC GEOLOGY.

GENERAL FEATURES.

The rocks of this region include a great variety of sedimentary, metamorphic, intrusive, and volcanic types. As stated above (p. 25), the several physiographic and geologic subprovinces are each in general characterized by distinctive rocks or groups of rocks, although some of the groups of rocks recognized below are common to several of the subprovinces. At no locality is there a geologic section showing anywhere near the complete stratigraphic sequence. The complex structure and the general absence of fossils throughout all but the eastern part of the region make correlation and the establishment of a complete geologic section rather difficult and subject to doubt. The first table following shows what is now believed to be the local geologic sequence in various parts of the region as well as the probable correlation between these local fragmentary columns. The second table shows also the probable relations of these rocks with those of the neighboring regions.

PALEOZOIC ROCKS.

GNEISSES AND QUARTZITIC SCHISTS.

Areal distribution.—The oldest rocks of this region are believed to be some highly metamorphosed sediments now appearing as gneisses, mica schists, and quartzites. These rocks occupy two districts, a southern one in the mountains between Iliamna and Pile bays, and a northern in the valley of Lake Clark from the valley of Kontrashibuna Lake northward to the mountains west of Tlikakila River. The areas occupied by these rocks are shown on the geologic map, Plate II (in pocket).

The southern district is probably divided into two detached areas by a large intrusive mass of granitic rocks. The rocks of the eastern area are exposed on the trail 2 miles west of the head of Iliamna Bay, and also on the Hicks and Dutton trails west of Cottonwood Bay. This area is bordered on the east in part by the slates described below (pp. 35–38), and in part, as west of the head of Iliamna Bay, by granite which also probably forms the western boundary of the area. The western area extends from near the head of Meadow Lake northward to the valley of Iliamna River. It is bounded on the west by Triassic (?) limestone and on the east by granite, possibly being connected through the area of the latter, in undetected belts, with the eastern area described above.

The northern or Lake Clark district of quartzite and mica schist also consists of two areas, which are separated by the waters of the lake. The southern area, which is on the east side of Lake Clark, *Sequence and character of rocks in different parts of the Iliamna region.*

Age.	General designation.	Coast north of Iliamna Bay.	Kamishak Bay.	Iliamna Bay.	Mountains west of Iliamna Bay.	Iliamna Lake.	Mountains east of Lake Clark.	Lake Clark.
Quaternary.	Recent volcanic material.	Flows from Mount Iliamna.	Flows and ash from Mount Augustine.	Absent.	Absent.	Absent.	Absent.	Absent.
	Beach and flood-plain deposits.	Beach and flood-plain deposits.	Beach and flood-plain deposits.	Beach and flood-plain deposits.	Flood-plain deposits.	Beach and flood-plain deposits.	Beach and flood-plain deposits.	Beach and flood-plain deposits.
	Terrace gravels.	Not seen.	Terrace gravels.	Absent.	Absent.	Terrace gravels.	Local terraces.	Terrace gravels at lower end of lake.
	Glacial deposits.	Moraine of existing glaciers.	Moraine of existing glaciers.	Thin moraine of extinct glaciers.	Moraine of extinct glaciers.	Till.	Moraine.	Moraine.
Tertiary.	Basaltic flows and tuffs.	Not recognized.	Basaltic and andesitic beds (on south shore only).	Absent.	Absent.	Basaltic flows and tuffs, and tuffaceous conglomerate.	Basaltic flows.	Basaltic flows and tuffs.
	Sedimentary beds.	Shale, sandstone, and conglomerate.	Shale and sandstone (on south shore only).	Absent.	Absent.	Possibly represented by beds at base of Tertiary volcanics.	Absent.	Not recognized.
Upper Cretaceous.	Absent.							
Lower Cretaceous.	Absent.							
Upper Jurassic.	Naknek formation.	Shale, sandstone, and volcanic beds.	Shale and sandstone.	Absent.	Absent.	Not recognized.	Absent.	Absent.
	Chisik conglomerate.	Conglomerate and tuff.	Not recognized.	Absent.	Absent.	Not recognized.	Absent.	Not recognized.
Middle Jurassic.	Chinitna shale.	Shale.	Not recognized.	Absent.	Absent.	Not recognized.	Absent.	Not recognized.
	Tuxedni sandstone.	Sandstone.	Not recognized.	Absent.	Absent.	Not recognized.	Absent.	Not recognized.
Middle or Lower Jurassic.	Granitic rocks.	Granite.	Granite.	Granite.	Granite.	Granite.	Granite.	Granite.
Lower Jurassic (?).	Porphyries and tuffs.	Basaltic and andesitic porphyries and tuffs.	Basaltic and andesitic porphyries and tuffs.	Amygdaloidal tuffs.		Quartz latite and tuff.	Rhyolites, andesites, and tuffs.	Rhyolites, andesites, and tuffs.
	(Beds belonging in this position are known in neighboring regions but not here.)							
Upper Triassic.	Kamishak chert.	Absent.	Chert and shale.	Chert.	Not seen.	Not seen.	Not recognized.	Not recognized.
	Limestone.	Not seen.	Limestone.	Limestone.	Limestone.	Limestone.	Not recognized.	Not recognized.
Triassic (?).	Greenstone.	Not seen.	Not recognized.	Banded greenstone.	Greenstone.	Amphibolite and chloritic schist.	Not recognized.	Greenstone.
Paleozoic (?).	Slate and chert.	Not seen.	Not seen.	Slate.	Not recognized.	Not seen.	Slate and chert.	Slate and chert.
Paleozoic.	(Beds belonging in this position are known in neighboring regions but not here.)							
	Crystalline limestone and calcareous schist.	Not seen.	Not recognized.	Not recognized.	Crystalline limestone.	Not recognized.	Crystalline limestone.	Crystalline limestone and calcareous schist.
	Gneiss and quartzitic schist.	Absent.	Absent.	Absent.	Gneiss, schist, and quartzite.	Absent.	Mica schist and quartzite.	Mica schist and quartzite.

Correlation of formations in southern and southwestern Alaska.

Age.	Western part of Alaska Peninsula (Atwood).[a]	Cook Inlet and Alaska Peninsula (Stanton and Martin).[b]	Iliamna region.[c]	Alaska Range (Brooks).[d]	Matanuska and Talkeetna basins (Paige and Knopf).[e]	Kenai Peninsula (Moffit).[f]	Prince William Sound (Grant and Higgins).[g]	Chitina Valley (Moffit and others).[h]
Quaternary.			Recent volcanic material.	Silts, sands, and gravels.				Volcanic deposits.
	Clay, sand, gravel, and glacial drift.		Beach and flood-plain deposits.					
			Terrace gravels.	Terrace silts, sands, and gravels.	Stream and glacial deposits.	Silt, gravel, and sand.		
			Glacial deposits.					
Tertiary.	Tuffs, agglomerates, breccias, and flows.	Kenai formation.	Basaltic flows and tuffs.		Basaltic lavas, breccias, and tuffs.			Lavas.
	Unga formation (clay, sandstone, and conglomerate).		Sedimentary beds.	Kenai formation.	Kenai formation.	Kenai formation.		
	Kenai formation (shale, sandstone, and conglomerate).							
	Basaltic flows, breccias, agglomerates, and tuffs.							
Upper Cretaceous.	Chignik formation (conglomerate, sandstone, shale).	Shale, sandstone, and conglomerate at Chignik.						
Lower Cretaceous.	Herendeen limestone (arenaceous limestone).	Beds with *Aucella crassicollis* at Herendeen Bay.			Limestone with *Aucella crassicollis*.			
	Staniukovich shale (shales with thin beds of sandstone).							
Upper Jurassic.	Naknek formation (sandstone, conglomerate, and arkose).	Naknek formation: Shale with *Aucella pallasi*.	Naknek formation.		"Upper Jurassic and Upper Middle Jurassic": Shale, sandstone, conglomerate, tuff, and arkose, with *Aucella bronni*.			Kennicott formation (conglomerate, sandstone, limestone, and shale.)
		Naknek formation: Conglomerate.	Chisik conglomerate.		"Upper Jurassic and Upper Middle Jurassic": Beds with *Cadoceras*.			
Middle Jurassic.		Enochkin formation: Shale with *Cadoceras*.	Chinitna shale.					
		Enochkin formation: Sandstone with *Inoceramus ambiguus* and *Trigonia doroschinii*.	Tuxedni sandstone.	Tordrillo formation (cut by granite).	"Lower Middle Jurassic": Sandstone, shale, and conglomerate with *Inoceramus*.			
Middle or Lower Jurassic.		Acidic intrusives.	Granitic rocks.					
Lower Jurassic.		Tuffs and cherty limestone at Port Graham and Seldovia.	Porphyries and tuffs.		"Lower Middle Jurassic": Andesitic greenstones,[i] tuffs, etc., with *Trigonia* (cut by quartz diorite).	Tuff, agglomerate, and cherty limestone.		
Lower Jurassic (?).		Shales and sandstones above known Triassic at Cold Bay.						
Upper Triassic.		Chert, shale, and limestone with *Pseudomonotis*.	Kamishak chert.					McCarthy shale (shales and thin limestones).
			Limestone.			Cherts and green diabase of Kachemak Bay.		Chitistone limestone.
Triassic (?).			Greenstone.	Skwentna group[i] (cut by granite).				Nikolai greenstone.[i]
Paleozoic (?).			Slate and chert.		Graywackes and slates of Knik River[i] (including basaltic greenstones, tuffs, and rhyolites).		Orca group:[i] Slate and graywacke.	
							Orca group:[i] Greenstone, slate, graywacke, and conglomerate.	
Paleozoic.			Crystalline limestone and schist.	Limestone (Middle Devonian).				
			Gneiss and quartzitic schist.	Tonzona group (Silurian or Devonian).	Slates and schists of Lower Talkeetna Valley.[i]	Sunrise "series"[i] (slates and arkose).	Valdez group[i] (slate and graywacke).	
				Tatina group (Ordovician).				
				Birch Creek schist.	Mica schists of Willow Creek.[i]			

[a] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: Bull. U. S. Geol. Survey No. 467, 1911.
[b] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 391–410.
[c] This report.
[d] Brooks, A. H., The Mount McKinley region: Prof. Paper U. S. Geol. Survey No. 70, 1911.
[e] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907.
[f] Moffit, F. H., Gold fields of the Turnagain Arm region: Bull. U. S. Geol. Survey No. 277, 1906.
[g] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1911, pp. 20–33.
[h] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909; Moffit, F. H., and Capps, S. R., The geology and mineral resources of the Nizina district: Bull. U. S. Geol. Survey No. 448, 1911.
[i] The age assignments and correlations are those of the authors of this report and not, in the cases thus indicated, those of the authors quoted above.

lies in the mountain west of the lower half of Kontrashibuna Lake, being bounded on the east by crystalline limestone and calcareous schist and on the west and south by much younger volcanic rocks. The northern area is on the northwest side of Lake Clark, from 3 to 5 miles south of the mouth of Tlikakila River. This is believed to be continuous with the other area, separated only by the waters of the lake. This area apparently has crystalline limestone on each side of it, the probable relation being anticlinal structure (see p. 107) and limestone overlying the schist.

Lithologic character.—The gneisses and schists lying west of Cottonwood Bay include both coarse and fine grained types, between which are many intermediate phases. The coarse-grained rocks are light colored and are either decidedly gneissic or granitoid in texture. They are composed of quartz, feldspar, and biotite, and in places also hornblende. The fine-grained types include dark-colored hornblende-feldspar rocks approaching schists in texture and quartzitic schist which is among the predominant rocks along the Dutton trail. These rocks have a general northeast strike and steep northwest dip. They are probably overthrust or overfolded upon the slate and greenstone which lies east of them.

The rocks of the western area north of Meadow Lake include some biotite gneiss but a larger proportion of coarse to fine hornblende gneiss and some chloritic schist. The adjacent rocks are limestone on the west, which is believed to overlie the gneiss unconformably, and granite on the east, which is regarded as intrusive into it.

The rocks of these two areas constitute an assemblage made up of members of at least two more or less distinct types. These are the coarser-grained and more highly metamorphosed gneisses and the finer-grained and less metamorphosed schists and quartzites. These two groups are deserving of differentiation and possibly belong to widely separated geologic periods.

The metamorphic rocks of Lake Clark consist of quartzite, mica schist, calcareous schist, and crystalline limestone. These are believed to be separated into the older series of quartzite and mica schist here described, and a younger series of calcareous schists and limestones, described on pages 32–35.

These rocks include distinctly sheared quartzites and argillaceous quartzites composed largely of quartz with varying amounts of biotite and accessory magnetite and carbonaceous material. They resemble the less metamorphosed and presumably younger division recognized above in the district west of Iliamna Bay. The rocks exposed on the east shore of Lake Clark west of Currant Creek and on the opposite shore eastward from Portage Creek are quartzites, quartzitic schists, and mica schists, of undoubted sedimentary origin, in alternate succession of moderately thin beds. These are minutely plicated, the axial planes of the folds and the schistosity being vertical and striking about N. 40° E. (magnetic). Some basic dikes invading this formation have been folded with it. Later undeformed granitic intrusives into this formation were seen also on the northernmost of the two islands opposite the mouth of Currant Creek.

Age.—The only evidence now available as to the age of the gneisses and schists is their degree of metamorphism. They are much more altered than any of the other rocks of the region and, as they are apparently not connected with them by metamorphic gradation facies, it must be concluded that they are older. This determines their age as certainly pre-Triassic. As some of the less metamorphosed rocks of the region also are pre-Triassic, the gneisses and schists must belong well down in the Paleozoic or possibly in part below it.

The rocks of other Alaskan regions with which these may be compared include the schists of Willow Creek[1] on the edge of the lower Matanuska Valley, and the "Klutina series"[2] farther east. Both of these lie in the same general belt with the rocks here described, and neither is of determined age. Other areas of rocks of the same general lithology occur in many parts of Alaska.[3]

CRYSTALLINE LIMESTONE AND CALCAREOUS SCHIST.

Areal distribution.—The more highly metamorphosed and presumably older calcareous rocks of this region are found in two districts—the shores of Clark and Kontrashibuna lakes, and the mountains west of Iliamna Bay.

The calcareous rocks of Lake Clark outcrop as a continuous belt along the eastern margin of the quartzitic schists described above (pp. 30–31) from a point near the mouth of Currant Creek on the shore of Lake Clark, southward to a point near the head of Kasna Creek, about 2½ miles south of Kontrashibuna Lake, beyond which they were not followed. They also outcrop on both east and west sides of the schist on the west side of Lake Clark about 4 miles below the mouth of Tlikakila River. Calcareous schist was seen on an island in the middle of Lake Clark west of the mouth of Currant Creek, this outcrop being interpreted as part of a limestone belt along the west side of the quartzitic schists, the rest of this belt, except at the exposure 5 miles below Tlikakila River, lying in the lake or concealed by younger volcanic rocks.

The crystalline limestone west of Iliamna Bay occurs in two small areas surrounded by gneiss. One of these areas is about 2 miles

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 10–11.

[2] Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 410.

[3] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 208–218.

west of the head of Iliamna Bay on the trail to the village, and the other is 3 miles from the head of Cottonwood Bay on the Dutton trail to the copper prospects.

The limestone southwest of Iliamna village might also be described here, but there is considerable doubt whether it is to be correlated with these older crystalline limestones or with the less-altered Triassic limestone described later (pp. 41–47).

Lithologic character.—The limestone and calcareous schist on Lake Clark apparently overlie the mica schists and quartzites already described. They have an apparent thickness of many hundred feet, but the complexity of folding is such that the actual thickness can not be determined. They are predominantly calcareous throughout, and pure limestone beds contribute to a large proportion of the thickness. The separation from the presumably underlying quartzitic rocks is made wholly on the basis of calcareous and noncalcareous character, neither unconformity nor difference in degree of metamorphism having been detected.

On the east side of Lake Clark the western and presumably lower part of the calcareous rocks is made up of thin interlaminated bands of schistose material and of fine-grained crystalline limestone. Immediately east of this a presumably higher horizon consists of fine-grained, light-colored limestone, in places coarsely crystalline. The exposures of this limestone are cut off on the north by the alluvial lowlands of Currant Creek. On the headland just north of Currant Creek the cliffs are of calcareous schist composed largely of sericitic and serpentinous material and calcite with chlorite and quartz and containing veinlets of quartz and epidote. A secondary parallelism of the materials is well developed. The rock is without much question a sheared calcareous argillite. This rock lies in line with the belt of the calcareous rocks south of Currant Creek, and the two have approximately parallel strike and dip. It may be regarded as the equivalent of the western part of the calcareous outcrops seen south of Currant Creek, or it may be a third, and presumably the highest horizon of the limestones. These rocks at all localities observed on Lake Clark are thoroughly recrystallized as the result of regional metamorphism. The degree of metamorphism is moreover the same in each of the recognized horizons.

The crystalline limestone or marble of the two small areas west of Iliamna Bay is a coarse rock composed almost exclusively of large grains (one-eighth to one-fourth inch) of calcite. No trace of bedding or of the original unaltered calcareous material remains. Noncalcareous constituents are practically lacking except for quartz veins.

These masses of marble may possibly be lenses in the surrounding gneiss, but they are more probably small detached areas of an unrecognized larger mass, having undetermined structural and stratigraphic relationship to the gneiss.

Age.—These calcareous metamorphic rocks have yielded no fossils, so the only available evidence of their age must be derived from their stratigraphic relation to the rocks in contact with them or from correlation on the basis of lithology and sequence.

The rocks in contact with the limestone of Lake Clark are (1) the granitic rocks, (2) the porphyries and tuffs, (3) the mica schists and quartzites. The granite, which is presumably early Jurassic, is intrusive into the limestone, which was metamorphosed and folded prior to the intrusion. The porphyries and tuffs, which are probably Lower Jurassic, rest unconformably upon the limestone. The mica schists and quartzites, which belong at an indeterminate horizon in the Paleozoic, underlie the limestone without known unconformity. Their degree of metamorphism is approximately the same as that of the limestone. The local evidence thus merely shows that the calcareous rocks are certainly pre-Jurassic.

The coarse crystalline limestone of the two small areas west of Iliamna Bay is metamorphosed to the same extent as the surrounding gneisses. It is certainly older than any of the neighboring rocks except the gneiss. There is no definite proof of its relation to the latter, but it is certainly older than the activities by which the gneiss was metamorphosed.

The crystalline limestones of Lake Clark and of the hills west of Iliamna Bay may reasonably be grouped together in the same general position, as they are of the same lithologic character and are in both localities associated with schistose and gneissic rocks. Each appears from its relations to the neighboring rocks to be certainly pre-Jurassic and probably pre-Triassic. They are presumably to be correlated with each other, although there is no definite proof of their identity.

The question which next arises is whether these crystalline limestones can be correlated with any other rocks in this region. The other limestones, with which possible correlation must be considered, are the fossiliferous Triassic limestone of Iliamna Lake and Iliamna Bay, and a limestone of more or less dubious age outcropping southwest of Iliamna village (pp. 41–47).

The possibility of correlating the crystalline limestone of Lake Clark with the limestone of Iliamna Lake is suggested by the areal distribution of the outcrops. These two limestone belts are of about the same width and are approximately in line with each other, being separated only by an area of younger and presumably overlapping volcanic beds. This naturally encourages a search for evidence that they are identical, as does also the fact that at no point within this region has a section been found containing two obviously distinct limestones. There are, however, important differences between the limestones of these two belts. The limestone of Lake Clark is much more strongly metamorphosed, which suggests its greater age. Another difference lies in the intimate association of the limestone of Lake Clark with schists, whereas the limestone of Iliamna Lake is associated with only igneous rocks. This may, however, be due merely to the accidental distribution of volcanic rocks younger than the limestones, which have happened at Iliamna Lake to bury all the older rocks except a small area of limestone. It is, however, rather remarkable that the easily eroded limestone alone should happen to protrude through the volcanics at this point. It must consequently be concluded that the limestone of Lake Clark can not be correlated with the limestone of Iliamna Lake, but must be considered as older. The latter is Triassic (p. 46) so the former must belong somewhere in the Paleozoic. As the greenstones and slates described below are also older than the Triassic limestone, yet are less metamorphosed than these crystalline limestones, the latter must belong well down in the Paleozoic. The Devonian limestones, which are present in considerable thickness in many parts of Alaska,[1] are perhaps their most probable equivalents.

PALEOZOIC OR EARLY MESOZOIC ROCKS.

SLATE AND CHERT.

Areal distribution.—Slates which are in some places associated with chert and other rocks were seen at several localities widely scattered throughout this region. The grouping of all these under one heading depends entirely upon the general lithologic similarity.

One area of these rocks lies along the face of the mountain west of Cottonwood Bay and up the valley at its head. The length of this belt and the character of its termination at either end is not known, but it does not extend as far north as the valley at the head of Iliamna Bay. The adjacent rocks are gneiss and schist on the west side and greenstone on the east.

Somewhat similar slates with associated cherts were seen at three localities between Kontrashibuna Lake and Iliamna Lake. One of these areas is south of Lower Tazimina Lake, about halfway between it and Iliamna Lake. A second is on the mountain 4 miles east of the lower end of Lake Clark. The third is on the south shore of Kontrashibuna Lake, not far above the outlet.

Another area of slates with much associated chert and altered igneous rocks and with several thin beds of limestone, were seen on either side of Lake Clark just above the mouth of Tlikakila River.

[1] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 218–221.

These rocks form the west shore of Lake Clark from 2 to 4 miles above the mouth of Tlikakila River, and the east shore for 3 miles above a point opposite the mouth of the same river. The longitudinal extent of this belt is not known.

Lithologic character.—The slaty rocks of Cottonwood Bay constitute a monotonous succession of many hundred and possibly several thousand feet of black slate without characteristic subdivisions (Pl. IX, *A*, p. 98), although a few thin beds of limestone and quartzite were seen, and possibly some schist or phyllite should be included along the western margin. Slaty cleavage is well developed, but no evidence of stronger metamorphism was seen. These rocks are considered to overlie unconformably the gneisses and schists west of them, although in the actual contact the slates are apparently below. This relation is considered as due to overturned folding or faulting. (See pp. 102–103.) The rocks east of the slates are the greenstones described below, which apparently underlie the slates, although here, too, it is believed that the succession is inverted and that the greenstone belongs above the slate.

Some schistose rocks apparently interbedded with these slates, though of rather dubious relations to them, were seen on the trail about 2 miles west of Cottonwood Bay, where there are some thoroughly metamorphosed rocks with well-developed "flow cleavage." They are made up principally of quartz and biotite of very fine grain and with strong dimensional parallelism. In this are scattered dark mica plates from 4 to 5 millimeters to 3 centimeters in longer diameter. Most of these are thin and lie in the plane of the rock cleavage, but a few are more nearly equidimensional, some being oblique to the cleavage. These mica plates appear to be aggregates of crystallographically nearly parallel flakes, lying in the plane of the rock cleavage. Quartz and albite are present also as small "augen." Zoisite, chlorite, and magnetite were seen in small amounts. In one specimen there are abundant small crystals of pyrite. The albite augen are generally single large grains with no dimensional orientation with respect to the rock cleavage. The minute mica flakes immediately around them are to some extent wrapped about them; that is, they are parallel with the periphery of the albite grains. The quartz augen are aggregates of interlocking grains, in some cases larger grains in the central portion and finer grains in the thin edge of the "eye," which is drawn out parallel to the rock cleavage.

As to the original character of these schists the evidence is as follows: The rock whose thickness is unknown, being something like a hundred or a few hundred feet, is overlain and perhaps underlain by slates. It may be sedimentary like them or it may be a flow or a sill. The microscopic textural evidence is that there were, in the original rock, grains of quartz and albite and grains of femic material out of which the large aggregates of mica plates were developed. These conditions would be fulfilled either by a porphyritic rock or by a conglomeratic sandstone containing some pebbles of basic material. The evidence of the mineral composition is in favor of either, though the abundant mica might be taken to indicate a somewhat higher femic content than sandstones generally have.

At each of the three areas of slaty rocks between Kontrashibuna and Iliamna lakes the rocks consist of very fine-grained black slate, argillites, or graywackes, and banded, white, gray, and dark-colored cherts, or very fine-grained quartzitic rocks. The cleavage in the slates is only imperfectly developed. These rocks are all minutely crumpled and no evidence could be obtained as to their thickness and age. The adjacent rocks are all volcanics, which from their slight degree of alteration are evidently much younger and which are believed to overlie the slates unconformably, burying them except in the areas noted above and probably in other small undetected areas.

The rocks on the west side of Lake Clark from 2 to 4 miles above the mouth of Tlikakila River consist predominantly of chert and slate, with some associated beds which suggest altered volcanic rocks, and with at least one observed bed of limestone about a foot thick. The slate has fairly well developed cleavage; the limestone, although of very fine grain, is somewhat recrystallized; and the chert is apparently unaltered. These rocks differ from the Cottonwood Bay slates in being less altered and in the presence of associated cherts and igneous rocks.

Age.—The evidence as to the age of the slates and cherts is very unsatisfactory. No fossils have been found in them, or in any rocks of neighboring provinces with which they could be correlated on the basis of similar lithology and stratigraphic sequence. The stratigraphic relations to the areally associated rocks is not of much aid, as most of these do not have their own age relations well established. It is, moreover, more or less doubtful whether all the rocks of the widely separated areas, here grouped under one heading, really belong together. The correlation of these local rocks with each other depends chiefly upon general lithologic similarity, the rocks of each area differing from the others in considerable detail.

The slates of Cottonwood Bay are clearly younger than the more metamorphosed gneisses and schists west of them, and older than the greenstone on the east. Their age relative to that of the limestones of this and of the other local districts is less clear. They are somewhat more altered than the limestone on Iliamna Bay and on Iliamna Lake, probably not much more altered than the limestone north of Meadow Lake, but decidedly less altered than that of Lake Clark.

The slates and chert of the district between Kontrashibuna and Iliamna lakes are more metamorphosed and distinctly older than the volcanic rocks with which they are areally associated. The latter are believed to be of early Jurassic age, although the evidence is not positive.

At the head of Lake Clark the adjacent rock masses are chiefly granitic. A granite mass, which is intrusive into the slate, lies east of them. West of them, on the east side of Lake Clark, is also granite upon which the slates are overthrust. On the opposite side of the lake and west of the slates this fault was not seen, but a granitic arkose of undetermined age lies against the slates. This granite is supposed to be part of, and of the same age as, the granite on the coast of Cook Inlet, which was probably intruded in the Lower Jurassic.

It may consequently be concluded that the slates are all certainly pre-Jurassic, and that at least those on Cottonwood Bay are older than the greenstone and hence Paleozoic. They are comparable in lithologic character and in their general relationships with the slates of the Sunrise "series"[1] of the Kenai Peninsula, the Valdez and Orca groups[2] of Prince William Sound, and the similar slaty rocks of doubtful age occurring throughout much of the Pacific coastal region of Alaska.

GREENSTONES.

Areal distribution.—Altered volcanic rocks here grouped under the name of "greenstone" occur at several places within this region. Considerable diversity of character exists among them, but they possess in common the following features: The presence of original basic igneous material, such a degree of alteration that the original character of that material in general can not be determined, original banding or secondary schistosity or both, and superficial similarity in color, texture, and general physical appearance.

A belt of these rocks extends across the heads of Iliamna and Cottonwood bays and northeastward and southwestward for unknown distances. The adjacent rock west of the greenstone at the head of Cottonwood Bay is the slate described above (pp. 35–36). Granite lies west of the greenstone at the head of Iliamna Bay, and also lies east of the greenstone belt throughout its known length.

Another large area of greenstone occupies the mountain southwest of Iliamna village between the lower end of the Iliamna Valley and Meadow Lake, extending westward to the shore of Pile Bay. It lies immediately west of a belt of limestone, the greenstone evidently be-

[1] Moffit, F. H., Gold fields of the Turnagain Arm region: Bull. U. S. Geol. Survey No. 277, 1906, pp. 17–19.

[2] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, pp. 22–33.

ing younger than the limestone, though it is not known whether the contact represents unconformity or intrusion (p. 44). Granite is intrusive into the greenstone on the shore of Pile Bay.

A small area of schistose amphibolite of indeterminate origin lies along the contact between granite and rhyolite near the mouth of Pile Bay.

Somewhat similar green schist (probably chloritic schist) occurs on the south shore of Kakhonak Bay near its head. The neighboring rocks are much younger altered volcanics, which are believed to be unconformable above it and here locally cut through by erosion.

Schistose greenstone also was seen on the west shore of Lake Clark opposite the mouth of Currant Creek. The extent of this area and its relations to neighboring rocks were not determined.

It is possible that the rock on the east shore of Lake Clark from 4 to 6 miles above the mouth of Currant Creek and on the west side of the Tlikakila Valley should also be grouped with this greenstone, but it may be only a facies of the Lower Jurassic porphyries and of tuffs, locally intensely altered by intrusion of the large neighboring granitic masses.

Petrographic description.—The greenstone on Iliamna Bay consists for the most part of dark-green aphanitic rocks here and there marked by whitish and epidote-green bands, and generally slightly schistose. In some places, as at the head of Iliamna Bay, the rocks show considerable schistosity, possibly due to local shearing, while at near-by localities they are rather massive but mottled with roundish bright-green spots from 1 inch to about a foot in diameter. Under the microscope one of the banded forms is seen to be made up largely of epidote, zoisite, and quartz with less important amounts of amphibole and feldspar. Variations in size of grain and in relative amounts of constituents produce the noticeable banding. Secondary (flow cleavage) structure cuts the banding, which is presumably primary, at a small angle. From the structure and composition it is assumed that the rock is a metamorphosed volcanic, perhaps a tuff.

The rocks of the area southwest of Iliamna village are for the most part thoroughly recrystallized quartz amphibolites or quartz-epidote amphibolites, their composition indicating that they have been derived from rocks related to diorite or diabase. One less thoroughly recrystallized rock from within this greenstone area, at a point about 7 miles southwest of Iliamna village (9M52), is very probably a partly altered pyroxenite. In it augite is seen altering the fibrous amphibole, beside which there is in the section some epidote, sericitic material, calcite, and limonite. The beds exposed on the shore of Pile Bay from 2 to 4 miles below the mouth of Iliamna River are in part tuffaceous. The rocks of this area as a whole are in general not very schistose.

The greenstones seen near the mouth of Pile Bay, near the head of Kakhonak Bay, and on the west shore of Lake Clark opposite Currant Creek, are much more altered than any of those described above, being completely recrystallized and possessing a thoroughly developed schistosity. They are probably to be classed as amphibolites and chloritic schists. No evidence of their origin was obtainable. They may be locally intensely metamorphosed representatives of the greenstones of the other areas or may belong among older series of rocks.

Age.—The greenstone on Cottonwood Bay is in contact with the slates described above (pp. 35–37). Although the slates rest upon the greenstone the former are considered older, as they are more metamorphosed, and the local attitude of the rocks is explained as being due to a fault or an overturned fold.

The contacts of greenstone and granite were seen at many places on Iliamna, Cottonwood, and Pile bays. At all of these places it is clearly evident that the contact is one of intrusion, the granite being younger. The granite is shown below (p. 76) to be of probable Lower Jurassic age. The greenstones must consequently be Triassic or older.

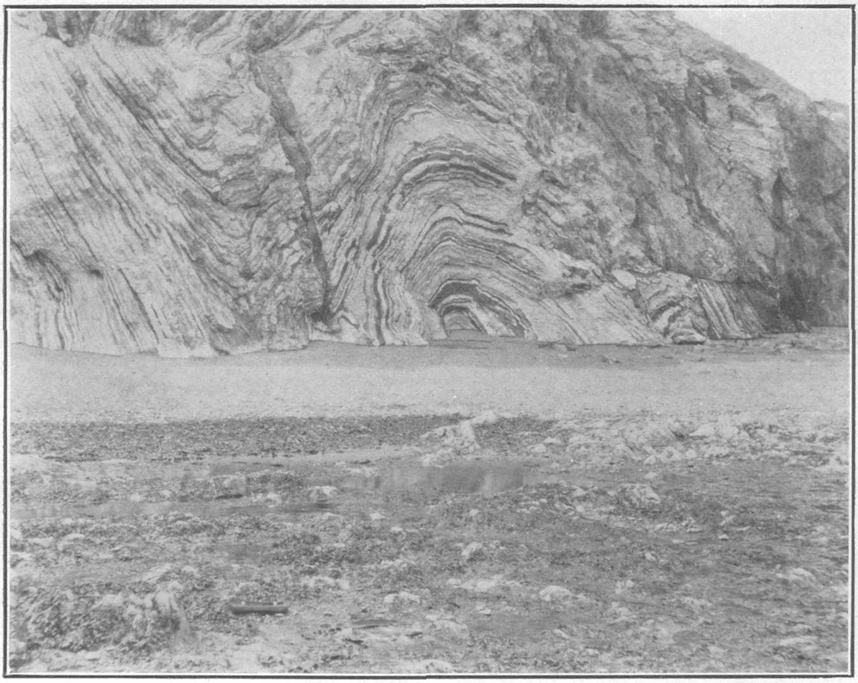
The Upper Triassic Kamishak chert at Ursus Cove contains much associated igneous material (Pl. V, *B*), some of which closely resembles the greenstone on Cottonwood Bay. This material is most abundant in the lower part of the Ursus Cove section (p. 47), the relations suggesting that the Kamishak chert grades downward into the greenstone and that the latter possibly belongs within the Triassic. It should be noted that the Upper Triassic cherts in the vicinity of Seldovia are also associated with volcanic material,[1] chiefly diabase. No evidence was obtainable as to whether these rocks were erupted contemporaneously with the deposition of the cherts or were intruded later. They were, however, deformed with the cherts, and are consequently pre-Jurassic. The similarity of conditions at Seldovia and at Ursus Cove is striking and suggestive.

The rocks of other neighboring regions with which these should be compared include the greenstone in the lower part of the Orca group[2] of Prince William Sound, and the Nikolai greenstone[3] of the Chitina Valley. The latter underlies the Chitistone limestone,

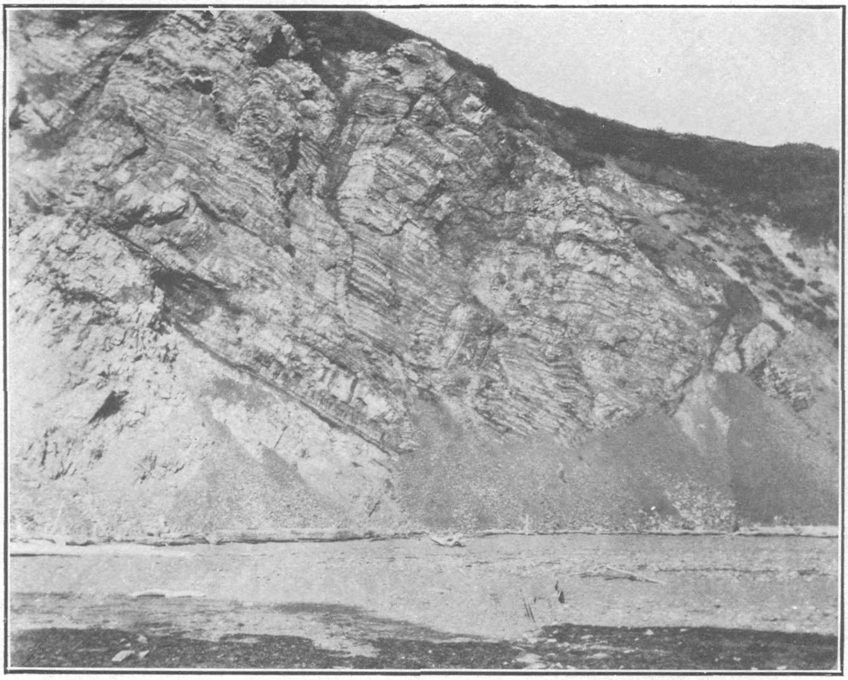
[1] Moffit, F. H., Gold fields of the Turnagain Arm region: Bull. U. S. Geol. Survey No. 277, 1906, p. 23.

[2] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, pp. 25–33.

[3] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, pp. 23–25.



A. CLOSELY FOLDED KAMISHAK CHERT ON SOUTH SHORE OF BRUIN BAY.



B. KAMISHAK CHERT WITH INTRUSIVE SHEET OR FLOW OF BASIC IGNEOUS ROCK, ON NORTH SHORE OF URSUS COVE.

which is of upper Triassic age,[1] thus corresponding very closely in relation and presumably in position with the greenstone here described.

MESOZOIC ROCKS.

UPPER TRIASSIC ROCKS.

LIMESTONE.

Areal distribution.—Upper Triassic limestone is present on the north shore of Iliamna Lake at a point west of Chekok Bay and on the south shore of Iliamna Bay. The limestone southwest of Iliamna village is regarded as probably identical with this, and the already described crystalline limestones of Lake Clark and the mountains west of Iliamna Bay may possibly be its metamorphosed representatives. Limestone beds were also seen on the north shore of Ursus[2] Cove and on the south shore of Bruin[2] Bay in intimate association with the Kamishak chert. These beds may possibly be identical with the limestone here described, but as they have not been cartographically differentiated, and as they may be but thin members of the Kamishak chert, it seems best, temporarily at least, to include them in the Kamishak chert and to discuss them under that head in this report.

The limestone on the north shore of Iliamna Lake is exposed in the lake cliffs about 3 miles west of the mouth of Chekok River, or just east of Millet's copper prospects, which are located on the western edge of the limestone. The limestone belt is about two-thirds of a mile wide, and extends from the lake shore northward over the first ridge and down to the edge of the alluvium-floored valley beyond. No limestone was seen in the hills north of this valley, but possibly it may outcrop at points which were not visited, or more probably it may be buried beneath the volcanic rocks which were seen in these hills.

The limestone on Iliamna Bay occupies the cliffs on the south shore of the bay from a point due west of White Gull Island to a point almost south of it. The outcrop along the shore is somewhat over a mile wide, interrupted locally by several masses of igneous rock. The area of the limestone south of the bay is not known, but an outcrop of limestone was seen on the north shore of Ursus Cove, which may possibly be the same limestone as that on Iliamna Bay, but it is not believed to be areally continuous with it.

The limestone of the district southwest of Iliamna village occurs in a belt about 1,000 feet wide and is known to extend from a point 2 miles south of Iliamna village, on the edge of the flats of Iliamna Valley, to a point 9 miles southwest of the village, near the north end

[1] Moffit, F. H., and Capps, S. R., The geology and mineral resources of the Nizina district, Alaska: Bull. U. S. Geol. Survey No. 448, 1911, pp. 23–25.

[2] Ursus Cove and Bruin Bay are names adopted by the United States Geographic Board. These features are known locally and in earlier geologic publications as Bear Cove and Bear Bay.

of Meadow Lake. It may possibly extend northward through the valley of Iliamna River and southward through the valley of the river draining Meadow Lake. In this case the northern termination of the belt may be an indefinite distance within the unexplored mountains, and the southern termination beneath the Tertiary lavas and tuffs east of Kakhonak Bay.

Lithologic character and stratigraphic relationships.—The limestone on the north shore of Iliamna Lake is a fine-grained blue rock with a considerable amount of bituminous matter, which is revealed by a strong odor when the limestone is broken. It has been much shattered and crushed, the fractures healed by the deposition of fine-grained white calcite and some quartz. Otherwise it has not been much altered, no coarse crystallization of the noncrushed fragments having been observed except along the Millet copper lode, and there being apparently no development of secondary silicates. A part of the formation near Millet's cabin is rather siliceous.

The exposures in the cliffs on the shore of the lake (locality 1, p. 44) have yielded abundant but poorly preserved fossils, chiefly corals and mollusks. The corals are abundant, and the bed from which the specimens were collected is probably a reef, although the field observations, because of the complexity of the structure, are rather obscure on this point. It should be noted, however, that the identified species are true reef builders[1] and that reefs abound at this horizon in the Alps, in California, and in all the regions of lower latitude where this fauna is known. The occurrence here described is, however, the farthest north that Triassic corals have been found, and suggests a hitherto unknown extension of the distribution of Triassic coral reefs.

The stratigraphic relations to the neighboring rocks are obscure and offer so little aid in determining the position of the limestone that were it not for the presence of characteristic fossils no very definite determination of age could be made. The adjacent rocks on the south side of the limestone are tuffs which have at their base, resting discordantly across the beveled edges of the fossiliferous limestone, a bed of volcanic breccia consisting of angular fragments of limestone in a matrix of volcanic glass. This is regarded (p. 79) as the local base of a series of volcanic beds of Tertiary age. The rocks in contact with the limestone on the east and west sides are basic igneous masses, which are tentatively correlated on lithologic evidence (p. 58) with other volcanic rocks, which are believed to be Lower Jurassic. No local evidence of their relationship to the limestone was obtained. The exposures of limestone are cut off on the north by a gravel-covered flat. It may readily be seen that the only positive conclusions that can be drawn from the relationships at

[1] The writers are indebted to Prof. James Perrin Smith for these facts.

this locality are that the limestone is pre-Tertiary and that a profound unconformity separates it from the Tertiary beds.

The limestone on the south shore of Iliamna Bay is a large mass complexly folded so that no idea of its thickness may be obtained, and contains within its area intruded or structurally included masses of igneous rock. The limestone is white and blue, fine-grained, much shattered, the fractures healed with calcite, and very slightly altered save by this crushing and healing. In all this it resembles the limestone on Iliamna Lake, as it does also in the presence of a fauna which includes corals.

The associated rocks are amygdaloidal basaltic tuffs of indeterminate relationship on the west side and younger granitic intrusives on the east. The tuffs are probably Lower Jurassic (p. 58), but their structural relationships with the limestone have not been determined. The granitic rocks are believed to be late Lower Jurassic or Middle Jurassic (p. 76). They are intrusive into and hence younger than the limestone, which must consequently be pre-Jurassic.

The lithologic character and degree of metamorphism of the limestone at this locality is not very different from that of the limestone on Iliamna Lake. Fossils are present (locality 2, p. 44), but the fauna is scanty and poorly preserved and can not be definitely correlated with that from Iliamna Lake. Nevertheless the suggestion of identity of the limestones of these two localities, from the combined evidence of lithologic similarity, degree of alteration, and presence of approximately similar coral faunas, is very strong. It should be remembered that this locality is about 34 miles east of the locality of Iliamna Lake and across the granitic Chigmit Mountains.

The limestone southwest of Iliamna village is of the same general character as that on Iliamna Lake and on Iliamna Bay. It evidently was originally a rather pure and homogeneous rock. It is intricately folded and intensely crushed and shattered, but is not, however, greatly metamorphosed, coarse and thorough recrystallization being apparently largely confined to the lode zones. This rock is somewhat more altered than the limestone on the north shore of Iliamna Lake, but decidedly less so than that on Lake Clark. In its relation to the schist it resembles the latter, although there is here a strong suggestion of greater alteration of the schist than of the limestone and presumably of an important time break between their dates of deposition. The character of the folding is such that no estimate of thickness can be made.

The adjacent rocks are gneisses and schists on the east and altered basic igneous rocks (greenstone) on the west. Several masses of schist occur within the limestone, but whether they are interbedded or brought in by structural disturbances is not known. The latter is believed to be more probable, since the schists are apparently more metamorphosed than the limestone.

This limestone, which is about 13 miles distant from that on Iliamna Bay, has yielded no fossils and can be correlated with the limestone at the other localities of the region only on lithologic evidence. Its relation to the rocks in contact with it contributes a little to the evidence of its age. The gneisses and schists east of it are considerably more metamorphosed than the limestone and are believed to be unconformably below it and much older. The age of these rocks is, however, not known, so they give no proof of the age of the limestone. The fact that this limestone is less metamorphosed than the neighboring schist and gneiss, whereas the limestone of Lake Clark is metamorphosed to the same degree as the schist in contact with it, makes it necessary to conclude that if the limestone of Lake Clark and that southwest of Iliamna village are of the same age then the schists underlying them in the two districts are of different ages, or else the schist and gneiss in the latter district were metamorphosed prior to the deposition of the limestone and that in the former district subsequent to it. The rocks in contact with the limestone on its west side are altered basic igneous masses, originally diabase or diorite in composition and in part tuffaceous, but now altered to greenstone. These rocks are certainly older than the Lower or Middle Jurassic granite which is intrusive into them, and consequently are probably Triassic or older. (See p. 40.) The greenstone appears to be younger than the limestone, although the exact relations have not been positively established. The doubtful point is whether certain basic igneous rocks which are known to be intrusive into the limestone are an integral part of the main greenstone mass or are younger intrusions along the contact. Upon this point depends the determination of the age of the limestone. If the greenstone as a whole is younger than the limestone then the latter is pre-Triassic and probably belongs with the crystalline limestone described above (pp. 32–34) rather than with those under discussion here. If, however, the basic rocks which cut the limestone are not part of the main greenstone mass, then there is no local proof as to the relative ages of the limestone and greenstone, and they can be correlated, as the lithologic evidence seems to warrant, with the similar rocks on Iliamna Bay. This interpretation of the stratigraphic relationship is accordingly adopted, even though it can not be regarded as positively established.

Fauna.—Marine fossils have been collected from the following localities:

Locality 1.—North shore of Iliamna Lake, 3 miles west of mouth of Chekok River (near Millet's camp).

Locality 2.—South shore of Iliamna Bay, 1.1 miles S. 75° W. of west end of White Gull Island.

These collections were referred to Dr. George H. Girty, and on his determining them to be of Triassic age they were placed in the hands of Prof. James Perrin Smith, who is making an extensive study of the American Triassic faunas. The most striking feature of the present collections is that they consist largely of species of corals. Prof. Smith was already familiar with a closely related coral fauna in the Triassic of California and confined his report to the fossils of that zoologic group. Both reports are quoted below. Dr. Girty writes:

The largest collection, and that furnishing the most varied fauna, is from locality 1. The dominant types of this fauna are the corals, to which I shall refer later. There are in addition an echinoid spine, a large number of fragmentary and ill-preserved pelecypods, a smaller number of gastropods, which are likewise and for the same reason undeterminable, and two species of brachiopods. There are evidently several types among the gastropods, and also among the pelecypods. One of the latter is marked by radiating ribs and has the general appearance of *Pecten*, *Lima*, *Pseudomonotis*, etc. There may be two species of this sort. One of the brachiopods, represented by several fragments, is probably a terebratuloid, but its generic affinities are doubtful. The other species is fairly abundant, and it is provisionally referred to *Bittnerula*. This is a rather small plicated shell with ribs also on the fold and sinus. The ventral valve is high and conical, with a high area marked by longitudinal striæ, which give the hinge a crenulated appearance. The shell substance is punctate. Fragments of the spiral arms can be seen on the inside. There are also short dental plates which converge and unite with the septum, as in *Cyrtina* and *Bittnerula*. All the *Cyrtinas* have a simple fold and sinus.

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A comparison of the corals with those described by Frech[1] from the Alpine Trias reveals a striking resemblance between the Alaskan forms and those from the Alps. This is true of the astræid corals and is especially significant in the case of the spongiomorphine and tubularian forms. In view, therefore, of the fact that this fauna is completely unlike not only any Paleozoic faunas known from Alaska, but any known from North America, and that the corals are in the main of types unknown in the Paleozoic and show on the contrary marked affinities with Triassic corals, I am strongly of the opinion that the geologic age of this fauna is Triassic, in spite of the fact that it is unlike any of the known Triassic faunas of Alaska. If this opinion is correct, the occurrence in Alaska of this coral fauna of the Alpine Trias, and especially the development there of the singular group of spongiomorphine corals, is new and important.

* * * * * * *

Lot 2, from Iliamna Bay, contains a number of vague, imperfect shapes, of probably pelecypods, a few small corals, also indeterminable (cf. the form compared with *Thecosmilia*) and an imperfect *Halobia*-like type suggestive of some of the *Halobias* which have been brought down from the Triassic of Alaska elsewhere.

These collections will be described in detail in a future publication by Prof. James Perrin Smith, who has submitted the following preliminary report on them:

The coral fauna is certainly Upper Triassic, of the lower Noric horizon. The species are closely allied to the Zlambach coral fauna of the Fischerwiese

[1] Frech, Fritz, Die Korallenfauna der Trias: Palaeontographica, vol. 37, 1890, pp. 1–116, Pls. 1–21.

locality in the Alps, which is the best Noric coral fauna known. Some of the species are probably identical with forms I have collected in the Upper Triassic, Noric horizon, of Shasta County, Cal., and are represented by kindred forms in the Blue Mountains of Oregon.

These forms will have to be sectioned and studied with the microscope before positive identifications can be made, but the forms capable of more definite determination, and their probable affinities, are listed below:

Preliminary list of fossils from the limestone on Iliamna Lake.

Thecosmilia cf. fenestrata Reuss (also in Shasta County, Cal.).
Isastræa cf. profunda Reuss (also in Shasta County, Cal.).
Phyllocœnia cf. incrassata Frech.
Phyllocœnia cf. decussata Reuss.
Stylophyllopsis cf. mojsvari Frech (also in Shasta County).
Astrocœnia cf. waltheri Frech (probably same as in the Noric of Nevada).
Stylophyllopsis cf. zitteli Frech.
Heterastridium sp.? (probably the same as in Oregon).
Spongiomorpha sp.? (probably the same as in Oregon).

Age and correlation.—The paleontologic facts presented above clearly establish the age of the limestone on Iliamna Lake as Upper Triassic, and suggest the same age for the limestone on Iliamna Bay. The local stratigraphic relationships at the exposures of limestone on Iliamna Lake and Iliamna Bay prove only that the former is older than the Tertiary volcanic rocks and that the latter is older than the early Jurassic granite. The lithologic similarity of the limestones at these localities and the absence of anything which suggests discrepancy in age make it reasonable to assume that they are the same. The local stratigraphic evidence may also be considered as showing, with a fair degree of certainty, the identity of the limestone southwest of Iliamna village with that at the fossil localities, and as being perfectly in harmony with the assignment of the fossils to the Upper Triassic.

This limestone corresponds in its general character, as well as in its stratigraphic relationships, with the Chitistone limestone[1] of the Chitina Valley. It is similar in sequence, as is shown by the fact that the Chitistone limestone is overlain conformably by the McCarthy shale, which carries the same fauna as does the Kamishak chert, and is underlain by greenstone, as the limestone here under discussion is believed to be. The Chitistone limestone is now known to carry an Upper Triassic fauna, including *Pseudomonotis subcircularis* and *Halobia* cf. *superba*.[2] It should be noted that neither of these species has been recognized with certainty in the limestone of Iliamna Lake and of Iliamna Bay, but that they do occur (p. 48)

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[1] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, pp. 25–28.

[2] Moffit, F. H., and Capps, S. R., The geology and mineral resources of the Nizina district, Alaska: Bull. U. S. Geol. Survey No. 448, 1911, pp. 23–25.

in beds referred to the Kamishak chert. Part of these, including the limestone bed at Bruin Bay, from which Stanton collected *Halobia* cf. *superba*, should possibly be included (p. 50) in the limestone formation here under discussion.

KAMISHAK CHERT.

Areal distribution.—The Kamishak chert is typically exposed on the west shore of Kamishak Bay, especially in the vicinity of Bruin Bay. These rocks occupy practically all of the peninsula on the south side of Bruin Bay and also appear to form most of the southern shore of the bay west of the peninsula, as well as the eastern half of the north shore of the bay. These exposures are part of a northeast-southwest trending belt which occupies the coast of Kamishak Bay for 3 or 4 miles north of the entrance to Bruin Bay and probably also from the fourth to the seventh mile southwest of the entrance.

The same rocks were seen on Ursus Cove, where they occupy the greater part of the north shore, and extend thence northward in an apparently continuous belt to the south shore of Cottonwood Bay, near its head. At this last locality several hundred feet of chert is exposed in the cliffs just east of the low pass leading southward to Ursus Cove.

Lithologic character.—These rocks, where exposed on Bruin Bay, consist of thin-bedded chert, black calcareous shale, and impure limestone. The chert and limestone are generally black, green, or dark red when fresh, but weather to lighter shades. The whole series is complexly crumpled and faulted (see Pl. V, *A*, p. 40) and is cut by a multitude of small calcite veins. A large mass of quartz diorite, intrusive into these rocks at the end of the peninsula on the south shore of Bruin Bay, has locally transformed the limestone into white crystalline marble.

At Ursus Cove the predominant rock is the chert, which occurs in massive beds, interstratified with thinner beds of limestone, shale, and sandstone. In the lower part of the section at Ursus Cove there are large amounts of fine-grained, green igneous rock, intimately but obscurely associated with the chert. (See Pl. V, *B*, p. 40.) It is somewhat doubtful whether it is intrusive or interbedded. This rock is somewhat altered, especially in the formation of epidote, and resembles in a way the greenstone at the head of Cottonwood Bay. A bed of limestone exposed at the mouth of the creek which heads near Cottonwood Bay is of importance, as it has yielded a few fossils which are discussed below. (Lot 3, p. 48.) This limestone was regarded in the field as a thin bed interstratified with and a member of the Kamishak chert, because of the presence, practically in contact with the limestone, of chert beds which are essentially identical in lithologic character with those interbedded with the shales from which Stanton collected *Pseudomonotis subcircularis* in the same cliffs and only a short distance away, and because of essentially the same degree of alteration in the limestone and in the known Triassic beds. It was furthermore concluded in the field that this limestone was decidedly less metamorphosed than the limestone only 6 miles distant on Iliamna Bay, and was hence presumably younger and separated from it by a considerable time and structural break. This conclusion was supported by the fact that the cherts are found on Cottonwood Bay, only 2 miles from the limestone on Iliamna Bay, and are no more altered than on Ursus Cove. From these facts it seemed evident that the limestone at Ursus Cove was but a member of the Kamishak chert and that the limestone at Iliamna Bay was considerably older. Other possibilities must, however, be admitted. The structure at the Ursus Cove locality is complex and it is entirely possible, so far as the field observations are concerned, that the limestone is part of an older formation folded or faulted in with the Kamishak chert. If this is the case the limestone may well be the same as the Triassic limestone described above.

The exposures seen at Cottonwood Bay consist entirely of chert. These exposures, however, are not extensive, and probably only a small portion of the formation is represented.

The total thickness of the formation is not known, the beds being so disturbed that no accurate measurement could be made. At Ursus Cove the thickness probably exceeds 2,000 feet and may be much greater.

Fauna.—Fossils have been collected from the shales and limestones interbedded with the chert beds in this formation at Ursus Cove and at Bruin Bay. These, according to Stanton's determination, consist of *Pseudomonotis subcircularis* (Gabb) from Ursus Cove, and *Halobia* cf. *superba* Mojsisovics from Bruin Bay.

The limestone at Ursus Cove, described above (p. 47), has yielded a few fossils, which have been examined by Dr. George H. Girty, who says of them:

> They are much less extensive and diagnostic than the fossils from the Triassic limestone on Iliamna Lake (p. 45), but are connected with the latter by a massive astræid coral having similar characters with one of them. There are in addition a gastropod having the general shape of *Natica* or *Naticopis* and a pelecypod probably belonging to one of the subgenera of *Cardium*.

Age and correlation.—The *Pseudomonotis* and *Halobia* mentioned above are characteristic Upper Triassic species and clearly establish the Upper Triassic age of this formation.

Among the rocks of other Alaskan regions with which these should be compared are beds from Cold Bay on the Alaska Peninsula from which *Pseudomonotis subcircularis* was described by Fischer[1] as *Monotis salinaria* Bronn, and from which the same species has subsequently been collected by Stanton.[2] The presence of this species as well as the similarity of the rocks is sufficient to determine the equivalence of these beds with those at that locality.

The cherts and associated igneous rocks on the west shore of Kenai Peninsula[3] at Halibut Cove, Seldovia, and Port Graham, have previously been correlated[4] with these rocks on the basis of the lithologic similarity, and of the relation to Lower Jurassic beds which apparently overlie them unconformably. These rocks were reexamined in 1909 by Grant and Higgins.[5] Though they found no fossils in the rocks which they regarded as belonging indisputably to these cherts and tuffs, they collected *Halobia* cf. *superba* from cherts and limestones which they regarded as conformably beneath the previously recognized Lower Jurassic beds.

The McCarthy shale of the Chitina Valley, which consists of shales interbedded with thin limestones, is also characterized by the presence[6] of *Pseudomonotis subcircularis.* The stratigraphic relationship of the McCarthy shale to the conformably underlying Chitistone limestone is likewise similar to the apparent relationship between the Kamishak chert and its subjacent limestone.

A somewhat similar and possibly equivalent fauna, which, among other forms, includes *Pseudomonotis subcircularis* and *Halobia superba* (?) has been found by W. W. Atwood in limestones at Hamilton Bay, Kupreanof Island, in southeastern Alaska.[7]

The beds outside of Alaska with which these may be compared include the Swearinger slate, which is the uppermost Triassic formation of California and which is characterized by *Pseudomonotis subcircularis.* The relations of this formation to the other Triassic rocks of California, including the beds characterized by *Halobia superba*, has been discussed by Prof. James Perrin Smith.[8] It should be noted that these two fossils are regarded by Smith as characteristic, in California and elsewhere, of separate zones. The

[1] Fischer, M. P., Sur quelques fossiles de l'Alaska: Compt. Rend. Acad. Sci., Paris, vol. 75, 1872, pp. 1784–1786. Also in Pinart's "Voyages à la côte nord-ouest de l'Amérique," pt. 1, Paris, 1875, pp. 33–36, Pl. A.

[2] Bull. Geol. Soc. America, vol. 16, 1905, pp. 394–396.

[3] Emerson, B. K., General geology: Harriman Alaska Expedition, vol. 4, 1904, pp. 26, 27. Moffit, F. H., Gold fields of the Turnagain Arm region: Bull. U. S. Geol. Survey No. 277, 1906, pp. 19–20, 23.

[4] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 393.

[5] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, pp. 167–168.

[6] Moffit, F. H., and Capps, S. R., The geology and mineral resources of the Nizina district, Alaska: Bull. U. S. Geol. Survey No. 448, 1911, p. 30.

[7] Wright, F. E. and C. W., Bull. U. S. Geol. Survey No. 347, 1908, p. 57.

[8] The comparative stratigraphy of the marine Trias of Western America: Proc. California Acad. Sci., 3d ser., vol. 1, 1904, pp. 323–430.

Pseudomonotis he regards as characteristic of the highest California Triassic beds, being the equivalent of the Noric stage of the European geologists, and the *Halobia* as characteristic of beds lower down, and within the Hosselkus limestone, the European equivalent being the Karnic stage of the Upper Triassic. A suggestion of a somewhat similar range is found in Alaska, where the *Halobia* is found in the Chitistone limestone but not in the overlying McCarthy shale, in the limestone members (?) provisionally referred to the Kamishak chert but not in the typical and presumably higher beds of the formation, and in the beds of less certain horizon at Port Graham and Hamilton Bay. The *Pseudomonotis* is abundant, and is practically the only fossil in the typical beds of the Kamishak chert, in the presumably equivalent beds at Cold Bay, and in the McCarthy shale. It is reported, however, from the Chitistone limestone and from beds supposed to be below those which yielded *Halobia* at Hamilton Bay. This indicates, if the species and the horizons from which they have been collected have been correctly determined, that these species have in Alaska a somewhat different range from that which is supposed to be characteristic of them elsewhere. It is probably safer to assume the range to be the same and to look for specific differences or for errors in the field identification of horizons. The presence of *Halobia* in the limestone beds at Bruin Bay should perhaps be accepted as evidence that these beds are not members of the Kamishak chert but belong in or below the older Triassic limestone.

Beds carrying identical or closely related species of *Pseudomonotis* are known on Vancouver Island, the Queen Charlotte Islands, the mainland of British Columbia, and in Siberia and northern Europe.

LOWER JURASSIC (?) ROCKS.

PORPHYRIES AND TUFFS.

Areal distribution.—The rocks discussed under the above heading have been found in three districts: (1) On the shores of Iliamna Bay and elsewhere along the west coast of Cook Inlet; (2) north of Iliamna Lake from the valley of Chekok River northward through the valleys of Lower Tazimina and Kontrashibuna lakes to Lake Clark, possibly extending thence westward; and (3) at several detached areas on the south shore and on some of the islands of Iliamna Lake below Pile Bay. These rocks may or may not be of the same age. They are grouped together, in the absence of proof that they should be separated, for purposes of convenience, although it is admitted that further studies may show this grouping to be erroneous.

The rocks of the first district include those exposed on the south shore of Cottonwood and Iliamna bays and on the north shore of Iliamna Bay east of A. C. Point. These appear to be part of a more or less continuous belt extending parallel to the coast of Cook Inlet, other exposures of which are on the south shore of Ursus Cove, on the west and north shores of Iniskin Bay, near the head of Chinitna Bay, and on the western arm of Tuxedni Bay.

The second district includes an area east of the Newhalen Valley and of the southern half of Lake Clark and west of a line from the mouth of Chekok River to a point about two-thirds of the way up Kontrashibuna Lake. Most of the east shore of Lake Clark for a distance of about 8 miles above Tanalian Point also falls within it. It probably includes also an area between Currant Creek and Kontrashibuna Lake, and areas west of Lake Clark.

The third district includes four detached areas on the south shore of Iliamna Lake. The easternmost of these extends from near the mouth of Pile Bay, 15 miles below the head of the lake, to a point 27 miles below the head of the lake. Similar rocks occur near the head of Kakhonak Bay, and along the south shore of the lake from a point 4 miles west to 7 miles west of Kakhonak village and from 25 miles east to 19 miles east of the outlet of the lake. The islands south of Knutson Bay, as well as the north shore of Iliamna Lake between Knutson and Chekok bays, are also probably to be included in this district. These rocks show considerable difference in lithologic character from the volcanic rocks of Iliamna Bay and elsewhere in the first district on the west coast of Cook Inlet, which are described above. They appear, however, to correspond with them in general relation to the neighboring rocks, although little definite evidence of their age and relations is to be had. The same statements may be made concerning their relation to the rocks described from the second district.

Lithologic character in Cook Inlet district.—A thick series of volcanic beds, which include both flows and tuffs, overlies the Kamishak chert on the south shore of Cottonwood Bay with apparent conformity. Amygdaloidal basalts and volcanic agglomerates are among the more characteristic rocks of this series. Similar rocks were seen on the north shore of Iliamna Bay where they include fine-grained green and gray felsitic rocks and tuffs, in part cherty, invaded by large dikes of quartz-feldspar porphyry, and also on the south shore of Ursus Cove where quartz porphyry tuff, andesite, and andesitic and rhyolitic agglomerates are present. The belt also extends northward from Iliamna Bay, being exposed on the west and north shores of Iniskin Bay, where basalt, gabbro, and tuff are present; near the head of Chinitna Bay, where it includes olivine basalt and tuff, and on the upper arm of Tuxedni Bay, where quartz porphyry, augite andesite tuff, and quartz porphyry tuff were seen.

The basalts seen on Ursus Cove and Iliamna Bay are dark amygdaloidal porphyritic rocks containing small phenocrysts of basic plagioclase, augite, olivine (mostly serpentinized), and magnetite. The groundmass is a fine-grained holocrystalline aggregate of plagioclase, augite, and iron ores. Serpentine, calcite, opal, quartz and chalcedony, and limonite appear as secondary minerals and in the amygdules.

Augite andesites were found on the south shore of Tuxedni Bay and on Iliamna Bay. These are much-weathered rocks. Originally they had a groundmass of plagioclase and magnetite in which were phenocrysts of plagioclase and pyroxene, either diopside or augite. These latter minerals are now largely serpentinized or uralitized.

Andesites were seen on Chinitna Bay and Ursus Cove. The Chinitna Bay rock is a fine-grained, holocrystalline, slightly porphyritic rock composed largely of plagioclase, which is the only primary constituent now recognizable. Chlorite, serpentine, and iron oxides are present as secondary minerals.

The andesites of Ursus Cove are fine-grained porphyritic rocks considerably weathered. The groundmass contains plagioclase, a little quartz, and magnetite or ilmenite, together with secondary chlorite, calcite, and epidote. The phenocrysts are of plagioclase, about oligoclase or andesine in composition, so far as their weathered condition permits determination.

The quartz porphyries from Tuxedni Bay, Iliamna Bay, and Ursus Cove are greenish or dark porphyritic rocks with felsitic groundmass. The phenocrysts are corroded and embayed quartz and euhedral acidic plagioclase, in some specimens also magnetite. The groundmass is microcryptocrystalline to microcrystalline and seems to be composed chiefly of quartz and feldspar. Most of these rocks are considerably altered. The feldspars are clouded, and calcite, epidote, and limonite are abundant.

Pyroclastic rocks in association with the above rocks were found at all the localities. Those which are entirely clastic are designated tuffs. They consist of angular or subangular fragments of microcrystalline igneous rocks, quartz porphyries, andesites, and the like, of fragments of quartz and feldspar, and of crystals of quartz and feldspar all embedded in fine fragmental binding material whose nature is more or less obscured by its fine grain and by alteration. In some of these rocks there is notable uniformity in the size of most of the grains, in others there are grains of all sizes from fragments of several inches in diameter to submicroscopic grains. These rocks are all thoroughly indurated. Calcite, limonite, a little epidote, and serpentinous or chloritic material were detected in the matrix. Some of these rocks are distinctly stratiform. One such from Iliamna Bay, which is exceedingly fine grained, has a cherty appearance.

Other pyroclastic rocks, designated volcanic agglomerate, were found on Iliamna Bay and Ursus Cove. At the first-named locality there is a rock, composed of basic andesite or basalt, included in a matrix of amygdaloidal basaltic glass. The amygdules are of calcite and serpentine (?). On Ursus Cove the rocks of this class consist of fragments of altered feldspar, quartz, and of several kinds of microcrystalline igneous rock embedded in a base of cryptocrystalline eutaxitic lava.

Lithologic character in Lake Clark district.—Large areas around Lower Tazimina Lake and from there northward to Lake Clark are underlain by a group of rocks of porphyritic texture ranging in composition from acid rhyolites, through quartz porphyries, dacites, and mica andesites to intermediate hornblende andesites. Among these is a rhyolite (9AKz41) from a point 9 miles north of the mouth of Chekok River. This is a light-gray rock with small glassy quartz and white feldspar grains thickly studded in a lithoidal base. Under the microscope are seen phenocrysts of quartz, feldspar, and biotite. The quartz grains are generally without crystal outlines and many have "corrosion embayments." The feldspars include both orthoclase, slightly weathered, and plagioclase (about Ab_9An_1) quite fresh. These as a rule are euhedral. Biotite is less abundant than the quartz and feldspar and is considerably altered to chlorite. Numerous splinters of the above minerals are embedded in the groundmass, which is cryptocrystalline and shows flow texture.

Another of these rocks, at a point about 1½ miles southeast of the head of Lower Tazimina Lake, is a quartz porphyry (9AKz43), which is a dark felsitic rock in which minute quartz and white feldspar grains are macroscopically visible. The microscope reveals small abundant grains of quartz and acid plagioclase, commonly euhedral, and also a little biotite. The groundmass is a fine-grained intergrowth of quartz, feldspar, hornblende, and biotite. Small amounts of magnetite and apatite are present as minute crystals.

On the mountain 8 miles north of the mouth of Chekok River there is a dacite, a whitish light-gray microgranular rock (9AKz28), in which phenocrysts of feldspar are visible in the hand specimen. Under the microscope phenocrysts of acid plagioclase, biotite (much altered), and small magnetite grains are seen in a microgranitic groundmass of quartz and feldspar with small amounts of minute biotite and magnetite.

A hornblende andesite (9AKz35) from a point about 9 miles north of the mouth of Chekok River is a dense dark-gray rock in which small feldspars and hornblende grains are visible. Under the microscope plagioclase (about andesine so far as determinable) and hornblende are found as phenocrysts in a groundmass in which only plagioclase and magnetite are recognizable. Between these feldspar grains is an indeterminable base which is in part isotropic and may be glass.

The Roadhouse Mountain area is represented in the collections by an andesite (9M140) very fine grained and badly weathered (to which a rock (9M139) on Newhalen River is very similar) and a quartz porphyry tuff, consisting of fine angular fragmental quartz and feldspars in a seemingly fragmental binding material. These rocks are similar to some in the Tazimina area. Both of these specimens are from the southwest face of the mountain, and it is not known whether or not they are representative of the rest of the mountain mass, which was not examined.

These rocks usually have feldspar and sometimes quartz phenocrysts and rarely macroscopic ferromagnesian minerals. The groundmass, microcrystalline to cryptocrystalline and here and there eutaxitic, varies from bluish white or gray to black. Associated with these are tuffs, some composed of angular fragments of porphyry embedded in either a felsite or porphyry base, or again in a fine fragmental base, and others composed chiefly of fine feldspar crystals and fragments in a minutely comminuted base. The agglomeratic character of some is strikingly apparent, whereas others show it only faintly on weathered surfaces and still others resemble indurated grits or graywackes, and finally some which are light buff to purplish in color have soft sandy texture. These rocks seem to be related to one another as a succession of products of volcanic eruption. The various types in so far as any structures are discernible seem to lie in successive or alternating belts. This is particularly well shown on and near the mountain 8 miles north of the mouth of Chekok River, where a similar order of succession, gray dacite, eutaxitic vesicular vitrophyre, bluish felsophyre, and fine-grained black basalt is encountered on the southeastern and northern sides. About 5 miles south of Tanalian Point there are porphyries distinctly interbedded with tuffs, the whole formation there having a minimum observed thickness of 2,000 feet with uniform strike N. 65° W. (magnetic) and dip 25° NE. All these rocks are indurated but are internally undeformed and are altered only by weathering and cementation processes.

Fine-grained granular rocks occupy an area northward from the head of Lower Tazimina Lake for about 4 miles. These are of very fine grain, light color, usually with porphyritic texture and in many places miarolitic. They show considerable variation in appearance, and in the distribution of the different types of rock suggest a series of thick flows in approximately horizontal position. Mineralogically they consist of quartz, orthoclase, and acidic plagioclase with subordinate amounts of common hornblende or biotite or both. Hornblende in some is more abundant and important; others again are more basic, consisting only of plagioclase and pyroxene. These rocks should probably be considered part of the "porphyry and tuff" formation and not be grouped with the neighboring granites. They have about the same range in composition as the porphyries and tuffs, and though granitic they are generally also fine-grained, porphyritic, and miarolitic in texture, indicating crystallization under slight pressure, perhaps of thick flows at the surface. They seem to have the same bedded flow distribution as the porphyries and tuffs which they adjoin directly on the north and west. In the field only a part of them were recognized as granitic and they were provisionally mapped as identical with the porphyries and tuffs.

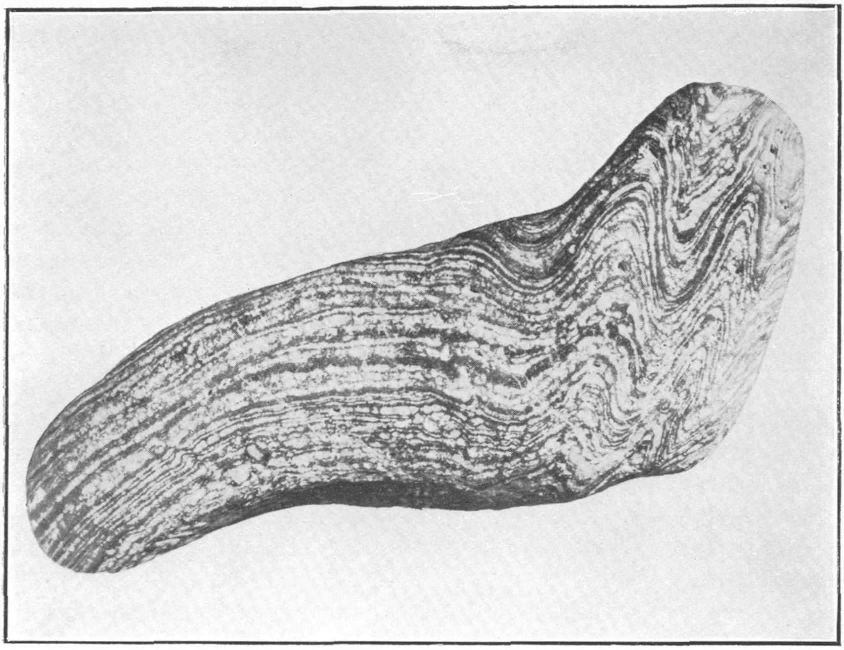
Summarizing, it may be said that these rocks range in composition from quartz alkali feldspar rocks with only small amounts of femic minerals to augite andesites. Their textures are usually porphyritic with aphanitic or exceedingly fine granular groundmass, and not infrequently flow structures are evident. Tuffs and agglomerates of like composition are intermingled with these rocks. Some are of coarse and angular grain which distinctly reveals their true nature, but associated with them, and in places connected with them by intermediate types (gradation phases), are considerable masses of dense aphanitic, light-colored, and banded rocks which were designated "chert" in the field but which on study appear to be thoroughly indurated pyroclastics of very fine grain.

In general these rocks as a group are not fresh. The feldspars as a rule are more or less completely kaolinized or saussuritized. The hornblendes and biotites are largely altered to chlorites and iron oxides, etc. Epidote, calcite, chlorite, quartz, and iron oxides (limonite) are abundant along fractures and in vesicles of the scoriaceous and tuffaceous members. The tuffs for the most part are thoroughly indurated.

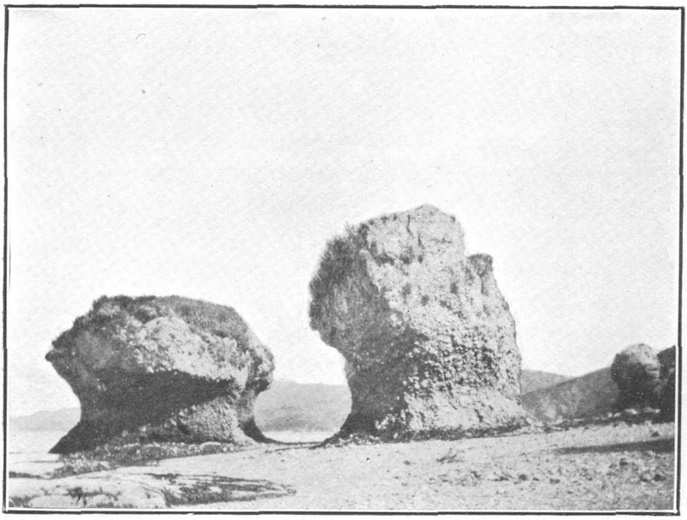
The southern part of the hill on the west shore of Lake Clark just above the mouth of Tlikakila River is occupied by rocks, part of which were regarded in the field as conglomeratic arkoses and part as porphyry breccia. These are light-colored, white and gray compact rocks, of which the constituents visible to the naked eye include, in some specimens, crystals and fragments of feldspar, and in other specimens bits of cherty looking material and of aphanitic porphyries which are generally rounded rather than angular. Three specimens under the microscope reveal material which is very much altered and fine grained and therefore of obscure relationships, but which indicates a tuffaceous rather than normal sedimentary character. In one rock, from the lake shore about a mile above Tlikakila River, bits of felsite and feldspar fragments, all more or less angular, are seen in a base too fine for determination. Another thin section of a rock near by shows small areas which, though obscure because of fine grain and decomposition, suggest in some cases micrographic and in others eutaxitic porphyritic textures. Other areas in the thin section are a jumble of much-altered feldspar (largely plagioclase), quartz, pyroxene, and biotite (?) with accessory amounts of apatite, ilmenite, magnetite, and pyrite (?) in a fine-grained mat in which are quartz, limonite, feldspar (?), and other unidentifiable material. Secondary calcite is abundant. The rock has the appearance of decomposed volcanic agglomerate or flow breccia. A specimen from the summit of the hill is composed of euhedral, angular broken and corroded grains of feldspar (largely plagioclase), of euhedral and corroded quartz grains, of fragments of acid porphyritic rocks and iron oxide. All these are in a matrix composed of fine granular quartz (?) and much chloritic or serpentinous material and limonite. There are undetermined but unimportant amounts of other accessory and secondary constituents. This rock may with little doubt be classed as a dacitic tuff. In composition and degree of alteration these rocks seem to be more closely allied to the porphyries and tuffs of the area around the Tazimina Lakes than to any other rocks of the region, and as there is no proof of their stratigraphic position they are provisionally grouped with the early Mesozoic porphyries and tuffs for lack of a better place to discuss them.

Lithologic character in Iliamna Lake district.—The rocks of the third of these districts, which include the older volcanic rocks exposed on the south shore of Iliamna Lake, and possibly in some of the mountains west of Newhalen River, are quartz latites. They comprise the following types: (1) Light-gray or greenish-gray lithoidal porphyries in which there are sparse megascopic feldspars and pyroxene. (2) Gray, bluish, and light-brown glassy rocks which have as a rule a finely banded flow structure, which is both minutely contorted (Pl. VI, *A*) and bent in a large way. The flow bands are marked by lines of lithophysæ or spherulites or both. Some of these rocks are perlitic. (3) Light-colored gray, green, and browish tuffs of fine grain, in part distinctly banded and in part closely resembling the lithoidal porphyries.

The microscope shows that in these rocks the phenocrysts, which are not very abundant, include quartz, plagioclase (about labradorite), and rarely a pyroxene resembling diopside. One specimen contains a little brown hornblende. The groundmass where crystallized seems to be made up principally of small feldspar laths in rudely parallel aggregates. Minute apatites are common. That the tuffs and agglomerates associated with these rocks were derived from lavas of the same kind is indicated by the fact that the recognizable minerals in them are the same, namely, quartz, similar plagioclase, and similar pyroxene. Furthermore, there are fragments of finely crystalline rock very like the groundmass of the lithoidal porphyries.



A. BANDED RHYOLITE FROM SOUTH SHORE OF ILIAMNA LAKE.



B. CHISIK CONGLOMERATE.

Large blocks fallen from cliffs on east shore of Iniskin Bay.

Although these rocks in the field specimen not uncommonly have a weathered greenish or rusty appearance, they are quite fresh. Under the microscope only the more distinctly stratiform pyroclastics showed strong alteration of the feldspars. The femic minerals are very little weathered, and the groundmass is generally unaltered where crystalline; where glassy it is commonly still perfectly vitreous or but slightly devitrified. In the glassy and tuffaceous members vesicles and other openings are unfilled, although a rusty incrustation is common.

The rocks on the north shore of Iliamna Lake between Chekok and Knutson Bays, and of the islands off the mouths of Knutson and Pedro Bays, are probably to be grouped, in part at least, with the rocks described above from the south shore of Iliamna Lake. The rocks which were studied from the mainland between Chekok and Knutson Bays are of two types. One specimen proves to be a grayish-white porphyritic lithoidal quartz latite. Another specimen from this vicinity is a light greenish-gray agglomerate in which the recognizable constituents are bits of quartz, feldspar, mica, hornblende (?), and small pieces of granite. The indeterminate matrix somewhat resembles the quartz latite tuffs, but the rock is not improbably an arkosic conglomerate, as it was regarded in the field. Specimens from Low Island (the large island southwest of Pedro Bay) and two small islands north of it include (exclusive of the granites) three light-gray porphyritic lithoidal quartz latites. There is also a fragmental rock of light-gray base spotted with small feldspars and quartz grains, which are for the most part angular, though some are rounded, and with a few grains of undetermined minerals. This rock looks tuffaceous, but may be arkosic. Another fragmental rock of light-gray, fine, granular base, weathering rusty, contains large subangular pieces of granitic material and quartz. A third doubtful rock is white, rusty weathering, fine grained, and porous. There is no sign of rounded material, and the rock is most probably a tuff. On the south end of Low Island there is a dark waxy porphyritic glass of low specific gravity and a black vesicular porphyritic fine granular dike rock, probably a basalt.

It may be seen from the foregoing descriptions that there are two types of rock in this vicinity. One includes the quartz latites and their tuffs and the other includes the conglomeratic and arkosic rocks the matrix of which somewhat resembles the quartz latite tuffs. These were not separated in mapping, and the field relationships of the two were not determined. The quartz latites and their tuffs considered alone bear a close resemblance to the rocks described above (p. 56) under the same name from the localities on the south shore of Iliamna Lake, although the finely banded glassy rocks of the latter localities are here absent. If the conglomeratic and arkosic rocks are really as intimately associated with the quartz latites as the present grouping might be assumed to imply, then these rocks have, in this part of the district, a facies not recognized elsewhere. Another and perhaps the most probable interpretation of the conglomeratic and arkosic rocks would be to regard them as younger than the areally associated latitic rocks. The granitic constituents would then have a probable source in the near-by early Jurassic granite masses, and the tuffaceous constituents might well have been derived from the erosion of the latites. If this interpretation be adopted they might be correlated with the Middle Jurassic or Upper Jurassic conglomerates described below (pp. 59, 68) from the shore of Cook Inlet, or be regarded as a basal member of the Tertiary volcanic rocks (p. 78) outcropping near by on Iliamna Lake.

Age and correlation.—The rocks described above from the south shore of Cottonwood Bay overlie the Kamishak chert. The relationships are apparently those of conformable stratigraphic succession, for not only was no erosional break observed but there is a more or less gradual gradation in lithologic character from the fine-grained homogeneous cherty beds below to the coarser heterogeneous volcanic accumulation above. The local relationships thus indicate that these rocks are either very high in the Triassic or low in the Jurassic.

These porphyries and tuffs of Cottonwood Bay accord fairly well in their relation to the Upper Triassic Kamishak chert, as also in general lithologic character, with the tuffs and associated rocks, probably of Lower Jurassic age, which are typically exposed on the west side of Seldovia Bay[1] and probably extend continuously from that locality to Port Graham. These beds consist chiefly of water-laid fragmental igneous material, although cherty limestone is present in the section on the north shore of Port Graham. The thickness is probably more than 1,000 feet, but no good estimate could be made. These beds were referred provisionally by Stanton to the Lower Jurassic on the basis of the fauna obtained at Seldovia.

No Lower Jurassic faunas have been found west of Cook Inlet, either in the beds here described or in any others, but the volcanic beds described above from the west shore of Cook Inlet, and also those from Iliamna and Clark lakes may possibly be correlated with the beds at Seldovia, and assigned to the Lower Jurassic, on the evidence of similar lithology and sequence. This suggested correlation is regarded as probable for the rocks on Cottonwood and Iliamna bays. The assignment of the rocks west of the mountains to the Lower Jurassic is dependent on a correlation through the rocks on

[1] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 396–397. Moffit, F. H., Gold fields of the Turnagain Arm region: Bull. U. S. Geol. Survey No. 277, 1906, pp. 20–22. Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of the Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, p. 167.

Iliamna Bay, and is hence doubly weak, since there is no very good local stratigraphic evidence on the age of the rocks on Iliamna Lake and east of Lake Clark or any definite proof that they are of the same age, or that any of them are synchronous with those on Iliamna Bay.

Comparison should also be made with the "andesitic greenstones, porphyries, and tuffs" described by Paige and Knopf[1] from the upper Matanuska Valley and by them referred to the lower part of the Middle Jurassic[2]; and with the Skwentna group of the Alaska Range.[3] The latter is known to underlie beds which carry the fauna of the Tuxedni sandstone (p. 63), and is possibly of early Middle or of Lower Jurassic age.

MIDDLE JURASSIC ROCKS.

TUXEDNI SANDSTONE.

Areal distribution.—The lowest known member of the Middle Jurassic of southwestern Alaska is the Tuxedni sandstone. This formation is typically exposed on the south shore of Tuxedni Bay, from which it is named,[4] and extends from there in a continuous belt, parallel to the general course of the shore of Cook Inlet, as far south as the east shore of Iniskin Bay, a distance of about 42 miles. Good exposures were seen on the south shores of Tuxedni and Chinitna bays and on the east shore of Iniskin Bay. It appears to be absent at the surface south of this point, probably being buried by Triassic and other rocks which are overthrust upon the Upper Jurassic beds. It probably extends north from Tuxedni Bay in line with its known outcrop southward, but the area of its probable position has never been visited by geologists. Beds correlated with these occur in other parts of Alaska, as will be described below.

Lithologic character and sections.—The Tuxedni sandstone consists of sedimentary beds of marine origin and is at least 1,100 feet thick. It is made up predominantly of sandstone, although it contains considerable shale and a few thin beds of limestone and conglomerate.

The basal contact of the formation is exposed on the south shore of the eastern arm of Iniskin Bay. The rocks of the Tuxedni sandstone at this point consist of fossiliferous sandstone and shale with beds of conglomerate containing pebbles, averaging several inches in diameter, of a variety of crystalline rocks, chiefly granite. The lowest of the several beds of conglomerate rests upon a sheared basic por-

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16–19.

[2] More recent evidence indicates that these rocks are of Lower Jurassic age. See Bull. U. S. Geol. Survey No. 500, 1912, pp. 29–32.

[3] Brooks, A. H., The Mount McKinley region: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 85–87.

[4] The Tuxedni sandstone and the overlying Chinitna shale have formerly been grouped as the "Enochkin formation," which is here divided because of the dissimilarity of the lithologic character and faunas of the two parts.

phyritic rock which is regarded as a member of the Lower Jurassic(?) porphyries and tuffs. The conglomerate dips 50° SE.; the cleavage or bedding of the porphyry dips 34° NW. There is consequently either discordance of bedding between the porphyry and the conglomerate, or a structure in the former which is not developed in the latter. In either case the presence of an unconformity is established.

The most complete known section of this formation is exposed on the south shore of the western arm of Tuxedni Bay. This section, measured by Stanton and Martin[1] in 1904, is typical for the lithologic and paleontologic character of the formation, although no exposure of either the base or the top is visible.

Section of part of the Tuxedni sandstone on south shore of Tuxedni Bay.

		Feet.
1.	Shaly sandstone with scattered fossils, *Inoceramus, Trigonia, Sphæroceras, Phylloceras,* etc	55
2.	Black sandstone with small white angular grains	8
3.	Hard gray sandstone	1
4.	Black sandstone with *Inoceramus ambiguus, Stephanoceras* cf. *humphriesianum, Sphæroceras oblatum?* etc	3
5.	Dark shale	8
6.	Soft coarse black sandstone with white grains	39
7.	Fine-grained gray shale with *Sphæroceras oblatum, Belemnites,* etc	18
8.	Fine-grained gray shale	35
9.	Bands of sandstone and shale	3½–6
10.	Dark soft shaly rock with coarse grains	10
11.	Dark limestone with abundant fossils, *Sphæroceras cepoides, Pleuromya,* etc	2 –4
12.	Dark shale	3
13.	Dark conglomerate rock (arkose)	7½
14.	Dark shale with conglomerate bands	26
15.	Sandstone	1
16.	Gray shale	15
17.	Sandstone	2
18.	Shale with scattered fossils	12½
19.	Sandstone and shale with *Stephanoceras carlottense, S. richardsoni Sphæroceras cepoides, Lytoceras, Phylloceras,* and many other fossils	3 –3½
20.	Shale with concretionary bands	10
21.	Concealed by a fault	±100
22.	Gray shale with numerous sandstone and concretionary bands and occasional fossils, including *Stephanoceras* cf. *humphriesianum*	100
23.	Gray shale with occasional sandstone and concretionary bands	150
24.	Gray sandstone with *Inoceramus ambiguus* and a few other bivalves	120

[1] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 399–400.

		Feet.
25.	Limestone conglomerate with clavellate and undulate *Trigonias*, etc	1
26.	Gray sandstone	3½
27.	Dark gray fossiliferous sandstone	1
28.	Gray sandstone with many small fossils	11
29.	Fossiliferous conglomerate with *Belemnites*	2
30.	Shaly sandstone with *Inoceramus lucifer* and *Lima* cf. *gigantea*	52
31.	Sandy shale with a few thin indurated fossiliferous sandstone bands	35
32.	Indurated ledges of argillaceous sandstone 1 to 4 feet thick, alternating with somewhat thicker beds of clay (fossiliferous)	25
33.	Shale with abundant ammonites, *Stephanoceras*, *Harpoceras*, etc	20
34.	Indurated bands of sandstone in ledges 1 to 1½ feet thick, alternating with thicker beds of shale	14
35.	More or less sandy shale weathering yellowish	100
36.	Sandstone with clay partings with abundant *Lima* cf. *gigantea*	36
37.	Softer sandstone and shale to base of exposure, partly covered by shale talus	100
		1,128

This section is especially appropriate for the type section of this formation, because it not only shows the most complete known representation of these rocks but both marine invertebrates and fossil plants are present, the former in great abundance and variety. It was, moreover, measured at one of the first localities in Alaska at which a large collection of Jurassic fossils was made, and at which the fauna has long been known, not only through the early descriptions by Eichwald[1] but through the material subsequently collected by Dall[2] and described by Hyatt.[3]

The following section on the east shore of Iniskin Bay[4] includes the base of the formation, but the concealed intervals are very large, less than half of the beds being represented, and the contact with the overlying formation probably is cut off by a fault (see fig. 7, p. 99).

Section of Tuxedni sandstone on east shore of Iniskin Bay.

"Zone C."	Feet.
Sandy shales with many *Belemnites* and other fossils	50
Concealed	20
Soft shale	20
Dark-drab shale with scattered fossils	33

[1] Eichwald, Eduard von, Geognostisch-palaeontologische Bemerkungen über die Halbinsel Mangischlak und die Aleutischen Inseln, St. Petersburg, 1871, pp. 88–200.

[2] Dall, W. H., Report on coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 869–870.

[3] Hyatt, Alpheus, Report on Mesozoic fossils: Idem, appendix 3, pp. 907–908.

[4] Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905, p. 42.

	Feet.
Hard calcareous shale full of fossils, principally *Inoceramus*, *Pleuromya*, and other pelecypods	2
Black sandstone	1
Dark shale	5
Black sandstone	1
Dark shale with many fossils	12
Reddish limestone	½
Dark shale with many fossils	14
Dark shale with scattered fossils	62
Dark soft sandstone with streaks of conglomerate	10
Concealed.	
"Zone B."	
Shale with several fossil bands containing *Trigonia doroschini*, etc	50
Concealed.	
"Zone A."	
Shale with several fossil beds each 10 to 25 inches thick and packed with fossils; *Trigonia doroschini, T. devexa*, etc	30
Concealed.	
Shale	12
Coarse conglomerate	20
Unconformity.	

Fauna and flora.—The Tuxedni sandstone contains a large marine invertebrate fauna, which is still for the most part undescribed. The following lists comprise some of the more common species as determined by Stanton:

Marine invertebrate fossils from the Tuxedni sandstone.

South shore of Tuxedni Bay:
- Stephanoceras loganianum.
- Stephanoceras carlottensis.
- Stephanoceras cf. humphriesianum.
- Sphæroceras oblatum.
- Sphæroceras cepoides.
- Phylloceras sp.
- Lytoceras sp.
- Trigonia dawsoni.
- Lima cf. gigantea.
- Inoceramus ambiguus.
- Inoceramus porrectus.
- Inoceramus eximius.
- Inoceramus lucifer.

East shore of Iniskin Bay, zones A and B (2919):
- Belemnites sp. Fragments.
- Thracia sp.
- Trigonia doroschini Eichwald. Abundant.
- Trigonia sp. Belongs to Clavellatæ group.
- Grammatodon? sp. a.
- Pseudomonotis? sp.
- Pecten sp. A single very small, smooth form.
- Ostrea sp. Fragmentary specimens of a small irregular species.

East shore of Iniskin Bay, near lower cabin, zone C (2920):
- Stephanoceras sp.
- Belemnites sp. a.
- Belemnites sp. b. Abundant.
- Belemnites sp. c.
- Grammatodon? sp. a.
- Grammatodon? sp. b.
- Inoceramus eximius Eichwald. Abundant.
  The forms described by Eichwald as I. eximius, I. ambiguus, and I. porrectus may all belong to one species.
- Pecten sp. Small form same as in lot 2919.
- Pecten sp. Large individual that may be adult of last named.
- Ostrea sp. Same as in lot 2919.

Fossil plants were obtained from several localities, at all of which they were interbedded with the marine sediments carrying the invertebrate fossils listed above. The following species have been determined by F. H. Knowlton:

Fossil plants from Tuxedni sandstone.

No. 915.—South shore of Tuxedni Bay:
- Sagenopteris göppertiana Zigno.
- Pterophyllum rajmahalense Morris.
- Macrotæniopteris californica Font.

No. 916e.—South shore of Tuxedni Bay, 2½ miles west of Chisik Island:
- Sagenopteris göppertiana Zigno.
- Pterophyllum rajmahalense? Morris.

No. 916f.—South shore of Tuxedni Bay, 2½ miles west of Chisik Island:
- Fossil wood, not studied.

No. 917h.—South shore of Tuxedni Bay, 3 miles west of Chisik Island:
- Sagenopteris göppertiana Zigno.

No. 928.—East shore of Iniskin Bay "zone C:"
- Sagenopteris göppertiana? Zigno.

No. 931a.—East shore of Iniskin Bay, 300 yards above lower cabin:
- Sagenopteris göppertiana Zigno.

Age and correlation.—The fauna of the Tuxedni sandstone is regarded by Stanton[1] as showing that it certainly includes at least part of the Middle Jurassic, although he holds that further study of the faunas must be made before exact correlations with the European faunas can be made. Practically the same conclusion was reached by Hyatt[2] from his study of the fauna from Tuxedni Bay.

This fauna has been recognized in the upper end of the Matanuska Valley,[3] and also in parts of the Tordrillo formation of the Alaska Range.[4] The occurrence of this fauna in the Kennicott formation

[1] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 401–402.

[2] Hyatt, Alpheus, Report on the Mesozoic fossils: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 7, 1896, pp. 907–908.

[3] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, pp. 17–19.

[4] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, p. 232; The Mount McKinley region: Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 90.

of the Copper River region is suggested by the reported presence there,[1] in the earlier but not in the later collections, of *Inoceramus eximius*.

The only localities in North America, outside of Alaska, where a fauna similar to this has been found are in the "lower shales and sandstones (subdivision C)" of the "Cretaceous" of the Queen Charlotte Islands, where Whiteaves[2] has recognized many species belonging in this fauna.

The following discussion of the age and relationship of the flora has been submitted by F. H. Knowlton:

The Jurassic plants, although few in species and not always well preserved, are of the highest possible interest, for they are found in intimate association with typical marine invertebrates of known Jurassic age. By combining the species found at the several localities we have the following lists:[3]

Tuxedni sandstone:
- Sagenopteris göppertiana Zigno.
- Macrotæniopteris californica Font.
- Pterophyllum rajmahalense Morris.

Chinitna shale:
- Cladophlebis denticulata (Brongn.) Sew.
- Ctenis grandifolia Font.
- Hausmannia sp.?
- Dictyophyllum cf. obtusilobum.

The forms that have been specifically named are determined with a great degree of certainty, the most abundant being the *Sagenopteris*, which occurs at five of the eight localities. The two remaining forms are mere fragments that will not admit of specific identification, though there can be absolutely no doubt as to the correctness of the generic reference, especially that of the *Dictyophyllum*, which seems to be in fruit. As to the distribution of the named species, the *Cladophlebis* occurs in the Jurassic of England and France as well as other parts of the Old World, and, moreover, is very close to what has been called "*Asplenium*" *whitbiense*, which occurs abundantly in the Jurassic of eastern Siberia and California. The other four named species, not to go farther afield, are found in the "so-called" Jurassic at Oroville, Cal., but apparently have not been found in the Cape Lisburne region of Alaska, although the *Sagenopteris* is not greatly different from a species that is.

Knowlton[4] has also recently discussed the relationship of this flora to that of the Monte de Oro formation of California and its bearing on certain problems in the stratigraphy of Oregon and California.

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[1] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, p. 50. Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, p. 31.

[2] Whiteaves, J. F., Mesozoic fossils: Can. Geol. Survey, vol. 1, 1876–1900, pp. 1–92, 191–262, 263–308. Dawson, G. M., Geological record of the Rocky Mountain region in Canada: Bull. Geol. Soc. America, vol. 12, 1901, p. 75.

[3] This discussion is based on not only the plants from the Tuxedni sandstone but also on those of the Chinitna shale, listed on p. 67.

[4] Knowlton, F. H., The Jurassic age of the "Jurassic fauna of Oregon": Am. Jour. Sci., 4th ser., vol. 30, 1910, pp. 49–50.

CHINITNA SHALE.

Areal distribution.—The Chinitna shale occupies a belt east of and parallel to the area of the Tuxedni sandstone from Tuxedni Bay to Iniskin Bay. It is well exposed on the west side of Chisik Island, on both shores of Chinitna and Oil bays, and on the east shore of Iniskin Bay. It has not been followed along the belt of its probable extension north of Tuxedni Bay. South of Iniskin Bay it does not appear at the surface within the area covered by this report, although it is known (p. 68) farther southwest on the Alaska Peninsula.

Lithologic character and sections.—The Chinitna shale is a lithologically rather homogeneous formation consisting of 1,300 to 2,400 feet of shale with subordinate amounts of sandstone and limestone. It rests with apparent conformity upon the Tuxedni sandstone, from which it is distinguished[1] by being argillaceous rather than arenaceous and by possessing distinctive faunas and floras.

The following section, measured by Stanton[2] on the north shore of Chinitna Bay, is typical of the lithologic character of the formation, although the base is probably not exposed, and no fossils were found in the upper 1,000 feet or more which is assigned to this formation on lithologic grounds.

Section of Chinitna shale on north shore of Chinitna Bay.

	Feet.
Indurated dark argillaceous shales with conspicuous thin bands and elongated lenses of yellowish impure limestone	500
At this point a change in the strike of the beds and in the direction of the coast carries the cliffs some distance from the shore. The section is continued on a small creek, which enters the bay about half a mile west of the end of the sea cliffs. Along this creek the exposures are not so continuous, nor so conspicuous as those in the sea cliffs, but they are sufficient to show the relation of the beds to the general section.	
Dark shales with occasional more indurated bands of argillaceous sandstone	425
Dark shales with beds of argillaceous sandstone forming many cascades. *Cadoceras* found near the middle	650
Indurated bands of argillaceous sandstone with abundant specimens of *Cadoceras* and *Belemnites*	10
Dark shales and argillaceous sandstones	115
Similar beds not well exposed	200
Dark shales weathering to brownish slopes with bands of small concretions containing *Cadoceras doroschini*, etc	75
Dark clay shales, weathering brownish, with concretions containing *Cadoceras* etc., near middle	110
	2, 315

[1] It was formerly grouped with the Tuxedni sandstone as the "Enochkin formation." See footnote, p. 59.

[2] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 400–401.

The section exposed on the east shore of Iniskin Bay, which is given below, has the top of the formation clearly defined and contains typical fossils throughout. The thickness of beds is much less than on Chinitna Bay. This is in all probability due to concealment of the base of the formation rather than to thinning.

Section of Chinitna shale on east shore of Iniskin Bay.

	Feet.
Dark-drab shale with numerous bands of limestone concretions filled with well-preserved specimens of *Cadoceras*, *Belemnites*, etc., and with occasional sticks of fossilized wood	146
Shale as above, partly concealed by talus at "Mushroom Rocks," thickness computed	77
Dark shales, as above, with same concretions and wood	196
Limestone	1
Shales, as above	363
Shales, partly concealed by talus, thickness computed	300
Shales, as above, with *Cadoceras doroschini* and a few other fossils	200
Concealed	25
	1, 308

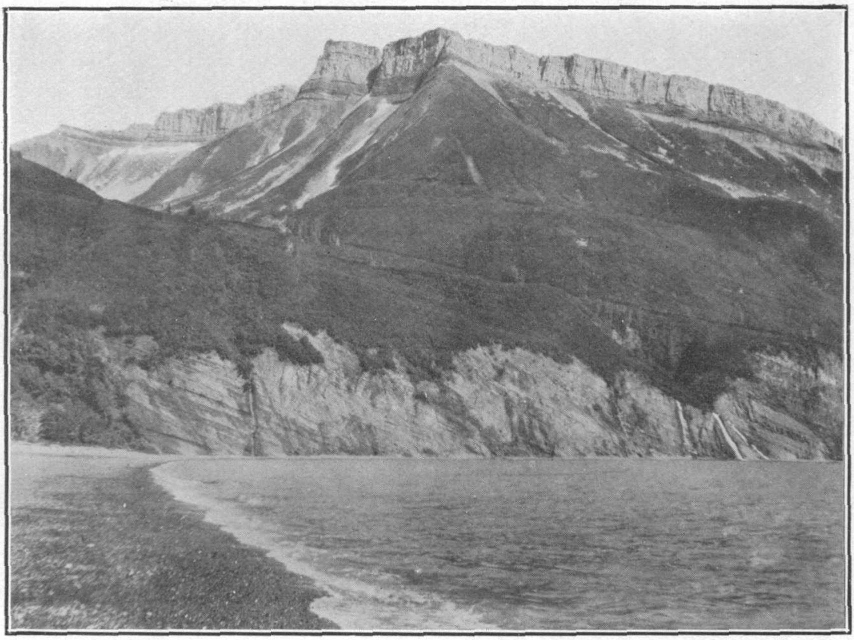
At Oil Bay, about 4 miles east of Iniskin Bay, the sequence and relations are practically the same as is shown in the following section. The beds represented in this section are shown on Plate VII, *A*.

Section of upper part of Chinitna shale on east shore of Oil Bay.

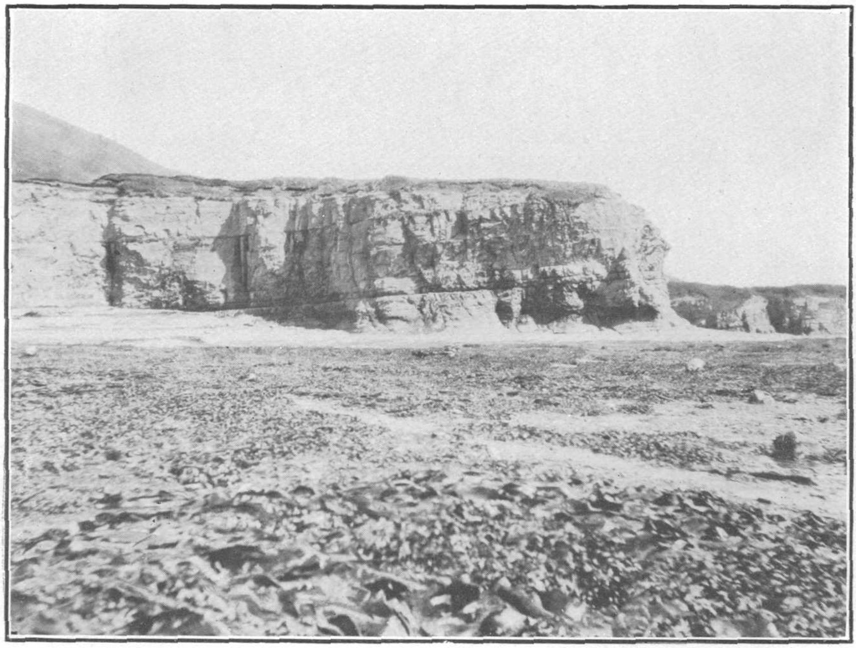
	Feet.
Dark shale with concretions	690
Hard dark sandstone	½–¾
Dark-drab shale with numerous concretions	530
Calcareous shale with *Cadoceras schmidti*, Pompeckj, *Cadoceras* sp. cf. *C. stenoloboide* Pompeckj, and *Phylloceras*	1
Dark shale with *Cadoceras doroschini*, etc	60
Soft green sandstone	½
Dark-drab shale	12
	1, 294

The rock exposed at the extreme western point of Chisik Island contains an exposure of several beds of coarse conglomerate aggregating more than 100 feet in thickness, and occurring as a lens in the Chinitna shale. The stratigraphic relationships are clear at the northern end of the outcrop (see fig. 2), where some beds of the conglomerate may be seen ending abruptly against a vertical wall of shale, suggesting a fault, though others continue unbroken across this line, proving that no fault is present.

Fauna and flora.—The Chinitna shale is characterized by the presence of an abundance of large cephalopods, especially several



A. NAKNEK FORMATION AND UNDERLYING CHINITNA SHALE ON EAST SHORE OF OIL BAY.



B. HORIZONTAL SANDSTONE BEDS OF NAKNEK FORMATION ON WEST SHORE OF KAMISHAK BAY.

species of *Cadoceras*. These, with *Belemnites*, predominate over all other forms.

Invertebrate fossils from Chinitna shale.

No. 2921.—East shore of Iniskin Bay:
Cadoceras doroschini (Eichwald). Abundant.
Cadoceras wosnessenskii (Grewingk).
Cadoceras schmidti Pompeckj.
Cadoceras catostoma Pompeckj?
Cadoceras sp.
Macrocephalites? sp.
Phylloceras subobtusiforme Pompeckj?
Stephanoceras sp. Form figured by Eichwald as Amm. astierianus d'Orb. aff.
Belemnites sp. a. One specimen.
Goniomya sp. One small specimen.
Lima sp.
Pecten sp. Small smooth form.
Pleuromya? sp. One specimen.
Serpula? sp. Small discoidal form abundant in one rock fragment.
Several undetermined bivalves represented by imperfect material.

No. 2941.—East shore of Oil Bay, 72½ feet above base of section:
Cadoceras schmidti Pompeckj.
Cadoceras sp. cf. C. stenoloboide Pompeckj.
Phylloceras sp.

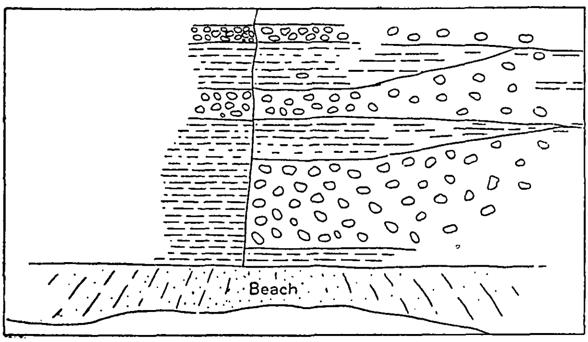


FIGURE 2.—Sketch showing conglomerate beds in the Chinitna shale on north end of Chisik Island.

A few fossil plants were collected from beds interstratified with those which yielded the ammonites. They have been identified by F. H. Knowlton as follows:

Fossil plants from Chinitna shale.

No. 929.—Iniskin Bay, east shore, ½ mile below lower cabin:
Cladophlebis denticulata (Brongn.) Sew.
Ctenis grandifolia Font.
Hausmannia sp.? Mere fragment.
Dictyophyllum cf. obtusilobum.

No. 929a.—Iniskin Bay, east shore, 1 mile below cabin:
Fossil wood, not studied.

Age and correlation.—The fauna of the Chinitna shale is regarded by Stanton[1] as indicating the boreal facies of the Callovian stage, which belongs at the top of the Middle or at the base of the Upper Jurassic.

The only localities in Alaska, outside of those here described, where these beds or their fauna have been recognized are at Cold and Dry bays[2] on the Alaska Peninsula, and in the upper end of the Matanuska Valley.[3]

Its fauna shows close relationships with that of the Callovian of Russia, Franz Josef Land, and elsewhere in the northern as well as in other parts of Europe.

The evidence of the flora on the age and relationships of these rocks has been presented on page 64.

UPPER JURASSIC ROCKS.

CHISIK CONGLOMERATE.

Areal distribution.—The Chinitna shale is overlain on Chisik Island and on the east shore of Iniskin Bay by the Chisik conglomerate. This formation is probably of very local development, not having been recognized elsewhere within this region except probably on the east shore of Oil Bay, and possibly at the head of Kamishak Bay.

Lithologic character.—The Chisik conglomerate consists of a variable thickness of predominantly coarse conglomerate, composed of well-rounded pebbles of granite and other crystalline rocks in an andesitic tuffaceous matrix. The general appearance of large blocks of this conglomerate which have fallen from the cliffs on the east shore of Iniskin Bay at the locality known as Mushroom Rocks is shown in Plate VI, *B* (p. 56). The thickness of the conglomerate at Iniskin Bay is 290 feet, and is possibly somewhat greater, although it was not measured, at Chisik Island. It is probably represented by the 147 feet of fine-grained conglomeratic beds at the base of the section at Oil Bay recorded on page 72.

A thin section (3M15) of the matrix of the coarse conglomerate at Iniskin Bay showed the presence of rock fragments which are much altered, but which apparently were originally fine-grained basic rocks and angular fragments or crystals of feldspar and quartz, in a fine angular iron-stained fragmental matrix.

Age and correlation.—The age of the Chisik conglomerate is determined within approximate limits by the presence of Middle Jurassic

[1] Stanton, T. W., Succession and distribution of the later Mesozoic invertebrate faunas in North America: Jour. Geology, vol. 17, No. 5, 1909, pp. 411–412.

[2] Martin, G. C., The petroleum fields of the Pacific coast of Alaska with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 52–53.

[3] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, pp. 21–23.

faunas below it and of Upper Jurassic faunas above. In its lithologic character, and especially in the presence of andesitic tuffs, it is more nearly related to the rocks bearing the latter than to those bearing the former fauna, and hence it may be most reasonably interpreted as the basal conglomerate of the Upper Jurassic. Paige and Knopf have described a conglomerate of similar lithology and at about the same stratigraphic position, occurring in the Upper Matanuska Valley.[1]

NAKNEK FORMATION.

Areal distribution.—The Naknek formation occupies the west shore of Cook Inlet from Chisik Island to Iniskin Bay and much of the shore from the mouth of Iliamna Bay to a point about midway of the south shore of Kamishak Bay. The continuity of exposure is interrupted by older rocks on Tuxedni Bay, Chinitna Bay, Oil Bay, Iniskin Bay, Iliamna Bay, Ursus Cove, and Bruin Bay, and probably also near the head of Kamishak Bay.

Lithologic character and sections.—The Naknek formation which overlies the Chisik conglomerate, or in its absence rests upon the Chinitna shale, consists of about 5,000 feet of shale, sandstone, arkose, andesitic tuff, and conglomerate.

The following sections show the local lithologic character of this formation:

Section of Naknek formation on the north shore of Chinitna Bay.

	Feet.
1. Coarse conglomerate with 6-inch (maximum) granite pebbles and smaller pebbles of various lithologic character, in a tuffaceous or arkose matrix	10
2. Shaly arkose or sandstone	2
3. Conglomerate	2½
4. Arkosic sandstone or andesitic tuff	1½
5. Conglomerate	½
6. Massive tuffaceous rock with numerous inclusions	9
7. Tuffaceous rock with much shale	3
8. Andesitic flow or tuff	12
9. Shale	2
10. Concealed	10
11. Andesitic flow or tuff	15
12. Concealed	5
13. Contorted shale with large *Belemnites* at base	23
14. Sandstone	½
15. Shale	½
16. Andesitic flow or tuff	4½
17. Contorted shale with concretions	3
18. Arkose with granite pebbles at top	7
19. Sandy shale	2
20. Sandy shale with fossil band at top (*Aucella* bed)	3

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 21–23.

	Feet.
21. Dark shale	15
22. Conglomerate with shaly matrix	5
23. Sandstone	½
24. Conglomerate	3
25. Dark shale	4
26. Conglomerate with much shaly matrix	13
27. Agglomerate	9
28. Dark shale	20
29. Coarse conglomerate	2
30. Pinkish sandstone with pebble bands	2½
31. Conglomerate	5
32. Sandstone	¼
33. Shale	½
34. Andesitic flow or tuff	2½
35. Agglomerate	2
36. Andesitic flow or tuff	7
37. Sandstone with shale bands	8
38. Dark shale	25
39. Concealed (for 1,350 feet at 20° dip)	462
40. Andesitic flow or tuff	18
41. Concealed (for 100 feet at 20° dip)	34
42. Andesitic flow or tuff	10
43. Concealed (for 50 feet at 20° dip)	17
44. Andesitic flow or tuff	5
45. Concealed (for 130 feet at 20° dip)	44
46. Andesitic flow or tuff	32
47. Agglomerate	3
48. Arkose with shaly bands	19
49. Andesitic flow or tuff with agglomerate at base	55
50. Andesitic flow or tuff	30
51. Shale	6
52. Andesitic flow or tuff	79
53. Concealed (for 430 feet at 25° dip)	182
54. Agglomerate	63
55. Andesitic flow or tuff	185
56. Shale	1
57. Andesitic flow or tuff	158
58. Agglomerate	2
59. Andesitic tuff with abundant pebbles	60
60. Shale	4
61. Concealed (for 60 feet at 24° dip)	24
62. Sandy shale	68
63. Sandstone and shale	30
64. Andesitic flow or tuff	25
65. Concealed (across cove for 800 feet at 25° dip)	338
66. Coarse gray sandstone mostly heavy bedded	66
67. Alternating bands of sandstone and shale	7
68. Coarse gray sandstone	12
69. Concealed	10
70. Coarse gray sandstone	25
71. Shaly sandstone	4
72. Coarse gray sandstone	26

		Feet.
73.	Coarse gray sandstone with bands of fine conglomerate	5
74.	Coarse gray sandstone with thinner shaly bands	27
75.	Coarse gray sandstone with bands of fine conglomerate	162
76.	Fault. Displacement probably small.	
77.	Coarse gray sandstone with bands of fine conglomerate	50
78.	Dark shaly sandstone	25
79.	Alternating bands of shaly sandstone and fine conglomerate	10
80.	Coarse gray sandstone with bands of fine conglomerate	12
81.	Dark shale	2
82.	Coarse gray sandstone with fine conglomerate	21
83.	Dark shale with *Belemnites*	40
84.	Coarse gray sandstone	25
85.	Dark shales with thinner bands of coarse gray sandstone	100
86.	Massive coarse gray sandstone	60
87.	Coarse gray sandstone alternating with more shaly layers	125
88.	Covered, except two or three small outcrops of shaly sandstone	425
89.	Dark shale with *Belemnites*	160
90.	Cross-bedded coarse sandstone	30
91.	Dark shales and shaly sandstones with *Aucella*, etc	290
92.	Alternating bands of coarse gray and argillaceous fossiliferous sandstones	100
93.	Coarse gray sandstone	20
94.	Thin-bedded argillaceous sandstone in irregularly alternating lighter and darker bands	338
95.	Coarse gray sandstone	30
96.	Banded argillaceous sandstone with *Belemnites*	300
97.	Coarse gray sandstone with *Belemnites*	40
98.	Banded argillaceous sandstone	56
99.	Coarse gray sandstone and fine conglomerate	35
100.	Banded argillaceous sandstone with several fossiliferous beds, and a few thin bands of fine conglomerate	156
101.	Somewhat massive dark-gray argillaceous sandstone with a few thin yellowish bands	150
		5,139

This section is given in detail on account of the very great apparent thickness. Possibly part of this thickness may be due to repetition of the beds by faulting, but such repetition could not be detected, the observed faults being apparently small and unimportant. Fossils were not abundant, but the characteristic *Aucella*, resembling *A. pallasi*, was found sparingly 113 feet below the top and near the base of the section.

The following section on Oil Bay apparently does not contain representatives of the highest beds of the Chinitna Bay section. The massive beds in the upper part of the section are those which make the cliffs capping the mountain top shown on Plate VII, *A* (p. 66).

Section of Naknek formation on east shore of Oil Bay.

	Feet.
Naknek formation:	
Arkose, andesite, sandstone, conglomerate, and shale	2,000±
Sandy shale with *Aucella* near base	600
Shale with fossils	380
Coarse sandstone	3
Shale with *Cardioceras*, *Astarte*, etc	165
Concealed	40
Sandstone and sandy shale with *Lytoceras*, *Phylloceras*, and plant impressions	310
Naknek formation (?):[1]	
Conglomerate with an abundance of small pebbles $\frac{1}{12}$ to $\frac{1}{25}$ inch in length, and with numerous poorly preserved plant impressions	7
Sandy shale and sandstone	85
Conglomerate with pebbles as above	3
Shale	1
Fine conglomerate of same pebbles as above	7
Fine conglomerate of same pebbles as above, but interbedded with shale	14
Olive shale with an abundance of small pebbles, and with indeterminate fragments of a crustacean 5 feet above the base	30

The following section on Iniskin Bay represents only the lower part of the formation. The beds at this point are noteworthy because they include a considerable thickness of conglomerate, very similar in lithologic character to the underlying Chisik conglomerate.

Section of lower part of Naknek formation on east shore of Iniskin Bay.

	Feet.
Sandstone, arkose, shale, andesite flows, and conglomerate	270+
Dark sandy shale with *Aucella* in upper part	583

The beds described as andesite or as andesitic tuff in the above sections are composed of fragmental material. The microscope reveals fragments and crystals of plagioclase (some of which were determined to be basic), hornblende, biotite, and quartz and also some bits of fine-grained igneous rocks. All of these are predominantly angular in outline, but a few are rounded. The matrix in some specimens is distinctly fragmental; in others it is so fine and iron stained as to be obscure, but is probably also fragmental and composed of the same materials as the other specimens. In one specimen, slightly coarser than the rest, the larger grains are well rounded. The clastic, angular character of the grains of the rocks and their composition leaves no doubt that they are tuffs derived from andesitic lavas. The fragments of rock are too fine grained and too much weathered to be determined, but seem to be basic.

[1] These beds are probably the local representatives of the Chisik conglomerate.

The exposures of this formation on the shores of Kamishak Bay differ somewhat in lithologic character from those represented in the above sections which are all north of Kamishak Bay. The dips are dominantly low in this part of the region and only a small part of the formation is exposed in the cliffs. These exposures are chiefly sandstone, the conglomeratic and volcanic beds not having been seen. Fossils (chiefly *Aucella*) are much more abundant than farther north. The type of beds exposed in this part of the region is represented on Plate VII, *B* (p. 66).

Fauna.—The fauna of the Naknek formation, according to Stanton, is especially characterized by the presence of one or two species of *Aucella* which are very closely related to and probably identical with *Aucella pallasi* and *A. bronni.* These fossils are at some localities very abundant, completely filling thick beds. Such localities are numerous on the south shore of Kamishak Bay. At other places they are so rare as to be easily overlooked, but in general a careful search will reveal them in one part or another of the section. Two or three species of *Belemnites* are associated with the *Aucella* at most localities. *Phylloceras*, a large *Lytoceras*, *Trigonia*, *Astarte*, and other pelecypods, and a few gastropods are present at some localities. *Cardioceras* cf. *alternans* and *Cardioceras* cf. *cordatus* were found in the lower part of the section on Oil Bay.

Age and correlation.—The stratigraphic position of the Naknek formation has been established by Stanton [1] as being clearly in the Upper Jurassic and not below the Oxfordian of the European geologists, the closest relationships with the European faunas being with the boreal Russian Volga beds.

In using the name Naknek formation for these rocks a definite correlation is made with rocks in the Alaska Peninsula on Naknek Lake and around Katmai where this formation was named and first described by Spurr,[2] and where he obtained a fauna consisting of *Aucella pallasi*, *Aucella* sp., *Natica* sp., *Belemnites* sp., *Terebratula* sp., *Avicula* sp., and *Astarte* (?) sp. The essential identity of this fauna with that obtained from the rocks here described, together with the strong similarity of the rocks in lithologic character, leaves little doubt that these beds are so closely related to those described by Spurr that they should be called by the same name.

This formation covers a broad area around the upper ends of Naknek and Becharof lakes and southeastward to Katmai and Cold Bay. This area possibly extends in a continuous belt northeastward to the head of Kamishak Bay, and may extend southwestward as far

[1] Stanton, T. W., Succession and distribution of later Mesozoic invertebrate faunas in North America: Jour. Geology, vol. 17, 1909, pp. 411–414.

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

as Chignik and Herendeen bays, where Atwood[1] has found a similar fauna.

The same fauna was found by Paige and Knopf[2] in beds of similar lithologic character in the upper end of the Matanuska Valley.

The same type of *Aucella* has also been found in the Kennicott formation[3] of the Copper River region.

The beds outside of Alaska which are related to these, according to Stanton,[4] are the Mariposa slate and equivalent formations of California and Oregon; the marine Jurassic of the Black Hills and Rocky Mountains, which represents apparently only the lower part of the Naknek; and the widespread boreal Upper Jurassic of north Europe, occurring in Russia, Spitzbergen, Nova Zembla, and elsewhere.

GRANITIC ROCKS.

Areal distribution.—Granitic rocks of considerable diversity of character, including granites of various kinds, granodiorite, and quartz diorite, occupy the greater part of the area of the Chigmit Mountains from the head of Bruin Bay northward beyond the heads of Lake Clark and of Tuxedni Bay. The rocks probably constitute one large continuous area with many smaller ones along its margins. Several of the latter were seen on Lake Clark. The position of the eastern border of the main mass of granite is known with certainty only at the heads of Tuxedni, Iliamna, and Bruin bays. The position of the western margin is known accurately only where it crosses the heads of Iliamna and Clark lakes. The northern end of the mass is probably far beyond the area which was mapped. The southern termination is probably at the head of Bruin Bay.

The margin of another mass was observed on the northern flank of Mount Douglas. This is probably the northern end of a large mass in the Aleutian Range, which is in all probability widely detached areally from the Chigmit Mountain mass, although it is doubtless closely related in lithologic character and period of intrusion.

Petrographic description.—There are many types of rock present, but by far the most abundant are hornblende granites and granodiorites. They are for the most part of medium grain, porphyritic habit, and light color, either light gray or pinkish. Mineralogic-

[1] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: Bull. U. S. Survey No. 467, 1911, pp. 35–36.

[2] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 20–23.

[3] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, p. 50. Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909, p. 31.

[4] Stanton, T. W., Succession and distribution of later Mesozoic invertebrate faunas in North America: Jour. Geology, vol. 17, 1909, pp. 410–414.

ally they are composed chiefly of albite or oligoclase-albite and quartz with either hornblende or biotite, or both. Apatite and magnetite are constant accessories. Orthoclase is not commonly a constituent of the rock and is nowhere important. The porphyritic habit is due to large crystals of feldspar.

Diorites composed of andesine feldspar, hornblende, biotite, and some augite are also less widely developed, but particularly between Iliamna Bay and Iliamna village. These diorites have considerable range in textures, from fine to coarse and from granitic to gneissoid.

At the mouth of Iliamna River, on the margin of the granitic area, are rocks ranging in composition from diorites to hornblendites, composed almost entirely of large hornblende crystals with very small amounts of feldspar, magnetite, and sulphides.

On some of the islands in Lake Clark, which are near the northwestern border of the granite, are augite diorites or gabbros composed of basic plagioclase, augite, and magnetite. These rocks may be marginal facies of the granite or independent intrusions. The latter conclusion seems indicated because other exposures in the vicinity and near the granite border, particularly those at the intrusive contact on Lake Clark above Tlikakila River, are of the types of granite more common in this region.

The granites are cut by numerous dikes generally only a few feet wide and chiefly porphyries of the granite or granodiorite family. One dike about 75 feet wide of very different composition was found near North Head on Iliamna Bay. This is a peridotite, considerably weathered where seen, apparently originally composed of enstatite, olivine, and magnetite or ilmenite, but now containing also much colorless amphibole, talc, and serpentine.

The most pronounced variation in composition and texture observed among these rocks is in the vicinity of the gneissic rocks west of Iliamna Bay. The granite is here much more basic than at other points and possesses a rough foliation not observed elsewhere. There is a strongly suggested possibility that granites of two types and ages are present; those neighboring the gneisses being intruded prior to at least part of the more intense deformation, while those on the flanks of the mountains were intruded subsequent to all but the later fault movements. An alternative, and in some ways the more attractive, hypothesis is that the granites are all of one general period and that the mountain range suffered part of its severer folding after the granites were intruded, this folding having been more severe in the heart of the range than on the flanks. Differences in composition would then find the most likely explanation in greater absorption from the invaded rock in the heart of the range.

The adoption of this hypothesis raises at once the question whether the gneisses and associated metamorphic rocks are really older than the sedimentary rocks flanking the mountains. The hypothesis may readily be extended to include the interpretation of the gneisses, schists, slates, and marble as locally intensely metamorphosed representatives of the unaltered Mesozoic sediments of neighboring subprovinces. This latter conclusion is, however, believed to be improbable.

Small porphyry dikes were seen on the shores of Iliamna Bay, and elsewhere, especially on the shores of Iliamna Lake and at the lower end of Lake Clark. They are younger than the granite and possibly belong to the Tertiary period of intrusion.

Age.—Regarding the age of at least part of the granitic rocks the evidence is conclusive even to a rather close time interval. Quartz diorite of the normal type for this region was intruded into the Upper Triassic rocks on Bruin Bay subsequent to their close folding. Near by are broad areas of Upper Jurassic rocks which were not involved in this close folding and which are not cut by the granites. Middle Jurassic rocks are nowhere on Cook Inlet known to be cut by granitic rocks. The granites cut the porphyries and tuffs of Iliamna Bay, which are Lower Jurassic or older, and probably also cut rocks of similar lithology on Tuxedni Bay and north of Mount Douglas. From this evidence it may be concluded that the granitic rocks are certainly younger than the Triassic and older than the Upper Jurassic, and that they are probably older than the Middle Jurassic and possibly younger than part of the Lower Jurassic. Further evidence is yielded from the presence of granitic bowlders in the Mesozoic sediments. The Chisik conglomerate at the base of the recognized Upper Jurassic contains bowlders of granitic rocks of the same types as the granites which occur in the mountain areas. The conglomerates in the lower part of the Chinitna shale on Chisik Island (p. 66) and at and near the base of the Tuxedni sandstone on Iniskin and Tuxedni bays also contain pebbles of granite. The evidence of these conglomerates is, however, of no value if there are areas of older granite near the gneiss west of Iliamna Bay. The age of at least some of the granitic rocks may, however, be safely placed in the Lower Jurassic. This conclusion should be compared with the conclusions of Brooks, Knopf, Spurr, and Atwood for the age of the granites of the Alaska Range, Talkeetna Mountains, and Alaska Peninsula.

The granitic rocks of the Alaska Range are, according to Brooks,[1] younger than the Tordillo formation, part of which at least carries the fauna of the Tuxedni sandstone, which is consequently very low in the Middle Jurassic. Younger rocks than these are not known in the vicinity of the Alaska Range granites, so the upper limit of the possible period of intrusion can not there be determined.

[1] Brooks, A. H., The Mount McKinley region: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 91–92.

In the Talkeetna Mountains and upper Matanuska Valley are quartz diorites which Paige and Knopf[1] state are younger than the "andesitic greenstones," which they regard as of Middle Jurassic age, and older than the Upper Jurassic.

The granitic rocks of the western flank of the Aleutian Range in the vicinity of Naknek Lake are described by Spurr[2] as including syenite and hornblende-biotite granite of pre-Jurassic age. The evidence of age consists in the presence of pebbles supposed to be derived from these rocks in beds of arkose which form part of the Naknek formation, now known to be of Upper Jurassic age.

In the western end of the Alaska Peninsula in the vicinity of Chignik and Herendeen bays the oldest rocks, according to Atwood,[3] are Upper Jurassic, and intrusives of the granitic type are absent. This may be accepted as corroborative evidence that the granitic rocks of southwestern Alaska are all pre-Upper Jurassic.

It should also be noted, however, that the granites of Alaska include intrusions of much broader periods than are represented in southwestern Alaska. Prindle[4] has determined some of the granite of the Yukon Valley to be Upper Cretaceous.

TERTIARY ROCKS.

SEDIMENTARY BEDS.

Areal distribution.—Tertiary sedimentary beds, excepting those which are intimately associated with the Tertiary volcanic rocks and are described below, are locally restricted to a locality on the north shore of Chinitna Bay near its mouth. Only a single small exposure in the cliffs is known. The beds are horizontal, and the relations to the neighboring exposures of the beds of the Naknek formation are concealed. There is no evidence as to the area of these rocks, but it can not be large.

Lithologic character.—The following section shows the stratigraphic sequence at this point.

Section of Tertiary rocks at mouth of Chinitna Bay, north shore.

	Feet.
Conglomerate with interbedded shale and sandstone	15
Dark shale	20

The shale at the base of the exposure contains several fossil tree trunks from 1 to 2 feet in diameter, at least two standing upright.

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[2] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 145, 232.

[3] Atwood, W. W., Geology and mineral resources of the Alaska Peninsula: Bull. U. S. Geol. Survey No. 467, 1911, pp. 26–27, 29.

[4] Prindle, L. M., The Fairbanks and Rampart quadrangles, Yukon-Tanana region, Alaska: Bull. U. S. Geol. Survey No. 337, 1908, pp. 26–27.

Numerous small sticks lie in the bedding of the shale. The tree trunks are silicified and show the structure of the wood very distinctly (922a).[1]

The contact of the conglomerate and shale is very irregular. The conglomerate also contains much fossil wood, partly lignitized and partly silicified (922b).

Above the lower bed of conglomerate comes a few feet of sandstone with shaly bands and lenses in which a few fossil leaves were collected (922c).

Obsidian was also found at this locality, apparently being interbedded with the Tertiary rocks. A thin section shows slightly devitrified glass containing rare quartz and feldspar phenocrysts.

Flora and age.—The fossils collected at Chinitna Bay have been identified by F. H. Knowlton as follows:

List of fossil plants from Tertiary beds at Chinitna Bay.

Nos. 922a, b.—Chinitna Bay:
 Coniferous fossil wood, not studied.
No. 922c.—Chinitna Bay, near entrance on north side:
 Ginkgo adiantoides (Ung.) Heer.
 Taxites olriki Heer.
 Populus sp.?
 Corylus macquarrii (Forbes) Heer.
Age—Arctic Miocene.

These beds are presumably the general equivalent of the Kenai formation of the east shore of Cook Inlet. They differ from those beds in degree of induration and in the presence of associated volcanic material, and probably bear a closer stratigraphic relation to the Alaska Peninsula type of beds carrying the Kenai flora. These latter beds occur just outside of the region here under discussion, being well developed in the vicinity of Cape Douglas.

BASALTIC FLOWS AND TUFFS.

Areal distribution.—Most of the shores of Iliamna Lake below the large islands at the mouth of Pile Bay, except those covered by sand and gravel, are made of basaltic rocks, including effusive sheets, tuffs, and probably some intrusive dikes and sills. A few thin beds of sandstone and shale were observed. These rocks cap all the high hills northeast of Intricate Bay, descending westward and reaching the lake shore just north of the end of the peninsula north of Intricate Bay. (See fig. 18, p. 109.) The basaltic rocks of this part of the area have a gentle westward dip but are not folded. The islands of Intricate and Kakhonak bays and the peninsula between them are likewise composed of basaltic tuffs, the basalt being prominently exposed in flat mesa caps where horizontal and in monoclinal strike ridges where steeply inclined. At most of the exposures the basalt

[1] The fossil wood described by Ward from "Iliamna Bay" (Mon. U. S. Geol. Survey, vol. 48, 1905, pp. 146, 147) possibly came from this locality.

shows the typical vertical columnar jointing characteristic of such sheets. Basaltic sheets also cap the high hills between Kakhonak Bay and Kakhonak Lake, many of the lower ridges being of conglomerate or conglomerate tuff. The latter rock is also exposed on some of the shores of Kakhonak Bay. These basic volcanic rocks with some interbedded conglomerate form the greater part of the south shore of Iliamna Lake from Kakhonak Bay west to a point about 25 miles east of the outlet of the lake. A few small outcrops protrude through the sands and gravels at scattered localities from here to the mouth of Newhalen River, from which point to the cape at the western side of Chekok Bay the shores and islands are entirely composed of these rocks except on the low beaches. Similar basalts and tuffs cap the high hills west of Newhalen River and Sixmile Lake. Basaltic masses, probably dikes or sills, occur at scattered points along the west shore of Lake Clark as far north as the head of Chulitna Bay.

Basalts, probably to be correlated with those already described, cap a group of high hills north of Chekok Bay and the low hill on the east side of Lake Clark about 7 miles northeast of Tanalian Point.

Petrographic character.—Sections of specimens of the basaltic rocks of Iliamna Lake, mainly taken from points on the south shore of the lake and neighboring islands, show them to be mostly augite andesites. They contain phenocrysts of plagioclase (labradorite and bytownite), common augite, and iron ores (magnetite and ilmenite), with abundant minute apatite. These are embedded in a groundmass which, where crystalline, shows the same minerals, which appear as phenocrysts. This groundmass varies in crystallinity from microophitic or microgranitic to a devitrified glass. Olivine was present among the phenocrysts of one section and possibly in another, a zeolitic amygdaloidal rock with opaque base and slightly weathered. As a whole these rocks are quite fresh.

A limestone breccia cemented by volcanic material was found at what is presumably the local base of these rocks at a point on the north shore of Iliamna Lake, 3 miles west of the mouth of Chekok River. This rock is composed of fragments of limestone and a few of quartz and other material embedded in a black matrix. Here and there in the rock are slightly rounded pieces; many more are irregular and angular in outline, but most of them are subangular. They range in size from a small fraction of an inch up to 2 inches in diameter, with few larger pieces. The majority are less than half an inch in diameter. The limestone fragments are of various colors, including white, light gray, pale bluish, salmon, and red. The few quartz fragments are white or salmon tinted, and the other unidentified materials are black or rusty red. The matrix is stony, dull, dark gray, or black. For the most part the fragments have a random arrangement, but in places flattish pieces are parallel. The grouping is in some parts close, in others dispersed so that the matrix constitutes a notable portion of the rock. In appearance the rock is striking and very like the particolored marble breccias ("Potomac marble") from the Triassic of Maryland. On the weathered surface of the rock there are pits, in places as deep as one-fourth of an inch, formed by solution of the limestone fragments. Even on comparatively smooth, wave-worn surfaces the larger limestone areas are slightly depressed. On the other hand the quartz makes little knobs. In rare instances the matrix is seen penetrating, for short distances, into cracks in the limestone fragments. A slight peripheral bleaching or discoloration was noted on two pieces of limestone. Very narrow rims of lusterless black material border some grains and a thin rusty streak fringes others. Study of a thin section of this rock shows the limestone to be made up of fine interlocking crystalline calcite grains which are not twinned. The matrix contains both opaque, black, lusterless material and pale yellowish transparent material. The latter is weakly birefringent or is made up of a cryptocrystalline aggregate of moderate or low birefringence. This material contains a few opaque grains with partial crystal outlines and with the color and luster of magnetite, and also a few minute bits of quartz (?). Around many of the limestone fragments are narrow fringes of twinned crystalline calcite, and there is also twinned calcite and limonite in cracks and cavities. That the matrix is a devitrified volcanic glass is suggested by its appearance under the microscope. This suggestion is strengthened by the peripheral discoloration of the limestone and the penetration of the matrix into the limestone as noted above.

The red basalts on the summits of the hills west of Sixmile Lake are porphyritic, having basic plagioclase and iron ores embedded in an opaque vesicular base in one specimen, and in a microophitic vesicular base of plagioclase, pyroxene, and iron ores in another specimen. These rocks are somewhat weathered, though the feldspars are still quite fresh.

The mountain 6 miles north of Chekok Bay is capped by fine-grained diabase or diabase porphyry. This rock contains, both as phenocrysts and in the groundmass, basic plagioclase, augite, and magnetite or ilmenite associated with apatite. Decomposition of the feldspars and augites of these rocks is common. They are more weathered than most of the other basaltic rocks, and are much broken by joints into small irregular blocks with rusty weathered surfaces. On the mountain 8 miles north of the mouth of Chekok River this rock lies above porphyries, and is probably in the shape of a nearly flat sheet. Its other geologic relations were not definitely discernible.

The rock on Lake Clark 7 miles northeast of Tanalian Point is petrographically very similar to that north of Chekok Bay. Here again it was found on the top of a hill whose base was porphyry and tuff. The relations were not determined.

Stratigraphic relations.—These rocks are considered to rest unconformably upon the rhyolitic lavas and tuffs already described. The chief evidence of the unconformity is the fact that the basaltic volcanic rocks are nearly everywhere flat or have low dips, while the rhyolitic rocks in most places stand at high angles. Along the south shore of Iliamna Lake from 15 to 25 miles below the head of Pile Bay the basalt caps the hilltops and is nearly flat, whereas the rhyolites outcrop along the shore, standing in many places at high angles. (See fig. 18, p. 109.) The same condition holds along the sides and base of the mountain 25 miles east of the lower end of Iliamna Lake. West of Sixmile Lake and Newhalen River, flat basalt sheets cap the hilltops and the rhyolites are below, but here the structure of the lower beds was not observed. The basaltic rocks are considered younger than the rhyolitic rocks, and to be mostly unconformably above, though in places intrusive into them.

Evidence showing the former to be the relationship was seen at Millet's prospects west of Chekok Bay, where along the beach and a short distance back from it are exposures of tuff, tuffaceous conglomerate, and lavas, which are considered part of the formation here described. The rocks in contact with them are older (Lower Jurassic?) volcanic rocks and Upper Triassic limestone. The contact of these older rocks with each other runs northward from a point near the shore. The younger volcanic rocks lap unconformably over both of these, their northern boundary running approximately east and west and intersecting the shore of the lake at the locality where the limestone breccia described on pages 79–80 was observed. At this point the breccia rests upon the upturned edges of the coral-bearing limestone (p. 42). It is considered to have been probably formed by a Tertiary lava flowing over and incorporating the rubble on the limestone surface.

Flora.—The sandstones which are probably at the base of the basaltic rocks have yielded small collections of fossil plants at two localities. These have been identified by F. H. Knowlton as follows:

Fossil plants from base of basaltic rocks on Iliamna Lake.

No. 4.—South shore of Iliamna Lake, 25 miles below head of Pile Bay (three-fourths of a mile southwest of Cache Point):

Corylus macquarrii (Forbes) Heer.

Taxodium distichum miocenum Heer.

Age—undoubtedly Tertiary.

No. 5.—South shore of Iliamna Lake, 29 miles east of outlet (2 miles west of Salmon Creek):
Taxodium or Sequoia sp.
Salix sp.?
Age—presumably Tertiary, but material pretty poor.

Age and correlation.—These rocks evidently correspond in position and age with the basaltic lavas and tuffs from the Talkeetna Mountains described by Paige and Knopf,[1] which are regarded as of late Tertiary age, and also with at least part of the Tertiary volcanic rocks of the Alaska Peninsula. They are also of the same petrographic type as the Recent lavas and tuffs of the now active volcanoes of Cook Inlet and the Alaska Peninsula.

QUATERNARY DEPOSITS.

GLACIAL DEPOSITS.

AREAL EXTENT.

Although glaciers once occupied the greater part of this region, as is shown by the general physiographic features, as well as by the presence of more minutely scoured exposures, the surface areas of unmodified glacial deposits, such as till, are rather small. In fact, such material was seen only in the immediate vicinity of the existing glaciers (see map, Pl. I) and in the lower part of the valley of Newhalen River, for short stretches at the base of the bluffs on the lower part of Iliamna Lake, and along the upper part of Kvichak River. It may be stated, in anticipation of conclusions reached below, that the general absence of till is explained in part by the fact that the glaciation was of alpine character and so vigorous that the glaciers and the glacial floods and mountain-side erosion, which accompanied and followed their extinction, obliterated in large part their constructive products, and in part by the fact that drowning of the lower glacial sites, during and subsequent to the retreat of the ice, buried the larger accumulations of moraine beneath younger water-laid deposits. It follows from the latter condition that glacial deposits have a much wider extent beneath the terrace and alluvial deposits than they have at the surface.

CHARACTER OF THE DEPOSITS.

Good exposures of glacial till were seen on the north shore of Iliamna Lake, from 13 to 16 miles west of Newhalen River. The best of these exposures is represented in the following section:

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[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 29–30.

Section on north shore of Iliamna Lake, 15 miles west of Newhalen River.

	Feet.
Dune sand	1½
Stratified gravel	8
Stratified sand, very fine grained	17
Glacial till to lake level	32

The upper surface of the glacial deposits in these exposures is clearly marked by the abrupt change in lithologic character from the cleanly washed and well-stratified material above to the heterogeneous mass of unsorted material below. The till consists of unweathered sticky clay in which is embedded a great variety of material, ranging in grain from sand to blocks of rock several feet in dimension, and including rounded, faceted, and angular pieces of rock typical of most or all of the more resistant kinds seen in outcrop on Iliamna and Clark lakes. The contact between the morainic accumulation below and the stratified beds above is also marked by a line of springs caused by the porosity of the upper and the relative imperviousness of the lower beds. The upper surface of the till slopes westward, passing below the level of the lake, near the cape, 16 miles below Newhalen River. The local slope of the upper surface of the till appears to be about 30 feet per mile.

The best exposures of till on the Kvichak River are about 7 miles below the outlet of Iliamna Lake. The till here occupies most of the river bluffs, apparently being capped by a thin layer of stratified gravel and sand. The fact that the till here rises to a greater height than at the locality described above on the north shore of Iliamna Lake is regarded as caused by the presence at this point of a high ridge of terminal moraine, marking a long resting stage in the retreat of the Iliamna Lake Glacier, if not the position of its ultimate front.

Unmodified glacial deposits also were seen in the lower part of the Newhalen Valley, from 2 to 5 miles from the shore of Iliamna Lake. The character of these deposits is indicated by the hummocky surface typical of morainic topography. No sections of the beds were exposed.

CONDITIONS OF DEPOSITION.

Existing glaciers.—The existing glaciers of this region are not nearly as numerous as in other coastal parts of southern Alaska and they are not large. Only in the vicinity of Mounts Iliamna and Douglas, and outside of the area covered by the actual mapping, are there large unbroken areas above snow line which are competent to form the gathering grounds for extensive glaciers. Within the district shown on the map the areas above snow line are individually small and much broken up by lower valleys, and the glaciers are consequently limited in extent.

All of the larger streams tributary to Lake Clark near its head have their sources in glaciers. Most of these are, however, outside of the area mapped.

The four northernmost valleys on the east side of Lake Clark, above a point opposite the mouth of Tlikakila River, contain glaciers descending from the snow fields about 6,000 feet above tide. The smallest, something less than a mile long, descends to about 4,400 feet, while the northernmost and longest sends a very narrow tongue down to 2,000 feet about 2 miles below the cirque.

The valley of Currant Creek contains one or two very small glaciers, which were seen but not mapped, and is reported to contain a larger glacier farther east.

Near the head of the Kontrashibuna drainage there are 15 glaciers shown on the map, all just below the crests of northward-facing slopes. Just beyond the mapped area are many more. The lowest of these lies at an altitude between 3,400 and 4,800 feet, approximately, but most of them are between 4,000 and 5,000 to 5,800 feet. The largest is barely a mile in extreme length.

Another very small glacier is about 12 miles north of the head of Pile Bay, on the northwest face of the ridge west of Pile River. It lies between 3,500 and 4,500 feet above tide.

One of the smallest of all the glaciers of this region is about 3 miles west of the head of Iliamna Bay, and between the Iliamna and Hicks trails. It lies in the head of a gulch on a north slope at an elevation of about 3,000 feet.

The snow fields around Mount Iliamna send out several valley glaciers of fair size. Three of these go out to the south and are tributary to streams entering Chinitna Bay. They are known as East, Middle, and West glaciers. Another good-sized valley tongue goes out to the north and is tributary to the unnamed stream at the head of Tuxedni Bay. Several other glaciers of this type must flow west from these snow fields, but nothing is known of their position or size. The abundance of glacial silt in the waters of Iliamna and Pile rivers and of all the larger streams east of Lake Clark is conclusive evidence of the existence of many glaciers in that region.

The high country around Mount Douglas and the neighboring peaks at the north end of the Aleutian Range is the feeding ground for many glaciers. Seven or eight large glaciers, several of which reach almost to tidewater, are known to radiate from the snow fields in that locality.

The distribution and size of the existing glaciers appear to be governed primarily by the extent of large unbroken areas at high altitudes. The information at hand does not warrant a positive conclusion as to whether there is within this region a geographic difference in degree of glaciation independent of that based upon the extent of the high level areas. Such a further difference in present intensity of glaciation would be expected from the differences in temperature and precipitation which are believed to exist between the eastern and western sides of the Chigmit Mountains, but the actual observations on position of snow line and size of glaciers in the different parts of the region are not sufficient to positively confirm the conclusion that such is the case. It is an undoubted fact that the glaciers descend to lower altitudes in the Cook Inlet drainage than in the Bering Sea drainage, but this finds a possibly sufficient explanation in the fact that the divide lies well toward the eastern boundary of the mountains so that the eastward gradients are far steeper than the western.

Former glaciation.—The existing glaciers are insignificant in size and number in comparison with the recent but earlier and more extensive glaciers. The presence of these glacierlets therefore does not permit the positive conclusion that conditions now favor the development of glaciers in all of the areas of this region which they now occupy. It is perhaps rather to be supposed that some of these are but dying remnants of the earlier glaciers.

All the larger valleys of the region, and east of longitude 154° 30′ almost every considerable valley and even the inconspicuous gulches on the northerly slopes of the higher divides have been occupied by glaciers. This is evident by the U-shaped cross sections, the glacial scouring and débris, and the cirques. The glaciation was strictly alpine, that is, the glaciers were confined to and directed by preglacial drainage lines. As a result the higher interstream areas are unglaciated, whereas the lower portions of the valleys have been modified by glaciation, so that a striking topographic unconformity has been developed. In the higher nonglaciated interstream areas there are uniformly well developed, fairly mature, open V-shaped tributary valleys with sharp ridges intervening. In the lower areas are almost plane slopes on which the tributary streams are either not at all intrenched, or are but slightly incised in narrow gorges. The character of these two physiographic types is well shown on Plate VIII, *A*, page 86. In some places the development of the glaciated type of physiography has been due to the truncating or complete erosion of the ends of the minor interstream spurs, leaving the sides of the major valleys in which the glaciers moved, steeper than the unglaciated parts and smooth and regular up to the height of the former ice surface. In other places the lower areas have been filled with glacial débris and their slopes have been decreased. The preglacial topography which remains at higher altitudes has at lower altitudes been effaced, in one case by degradation, in the other by aggradation. The truncation of interstream spurs is well shown on the west of the Tlikakila River and on Tanalian

Mountain. The filling and mantling of preglacial topography is seen to advantage on the south face of the mountains north of Chekok Bay.

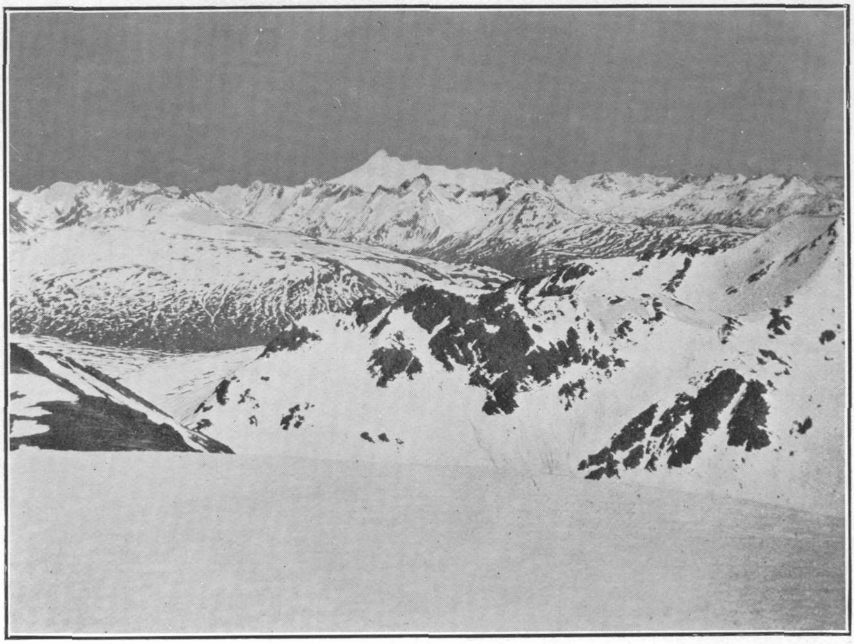
The Lake Clark valley received large ice streams from the valleys of Tlikakila and Chokotonk rivers and Currant Creek. The gathering grounds for these glaciers lay mainly to the east of the region mapped. Ice entered Lake Clark valley from Kontrashibuna Valley through the valley of Tanalian River, and possibly also through the pass east of Tanalian Mountain. Kontrashibuna Glacier received tributary ice streams from dozens of cirques all along both sides of its course, except from Tanalian Mountain, which faces south, and also from a great number of cirques in the high mountains on the edge of the mapped area and eastward. Two or three small glaciers also came out from small valleys below Takoka Creek. There is no good evidence that there were, to the west of these, other ice streams tributary to Lake Clark from the east, and on the west side of Lake Clark there was apparently none below Tlikakila River. It is a noteworthy fact that, in the upper part of Lake Clark valley, the mountains east of the lake are clearly shown by their physiographic character to be glaciated to a considerably greater height than the mountains on the west side of the lake. This is regarded as evidence that the bulk of the glacial flow came from the east and that the valley of Lake Clark existed prior to the glacial invasion and deflected the westward glacial flow from the Chigmit Mountains so that large areas west of the lake were not overridden.

The Tazimina Valley glacier received its ice chiefly from the mountain area at the head of the drainage basin. There was one important tributary from the southeast entering at Chekok Pass and many small ones from the south valley wall. Ice lay in the col on Chekok Pass and probably moved northward at times and at other times southward.

Knutson Creek glacier headed against the area tributary to Tazimina Glacier with which it was probably merged in the ice that lay in a col between the two drainage basins. Along the present Knutson Valley, 10 small tributary glaciers entered from the east, but there were none from the west.

Pile River glacier headed beyond the mapped area. About 4 miles above the head of Pile Bay it received a large glacier from the northwest whose feeding grounds adjoined that of the Tazimina Glacier, and also lay on the westward-facing slope of the ridge west of the lower part of the valley of Pile River.

The valley of Iliamna River was occupied by a glacier formed by the fusion of glaciers in the north and south fork. The former was fed mainly beyond the limits of the district mapped. So also in part was the latter, but it received many small glaciers from the area



A. ACCORDANT MOUNTAIN SUMMITS.

Showing Mount Iliamna rising above them and smooth glaciated slopes below. Looking northeast from point near head of Pile Bay.

B. MOUNT AUGUSTINE FROM THE WEST.

between it and Chinkelyes Creek. The valley of this creek received many small glaciers which united and flowed down to Iliamna. The Iliamna and Pile River glaciers overrode the ridge separating their lower courses and there united. About a mile or two northeast of Pedro Bay this ice stream joined that coming down Knutson Bay.

At the headwaters of Kakhonak River and in the neighboring valleys were a number of glaciers. Their extent and distribution is not well known, but most of them probably united in the main valleys and extended as low tongues to Iliamna Lake basin, where they met the ice streams from further northeast.

The lower end of the Lake Clark glacier perhaps sent a lobe up the Chulitna Valley and up the valley entering the extreme southwest corner of Lake Clark. Another lobe entered Kokteekish Pass to meet one from the Tazimina Glacier. The main mass of ice probably moved through the basin of Sixmile Lake and Newhalen River, there receiving the Tazimina Glacier and continuing to the Iliamna Lake basin, where it united with other ice streams from the northeast and east. In the lower part of the Iliamna Lake basin the combined glacier with a width of from 35 to 40 miles extended at least as far as the present foot of the lake.

Iniskin and Iliamna bays and Ursus Cove, all received glaciers from the valleys entering them. At the mouth of Iliamna Bay the mountain sides are glaciated up to an elevation of at least 1,000 feet. Therefore it is probable that these glaciers rode a little distance out into what is now Cook Inlet, but whether into open water or to join a large glacier filling the Cook Inlet basin is not known.

The glaciers filling the major valleys to considerable depths, in several instances blocked, without themselves filling, tributary valleys. Such, for example, are the valleys entering Lower Tazimina Lake from the north and those directly north of this point which enter Lake Clark from the southeast. The passes between the two lakes by way of these valleys have flat gravel floors, the one in the pass 7 miles east of Kokteekish Pass being at an elevation of 1,900 feet. These valleys were blocked by the ice of the Lake Clark and Tazimina glaciers and were probably filled by both outwash from the glaciers and by the mountain débris carried down the tributary gulches. Whether these deposits were laid down in dry or in water-filled basins could not be determined, for even where postglacial erosion has gullied and terraced these deposits they are mantled by grass and small shrubbery. It, however, seems probable that these blocked valleys held ponds.

Similar deposits (fig. 3) were found in the valleys of the streams entering Lake Clark 7 and 5½ miles below Tanalian River. In the latter valley the gravels seem to have formed a broad floor about 2,400 feet above tide in the basin at the forks of the stream and to have extended through a col to the valley of the next small stream to the north. Recent erosion has terraced this deposit, leaving only remnants at the higher elevations here and there on the valley walls. In its lower course the stream has cut a gorge 300 feet deep in these gravels. The valley east of the mountain 7 miles north of Chekok is another one which is thus filled because of a former ice dam.

The height of these gravels in blocked valleys affords one clue as to the summit of the glaciers. Along the south side of Lake Clark this appears to have been about 2,000 feet at Kokteekish Pass and 2,400 feet at a point about 4 miles below Tanalian Point. These figures correspond with the height of glacial erosion on the mountain sides along Lake Clark. Farther up the lake the high gravels were not seen, but the height of the ice is well marked by the maximum height of the truncated mountain spurs. By this criterion the ice in the vicinity of the mouth of Tlikakila River was about 3,000 feet above tide. The thickness of this ice stream must have ranged between 2,500 and 3,500 feet. The slope of the ice surface, according to these figures, was nearly 30 feet to the mile in the valley of Lake Clark. In the other larger valleys, including those of Kontrashibuna, Tazimina, Pile, and Iliamna rivers, evidence for the determinations of the thickness of the ice is not so reliable as that on Lake Clark. But it is probable that the ice lay in these valleys up to elevations of about 3,000 feet at their heads and about 1,800 feet near their mouths. These statements of course apply only to the large composite ice streams in the master valleys. The tributary and head glaciers lay at elevations above 3,000 feet up to 6,000 feet, descended over steep gradients, and were not so thick. Over the lowlands around Roadhouse Mountain and Chekok Bay, where the Clark and Tazimina glaciers and those from the east met, they spread out notably, and as would be expected the upper limit of glaciated surfaces and glacial débris descends to about 1,400 feet. In the still broader basin of Iliamna Lake, which received practically all of the glacial ice of the region, the glacier deployed considerably and its surface stood at a still lower elevation.

TERRACE GRAVELS.

AREAL EXTENT.

Broad areas on the shores of Lake Clark below Currant Creek, on the north shore of Iliamna Lake west of Chekok Bay, and on the south shore of Iliamna Lake for 25 miles east of the outlet are covered with stratified gravels and sands. The same deposits extend throughout the Kvichak Valley and the Bering Sea coastal plain. These deposits occur in minor development in other parts of the region, but are there conspicuous for their small and irregular extent. On the west shore of Cook Inlet they were seen on the north shore of Ursus Cove at the mouth of the valley heading near Cottonwood

Bay, and on the neck of land connecting the peninsula at the mouth of Bruin Bay with the mainland.

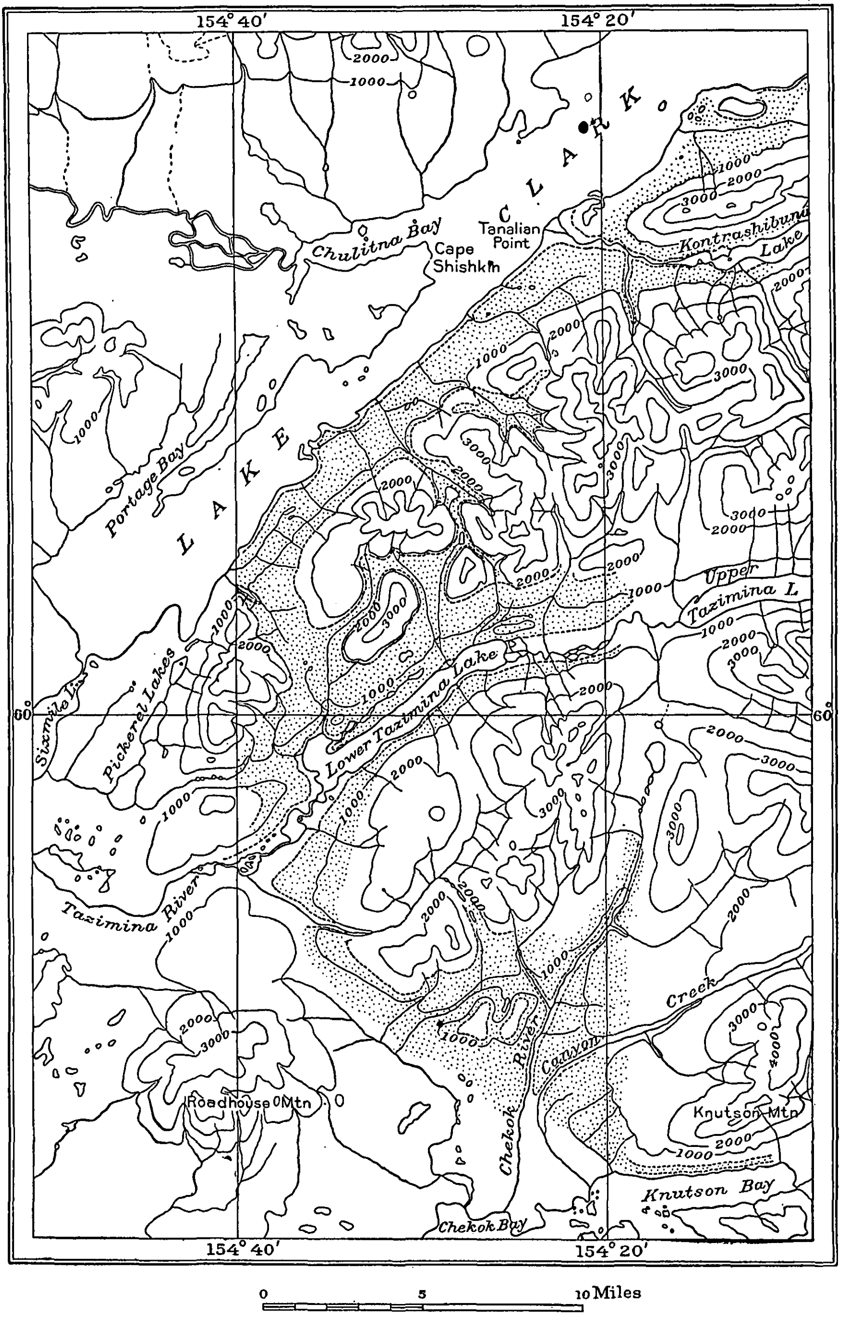


FIGURE 3.—Map showing observed distribution of the higher gravels southeast of Lake Clark.

The areal extent of the better-developed terrace gravels at lower altitudes is shown on the geologic map (Pl. II). These are regarded as having been deposited in estuarine waters and are consequently, in general, uniformly well developed and conceal the hard rocks over broad areas. Other gravels (pp. 87–88, 91–92) at higher altitudes, which also occur partly in terraces, were mapped in part of the region. The areal extent of these, as far as mapped, is shown on figure 3, page 89.

CHARACTER OF THE DEPOSITS.

The character of these beds, as exposed in the bluffs on the shore of Iliamna Lake, is well shown in the following sections:

Section of terrace deposits on north shore of Iliamna Lake, 18 miles west of Newhalen River.

	Feet.
Sand and gravel in thin beds of diverse character and degree of homogeneity	6
Gravel, containing pebbles one-half to 1 inch in diameter, roughly to smoothly rounded	12
Sand, very fine-grained and cross-bedded	30
Concealed to lake level	12

Section of terrace deposits one-half mile east of the last.

	Feet.
Dune sand with much vegetable material	8
Fine gravel with pebbles about one-half inch in diameter	5
Sand, very fine grained, with suggestion of wind-bedding, and in places with iron crusts	30±
Concealed to lake level	10

Section of terrace deposits on north shore of Iliamna Lake, 16 miles west of Newhalen River.

	Feet.
Dune sand	31
Gravel	10+
Fine sand to lake level	42

The section given on page 83, which is 1 mile east of the last, also shows the character of these deposits and of their contact with the underlying beds.

The deposits exposed on the south shore of Iliamna Lake 15 miles east of the outlet are composed of fine sand with poorly defined stratification, containing pebbles and bowlders of many igneous rocks, including granite, porphyry, rhyolite, basalt, and tuffs of various kinds.

Numerous remains of a mammoth were found by A. L. Pinart in the bank of Kvichak River. Paleontologic descriptions of the material have been published by Gaudry,[1] but no information was

[1] Gaudry, A., Sur une dent d'*Elephas primigenius,* trouvée par M. Pinart dans l'Alaska: Compt. Rend. Acad. Sci., Paris, vol. 75, 1872, pp. 1281–1283; Sur une dent d'*Elephas primigenius,* trouvée sur la rivière Koultchak, dans l'Alaska: Voyages à la côte nord-ouest de l'Amérique, Paris, 1875, pp. 29–31, Pl. A.

given concerning the exact locality or the character of the beds containing the remains.

The surface of these beds is beautifully terraced, well-marked benches being especially distinct at the end of the portage 4 miles northeast of the mouth of Newhalen River and at Millet's camp 3½ miles west of Chekok River. At each of these points several parallel beaches were observed, the highest being about 40 feet above the level of the lake. Similar beaches extending up to an elevation of about 100 feet above the present lake level were seen at a point about 23 miles east of the outlet of the lake.

These terrace deposits and the abandoned beaches are not well developed at the eastern end of the lake, although they were observed in places. A distinct bench is shown on the islands of Kakhonak, Intricate, and Pile Bays, as well as on the scattered islands in other parts of the lake. They are, however, cut benches rather than constructional beaches.

The terrace deposits were observed on the shores of Cook Inlet only at Bruin Bay and Ursus Cove. At the former point the neck of the peninsula projecting from the south shore of Bruin Bay is filled in by a deposit of cross-bedded and locally indurated sand and gravel. The deposit is 80 feet thick at this point, and is well terraced on the west side of the peninsula. Similar deposits occur on the south shore of the bay, west of the island, but were not observed except from a distance.

The valleys tributary to Iliamna Lake on the north side east of Newhalen River, and the valleys tributary to Lake Clark from the east, contain terraced gravel deposits of a somewhat different type and extending high up the mountain sides. (See fig. 3.)

On the east side of Knutson Creek a gravel terrace with smooth top and steep face about 40 feet high was seen. It appears to have been developed by the reworking of originally morainic material. Along the north shore of Knutson Bay there is a gravel terrace about 20 feet above the lake, sloping slightly for one-fourth to one-half mile to the base of Knutson Mountain, where it is perhaps a hundred feet above the lake. Extending westward from Knutson Mountain, this terrace merges into the broad lake-dotted gravel plain north of Chekok Bay. Northward this plain rises by very gentle slopes to an elevation of over 1,200 feet at the base of the mountains. Chekok River, Canyon Creek, and other streams have notched terraces in this deposit, and now occupy rather narrow canyons in the gravels. Canyon Creek, however, is so named because of a canyon, 300 feet deep in one place, which is cut in granite. Along this canyon the gravel mantle is comparatively thin and lies on a gently sloping rock bench.

The minor valleys and gulches in the mountains, 7 miles north of Chekok Bay, have these gravel terraces extending up to a nearly uniform level of about 1,400 feet. Above this height the streams have open mature valleys within the mountains; below it they are intrenched in recent gorges in the gravel plains. The gravels extend westward along the face of these mountains and through the pass between them and Roadhouse Mountain. They also occur on both sides of Tazimina River and Lakes, and continue northward from the foot of Lower Tazimina Lake, through Kokteekish Pass, to merge with those on the south side of Lake Clark.

On the south side of Lower Tazimina Lake the mountain wall lies nearer the shore than on the north side, and is quite steep, so that the gravel terrace is neither wide nor high, but at the southwest end of the lake the gravels run up to about 1,400 feet, forming at least four distinct benches at about 800, 1,000, 1,200, and 1,400 feet above sea level. On the north side of the lake there is a pond-dotted gravel plain about a mile wide, with one distinct bench at about 1,000 feet. From this bench the gravels slope up to the mountains, extend into the valleys, and fill a 1,900-foot pass to the Lake Clark drainage. On the east side of Lake Clark from Kokteekish Pass to Currant Creek and extending up the valley of Tanalian River there are wide gravel deposits bordering the lake and lying up to 600 or 800 feet above the lake. At a few places there are rock outcrops on the beach, so that it seems likely that the gravels lie on a rock bench. These gravels rise from the beach in two or three terraces and are marked by long ridges paralleling the shore, between which lie several elongated ponds.

The valleys entering Lake Clark from the east are gravel-filled up to elevations of 2,000 to 2,400 feet at successively higher levels on the creeks toward the head of the lake.

The lower part of the valley of Kontrashibuna Lake and Tanalian River are flanked by gravel terraces lying as high as 1,000 to 1,100 feet. They are narrow and lower or lacking where the mountain walls descend steeply to the lake.

CONDITIONS OF DEPOSITION.

These terrace deposits were probably derived chiefly, if not almost entirely, from glacial detritus. They were laid down in their present position by water.

The terraces at the lower levels on Iliamna and Clark lakes probably consist chiefly of material deposited near its present position as moraine and reworked by waves. The waters in which the reworking and redeposition were accomplished are believed to have been those of an estuary extending from the present Bristol Bay into the lower ends of the valleys of Iliamna and Clark lakes. The reason for the postulation of an estuary rather than a larger lake follows from the absence of a barrier high enough to hold a lake up to the higher terrace levels. The absence of the terraces and terrace deposits in their complete development at the upper ends of the lakes is ascribed to the presence of large glaciers in these localities during the time of the formation of most of the terraces. The higher elevation of the terraces on Lake Clark may be explained as due to the presence of the large Iliamna Lake glacier across the lower end of the Newhalen Valley after the Lake Clark glacier had retreated well up the lake. The waters in which these were laid down were thus lacustrine rather than estuarine.

The higher terraces in the Chekok, Tazimina, and Kontrashibuna valleys and east of the lower end of Lake Clark, which are shown on figure 3 (p. 89), are regarded as having been deposited in a series of small local marginal lakes in small valleys tributary to the larger valleys which were occupied by the main glaciers. These marginal lakes existed because of ponding by the main ice stream, and were hence local temporary features existing only at favorable times and places.

BEACH AND FLOOD-PLAIN DEPOSITS.

Beaches are well developed on the lower ends of Iliamna and Clark lakes, but are noticeably absent on much of the shores of the upper ends of these lakes, where glacial erosion has been most active and where glacial and terrace deposits are less abundant. The difference in degree of development of the beaches is in part due to the fact that the lower ends of the lakes are older, as the ice retreated from them before it left the upper ends. It is, however, in larger part caused by the presence of abundant unconsolidated deposits at the lower ends of the lakes and of resistant granite at the upper ends and by the fact that the lower ends of the lakes are broader and, in the case of Iliamna Lake, less broken up by islands, so that the waves have broader sweep.

Beaches are not well developed on the coast of Cook Inlet south of Chinitna Bay, apparently because of the youth of the coast and the absence of unconsolidated materials on which the waves could easily work.

Flood-plain deposits are well developed in many of the larger valleys, such as those of Iliamna River, Pile River, Knutson Creek, Chekok River, Tazimina River, Tanalian River, Currant Creek, Chokotonk River, and Tlikakila River. These deposits form the flat alluvial floors, which are particularly broad along their lower portions. They are made up chiefly of coarse gravels, largely of ultimate glacial origin, on the upper parts of their courses and of fine sand and clay near their mouths. Some of them, like Tlikakila

River, Chokotonk River, Currant Creek, and Pile River at their debouchures, have "reentrant deltas," built in fiord heads. Tanalian River has built a delta, Tanalian Point, in Lake Clark. Notable alluvial deposits on Kontrashibuna Lake are the cones and deltas which Kasna, Takoka, and other creeks have built into the lake.

RECENT VOLCANIC DEPOSITS.

Mounts Iliamna, Redoubt, and Augustine (see Pl. VIII, *B*, p. 86) are volcanic peaks which are still to be classed as active. Augustine had a violent eruption[1] in October, 1883, and is still giving off steam. Redoubt had an eruption on January 18, 1902, which sent showers of dust over the country from Lake Clark to the Skwentna Valley, and it is still giving off steam and occasional light showers of dust. Iliamna is not definitely known to have erupted in historic times, and small but fairly persistent clouds of steam are its only signs of life. There are, however, unsubstantiated newspaper accounts[2] of an eruption in 1854.

The entire area of Augustine Island is covered with volcanic detritus, chiefly ash, although some lava is present. The character of the material was determined by Becker[3] as andesitic.

The beach between Tuxedni and Chinitna bays is strewn with numerous fragments of a very fresh vesicular olivine basalt. It is considered highly probable that these fragments were derived from a recent lava stream from Mount Iliamna. On East Glacier Creek and near the base of Mount Iliamna volcanic rocks were seen which were considered as being recent flows from this mountain. One of these is an augite andesite consisting of phenocrysts of basic plagioclase, augite, and magnetite thickly studded in a microcrystalline groundmass of plagioclase and minute magnetites, with probably also some augite. Another specimen from this vicinity is a red porphyritic basalt containing laths of plagioclase, and possibly augite, in an opaque base. Cavities in the rock contain calcite.

STRUCTURE.

INTRODUCTION.

The following pages are intended to include all the available facts bearing on the structure of this region. In many areas the actual structure is not known, but it nevertheless seems desirable to present

[1] Davidson, George, Notes on the volcanic eruption of Mount St. Augustin, Alaska, Oct. 6, 1883: Science, vol. 3, 1884, pp. 186–189.

[2] Alaska's great volcano: Evening Star, Washington, D. C., Jan. 22, 1876, p. 7 (reprinted from San Francisco Chronicle).

[3] Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on the general geology: Eighteenth Ann. Rept. U. S. Geol. Survey, p. 3, 1898, pp. 28–30, 52–54.

here the known facts, even if it is not possible to interpret them and to describe systematically the structural relations.

It will be noticed that considerable detail is presented in the pages dealing with the Cook Inlet forelands, while there are less definite conclusions and far less detail for the other districts. The reasons for this inequality of detail are that the better known stratigraphic relationships in the former district permit more refined structural observations, while the more complex structure in the rest of the region introduces problems which would be difficult of solution even if there were unaltered sedimentary beds of known sequence upon which detailed structural observations could be made.

The matter presented under this heading must necessarily appear to be a mass of undigested facts. It is admitted to be just that. The reader should, however, remember that it is not intended as a systematic discussion of the structure, but rather as a record of the existing observations, made for the benefit of future observers.

COOK INLET FORELANDS.

GENERAL FEATURES.

The Cook Inlet forelands as a structural district to be discussed in this report may be defined as that portion of the Cook Inlet basin (see pp. 26–27) which lies between the west coast of Cook Inlet and the base of the Chigmit Mountains. The most logical position, structurally, for its western boundary is along the great fault or zone of faulting described below (pp. 96–100), which is at most places the western limit of the areas of Middle and Upper Jurassic sedimentary rocks. This is not, however, the limit of the geographic area discussed under this heading, which for purposes of convenience includes a complete discussion of the structures exposed on each of the bays entering Cook Inlet from the west, except Iliamna Bay, which is regarded as lying wholly within the Chigmit Mountains.

The Cook Inlet forelands are characterized structurally by the presence of bedded sheets of sedimentary and volcanic rocks, which are not metamorphosed and most of which are but gently folded. They are cut by intrusive masses which are in general neither large nor numerous, and which by their intrusion have apparently not appreciably altered the lithologic character or the structure of the adjacent rocks.

LOCAL OBSERVATIONS.

Tuxedni Bay.—The rocks exposed on Tuxedni Bay consist of granites at its head, a belt of volcanic rocks farther east, and a belt of Jurassic sedimentary rocks (Tuxedni, Chinitna, Chisik, and Naknek formations) on the lower part of the bay and on Chisik Island.

The granites include rocks of considerable diversity in composition and may represent several intrusions. If such various masses exist, their relations among themselves have not been determined. The contact of the granite mass with the volcanic rocks east of it is supposed to be one of intrusion, although the relations have not been determined locally.

The volcanic rocks likewise include several types of which the interrelations are not known. They may include successive flows, flows with intrusive masses cutting them, or either or both kinds of rock brought into their present structural arrangement by folding or faulting, or both. The nature of the contact of the volcanic rocks with the western edge of the sedimentary rocks east of them is not known. One of three possible relations exists. The Tuxedni sandstone, which is the lowest and westernmost of these sedimentary formations, may rest conformably or unconformably upon the volcanic rocks, the two may be separated by a fault, or the easternmost member of the volcanic rocks may locally be a dike younger than the Tuxedni sandstone. The fault relationship is believed, for reasons that will appear below (p. 97), to be the most probable.

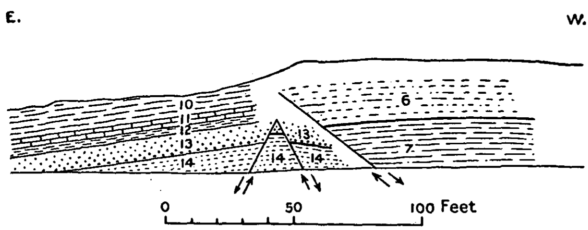


FIGURE 4.—Section showing faults on south shore of Tuxedni Bay, 2 miles west of Chisik Island. The beds in this section are numbered as in the stratigraphic section on pages 60–61.

The several sedimentary formations belong in normal, conformable, stratigraphic sequence one above the other in the order of their areal distribution from west to east. In harmony with this sequence there is a general easterly dip in this part of the bay.

This dip continues without interruption, except possibly between Chisik Island and the point on the mainland west of it, from the westernmost sedimentary outcrop on the western arm of the bay to and somewhat beyond the northern and southern extremities of Chisik Island. There is a western dip on the northern part of the eastern shore of Chisik Island, so the island is, in part at least, synclinal in structure.

Numerous small faults and probably several larger ones were observed on the south shore of the bay. Several of these are shown in figure 4.

Coast between Tuxedni and Chinitna bays.—The shore of Cook Inlet from Tuxedni Bay to Chinitna Bay is mostly a low, sandy beach behind which is a marshy flat. Except at the mouth of

Tuxedni Bay, the hills are a mile or two back from the shore. The easternmost of these hills form a monoclinal ridge parallel to the shore. They consist of the rocks of the Naknek formation, having a dip of from 10° to 30° east.

Chinitna Bay.—The upper end of Chinitna Bay is at or near the western edge of the presumably Lower Jurassic porphyries and tuffs. These rocks form all the outcrops on the western half of the north shore of the bay. The eastern half has magnificent exposures of the Chinitna and Naknek formations. At the entrance on the north shore is a lone outcrop of Tertiary rocks separated from the nearest Jurassic rocks west of it by an interval of sand beach and marsh. The southern shore has outcrops of Tuxedni sandstone near the head of the bay, and of Chinitna shale and Naknek formation near the entrance. Marshy land intervenes between them.

The structural relations of the porphyries and tuffs to the sedimentary rocks east of them could not be directly determined. The fact that westernmost outcrops of sedimentary beds are of the Chinitna shale on the north shore, but of the Tuxedni sandstone on the south shore, and that in each case the concealed interval [1] is not large, suggests that this contact is a fault. This condition is also indicated by the fact that the contact of the Tuxedni sandstone with the porphyries and tuffs has here transgressed eastward in comparison with its position on Iniskin Bay, so that there is on the north shore of Chinitna Bay only one fold between the eastern border of the porphyries and tuffs and the coastal monocline, while on Iniskin Bay (see p. 99) there are several folds in this interval.

The exposures of the Naknek formation at the mouth of the bay are part of the eastward-dipping monoclinal belt which extends parallel to the coast northward to Tuxedni Bay. The dip of the beds of the Naknek formation just within the bay is from 20° to 25°, but flattens going westward until, at a point about 3 miles inside the bay, the Chinitna shale exposed on the north shore is almost horizontal. Observations made at a distance from the outcrops suggested that the dip turns westward just before the contact with the volcanic rocks is reached.

Exposures on the south shore of the bay are lacking between the cliffs at the entrance to the bay and those near its head. Eastward dip was observed at both these points, but conditions farther south indicate that several folds may be present in this concealed interval.

The Tertiary rocks on the north shore of Chinitna Bay near the entrance are horizontal. It may be that the general structure has flattened at this point, and that the underlying Jurassic rocks also are

[1] The concealed interval on the north shore of the bay may contain a narrow belt of the Tuxedni sandstone and is so indicated on the geologic map (Pl. II) and on the structure section in figure 5, page 98.

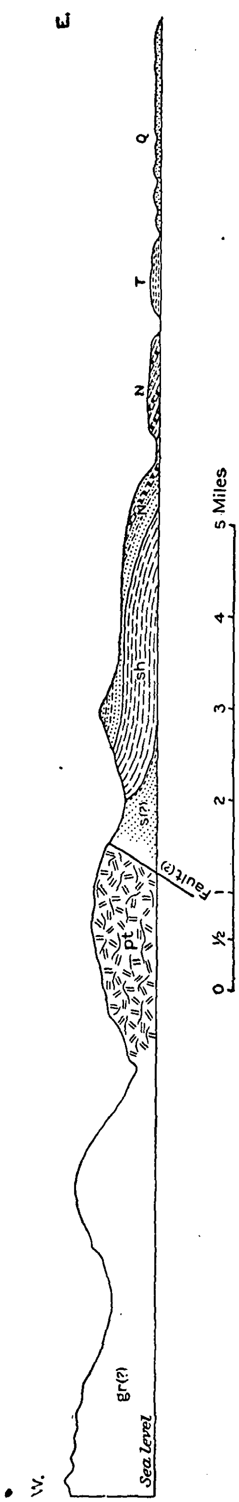


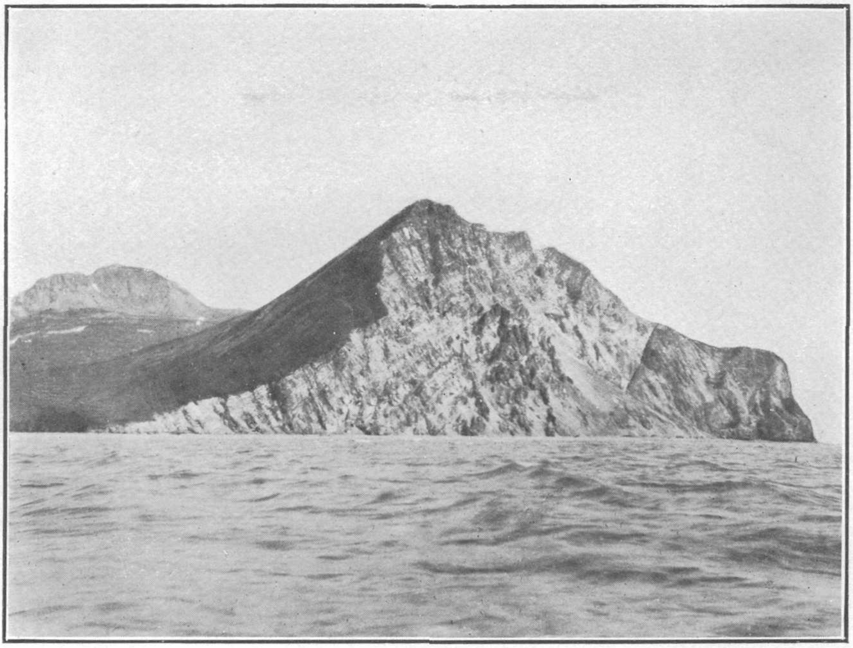
FIGURE 5.—Sketch showing structure on north shore of Chinitna Bay. gr, Granitic rocks (?); pt, porphyries and tuffs; s, Tuxedni sandstone (?); sh, Chinitna shale; N, Naknek formation; T, Tertiary beds; Q, Quaternary deposits.

horizontal, or the latter may continue dipping eastward beneath the Tertiary rocks which lie unconformably upon them in the attitude of deposition.

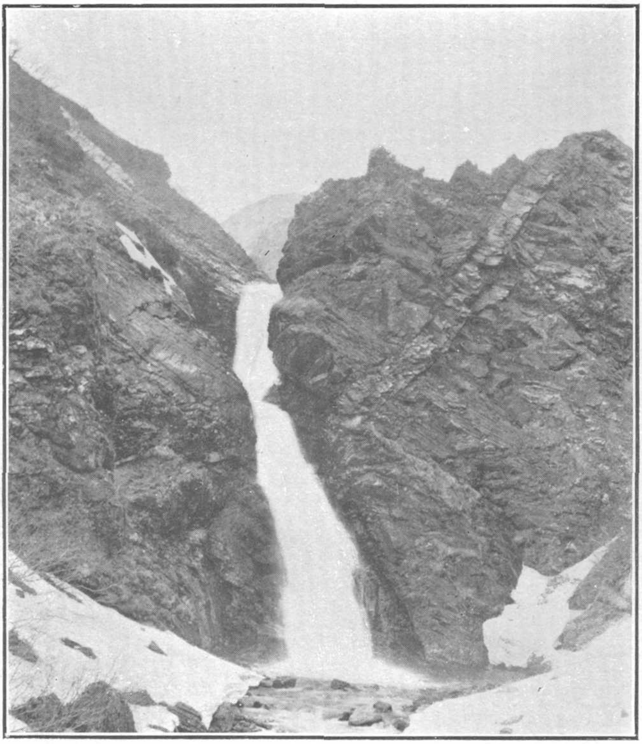
The structural facts observed on Chinitna Bay are presented graphically in figure 5.

Coast between Chinitna and Iniskin bays.—The shore of Cook Inlet from Chinitna Bay to Iniskin Bay consists of rocky cliffs giving clean but not very thick sections of the massive rocks of the Naknek formation. A range of hills parallel to the coast and monoclinal in structure lies close to the shore and contains the Naknek formation on its crest and east side, and the Chinitna shale on its western slope. The dip is uniformly eastward as in the already described continuation of this ridge north of Chinitna Bay. The ridge is broken through by drowned valleys at Dry and Oil bays. At the latter point magnificent exposures (Pl. VII, *A*, p. 66) of the rocks of the Naknek, Chisik (?), and Chinitna formations reveal the monoclinal structure of the range as shown in figure 6. The strike parallels the shore throughout the whole length of this belt, and the dip varies from 20° to 45°. The steepest observed dip is about a mile south of Chinitna Bay. The dip flattens eastward from the monoclinal ridge, and on the end of the low point at the entrance to Oil Bay and on the islands between there and Iniskin Bay it is almost horizontal.

Iniskin Bay.—The rocks exposed on Iniskin Bay consist of the presumably Lower Jurassic porphyries and tuffs with intrusive masses on the west and north shores, and of sedimentary Jurassic beds on the east shore. The latter lie in parallel belts consisting successively from north to south of the Tuxedni, Chinitna, Chisik, and Naknek formations. The structural relation of the sedimentary to the older igneous rocks is in part due to faulting, as is shown in figure 7, although at one locality the Tuxedni sandstone was observed to overlie porphyries and tuffs unconformably. (See pp. 58–59.)



A. KAMISHAK CHERT OVERTHRUST ON NAKNEK FORMATION ON NORTH SHORE OF URSUS COVE.



B. STEEPLY TILTED SLATES CUT BY DIKE ON CREEK NEAR HEAD OF COTTONWOOD BAY.

The sedimentary formations are flexed into open folds and are cut by faults. The dips are low and gently undulatory for the greater part of the length of the shore. Several folds are present of which the most prominent is the monocline exposed on the lower part of

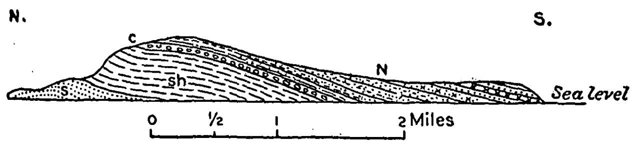


FIGURE 6.—Structure section on east shore of Oil Bay. s, Tuxedni sandstone; sh, Chinitna shale; c, conglomerate; N, Naknek formation.

the bay. This is the southern end of the monoclinal block which has been described above as extending down the coast from Tuxedni Bay. The section in figure 7 is believed to represent the structural details exposed on the east shore of the bay.

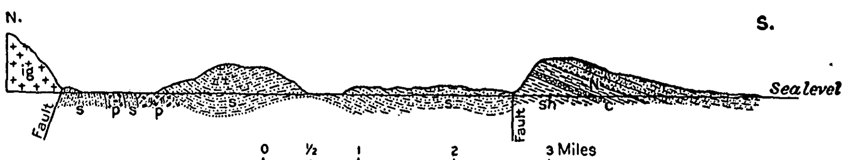


FIGURE 7.—Generalized structure section on east shore of Iniskin Bay. ig, Igneous rocks; s, Tuxedni sandstone; p, porphyry; sh, Chinitna shale; N, Naknek formation; c, Chisik conglomerate.

Ursus Cove.—The rocks exposed on Ursus Cove consist of the Lower Jurassic igneous rocks on the south shore, the Kamishak chert, with its associated igneous rocks and with possibly some older limestone, on the greater part of the north shore, and the shale and sandstone of the Naknek formation on the north shore at the entrance. The structural relationship of the various igneous rocks to each other and to the Kamishak chert is not known. The Kamishak chert is strongly folded and appears to lie in a syncline. In its deformation some minor faulting is known to have occurred, and the weaker beds are in places severely contorted. A beautifully exposed fault (see Pl. *IX*, *A*, p. 98, and fig. 8) at the north entrance to the cove shows the Kamishak chert overthrust upon the Naknek formation, which is locally folded into an overturned syncline with its axial plane dipping west. This fold either dies out northward or is more probably cut off by the eastward transgression

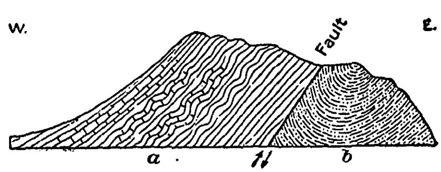


FIGURE 8.—Sketch showing Kamishak chert overthrust upon Naknek formation at mouth of Ursus Cove. *a*, Triassic cherts and limestone; *b*, Naknek shales and sandstones.

of the fault, for where the latter cuts the shore about 2 miles north of Ursus Cove the Naknek formation is almost horizontal.

Coast between Ursus Cove and Bruin Bay.—The fault seen at the north entrance to Ursus Cove cuts the shore of Cook Inlet again just south of Ursus Cove, and there separates the igneous rocks exposed on the south shore of Ursus Cove from the Naknek formation which forms the shore of Cook Inlet almost as far south as Bruin Bay, or for a distance of about 8 miles. The Naknek formation is here practically horizontal, as is shown on Plate VII, *B*, page 66.

Bruin Bay.—The rocks on Bruin Bay consist of the Kamishak and Naknek formations and granitic intrusives. The rocks of the Kamishak formation are closely crumpled (see Pl. V, *A*, p. 40) and cut by numerous small faults. The broader structure of these rocks could not be determined. They are overthrust, by the southern continuation of the fault seen at Ursus Cove, upon the Naknek formation, which here lies horizontal or flexed into very gentle wavy folds, whose dips do not exceed a few degrees. The granitic rocks are intrusive into the Kamishak chert, having been intruded after the latter was folded.

Coast of Kamishak Bay south of Bruin Bay.—The shale and sandstone of the Naknek formation in the cliffs at the entrance to Bruin Bay continue southward in an unbroken series of cliffs for about 5 miles. At this point the great overthrust fault, which has been followed southward, cuts the cliffs and brings up a series of massive or poorly bedded rocks, which may be Triassic sediments, but which look from the water more like fine-grained homogeneous crystallines. These extend southward to the southern end of the cliffs. The succeeding 5 or 6 miles of shore are low and sandy, with no rock outcrops.

The head of Kamishak Bay has horizontal rocks of undetermined age on its west shore and horizontal beds of the Naknek formation on its east shore. The relations of the two were not determined. From this point eastward along the south shore of Kamishak Bay for 10 miles, to the mouth of the first large river, the cliffs all show horizontal beds of the Naknek formation. The structural relations of these to the granites and other rocks south of them in the mountains and east of them on the coast is not known.

CHIGMIT MOUNTAINS.

GENERAL FEATURES.

The structure of the Chigmit Mountains presents great difficulties and can not be fully interpreted from the data now at hand. The problems involved are complex in the extreme and will probably be solved only after the sequence of the rocks and their areal distribution are much more accurately known than at present. Detailed mapping in some of the critical localities will probably be required.

The Chigmit Mountains are structurally an area of profoundly metamorphosed Paleozoic rocks, with which are associated intricately folded and much faulted blocks of slightly metamorphosed early Mesozoic sediments and volcanics, both being cut by enormous masses of plutonic Mesozoic intrusives and the whole faulted on a large scale. The general character of the structure is shown in figure 9.

The limits of the Chigmit Mountains as a structural province should probably be regarded as defined on the east by the great fault or zone of faulting described above (p. 95) as extending parallel to the coast of Cook Inlet from Tuxedni Bay to Bruin Bay between the Upper Triassic chert and Lower Jurassic igneous rocks on one side and the Middle and Upper Jurassic rocks on the other; and as defined on the west by the eastern boundaries of the flat or gently folded Tertiary volcanic rocks of the Iliamna basin.

LOCAL OBSERVATIONS.

Iliamna Bay.—The rocks exposed on Iliamna and Cottonwood bays include probably late Paleozoic slate and greenstone, Upper Triassic sediments, including limestone and the Kamishak chert, volcanic rocks, which probably include both flows and tuffs and which are probably of Lower Jurassic age, Lower or Middle Jurassic granites, and late Jurassic (or younger) porphyry dikes. These, except the last, occur in approximately parallel belts having a northeast-southwest trend. The slate outcrops only at the head of Cottonwood Bay, and the limestone and the Kamishak chert are shown only on Cottonwood Bay and on the south shore of Iliamna Bay, but the belts of other rocks cross the bay, the granite occurring in three such belts. The probable structural relationships are shown in figure 10.

The easternmost of the granite belts crosses the bay at its mouth, forming the headlands on each side of the entrance. It is in contact with the Lower Jurassic (?) porphyries and tuffs on the north shore of the bay, and with limestone on the south shore. Both contacts are believed to be intrusive. The limestone on the south shore of the bay is in contact on its west side with the lower Jurassic (?)

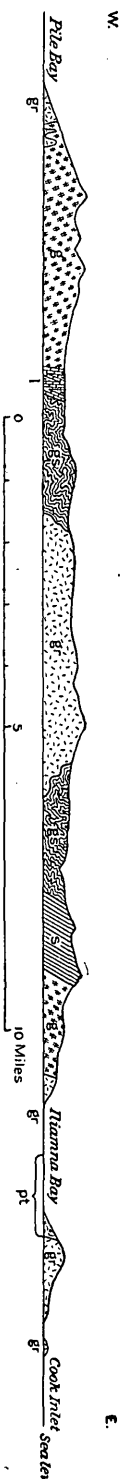


FIGURE 9.—Sketch showing probable structure of the Chigmit Mountains from Iliamna Bay to Pile Bay. gr, Granite; g, greenstone; gs, gneiss and schist; l, limestone; s, slate; pt, porphyries and tuffs.

porphyries and tuffs. The nature of the contact and the structural relations are not known. The limestone itself is complexly folded and includes within its general area many small masses of igneous rocks of indeterminate structural relations to it. The Lower Jurassic (?) porphyries and tuffs appear to rest conformably upon the Kamishak chert on the east shore of Cottonwood Bay, and are in contact with a second belt of granite on the north shore of Iliamna Bay. The dips are steeply eastward. The Kamishak chert also has a steep eastward dip. It does not cross the bay, apparently being cut off by the mass of granite which lies west of it and which on the north of the bay is in contact with the porphyries and tuffs. West of this granite is a belt of greenstone, the contact between the two being possibly intrusive, but more likely one of faulting. Granite appears again to the west of the greenstone at the extreme head of Iliamna Bay, the contact appearing to be intrusive. At the head of Cottonwood Bay slate is west of the greenstone. The bedding or cleavage of the slate (Pl. IX, *B*, p. 98) is uniformly northwestward at dominantly high angles, being in general parallel to that of the greenstone. This slate is believed to be older than the greenstone and to be locally overthrust or overfolded upon it.

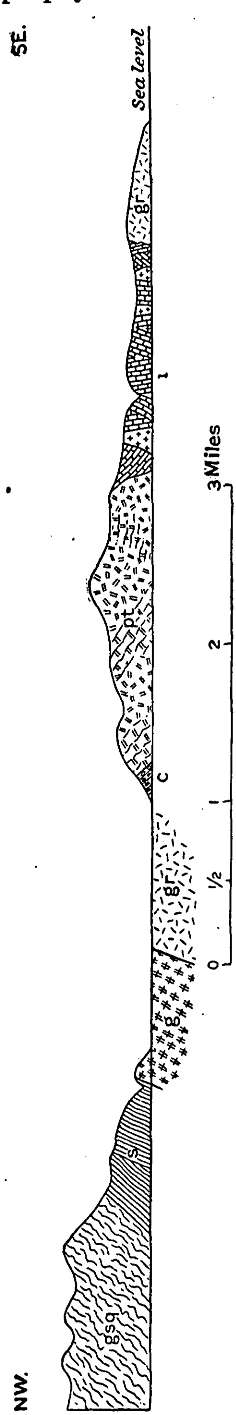


FIGURE 10.—Sketch showing probable structure on south shore of Iliamna Bay. gsq, Gneiss, schist, and quartzite; gr, granite; g, greenstone; s, slate; c, chert; l, limestone with associated igneous rocks; pt, porphyries and tuffs.

Mountains between Iliamna and Pile bays.—The rocks of the mountain area west of Iliamna Bay comprise a group of strongly metamorphosed gneiss, schist, quartzite, and crystalline marble; a group of less metamorphosed and younger rocks including slate, greenstone, and limestone; and one or more intrusive masses of granite. The general interpretation of the structure is shown in figure 9, page 101.

In areal distribution there is a central zone of granite, flanked on both the east and west sides by gneiss with associated schist and quartzite. Within the boundaries of the gneiss and schist are two small areas of crystalline marble. East of the gneiss comes the slate and greenstone of the shores of Iliamna and Cottonwood bays. West of the gneiss is limestone, which is succeeded by greenstone and granite.

The gneiss, schist, and quartzite together constitute a stratigraphic and structural complex which could not be cartographically subdivided in the reconnaissance here described. The crystalline marble occurs within the area of the gneiss either as small lenses or, more probably, as small detached areas of undetermined structural and stratigraphic relations. The quartzite and mica schist also are intimately associated with the gneiss, but probably represent a younger formation at present not separable from the gneiss. The gneiss, schist, quartzite, and marble together have general northeast strike and steep northwest dip. They are probably overthrust or overfolded upon the slate and greenstone at the heads of Iliamna and Cottonwood bays.

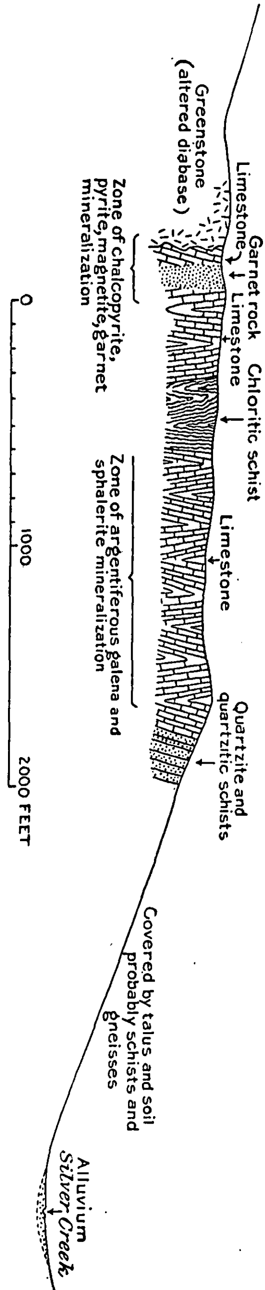


FIGURE 11.—Structure section showing type of folding of the limestone north of Meadow Lake.

A belt of much folded and shattered but otherwise not much altered limestone adjoins the gneiss and schist on the west. This limestone is believed to overlie the gneiss unconformably. The structure of the limestone is shown diagrammatically by figure 11. Associated with the limestone are masses of chloritic schist. These are believed to be part of an older formation folded or faulted in with the limestone but not separated from it in mapping. Their exact stratigraphic and structural relations to the limestone could not be determined.

A large mass of greenstone lies west of the limestone. The structural relations between the two could not be definitely determined. Basic rocks of the same general type as the greenstone and lying along its eastern margin are known to be intrusive into the limestone. The point in doubt is whether these rocks are an integral part of the main greenstone mass, or are later intrusive rocks. West of the greenstone is granite which is clearly intrusive into it.

Pile Bay.—The exposures on the shore of Pile Bay are all of granite, except for an interval of about 3 miles on the east shore and at the cape on the south side of the entrance to the bay, where there is greenstone.

The contact of granite and greenstone at a point 4½ miles below Iliamna River is clearly one of intrusion. The granite has sent anastomosing dikes into the greenstone, as is shown in figure 9, p. 101, and also in figure 12, and blocks of the greenstone occur as inclusions in the granite. The other contacts of granite and greenstone were not observed, and may be either intrusive or faults. This greenstone mass has general northeast strike and steep dip, and is closely folded, the folding having affected both the bedding and some of the quartz veins.

The exposures of greenstone at the mouth of the bay are less conclusive regarding the relationships, but it is believed that the greenstone is overlain unconformably by porphyries and tuffs and that the two are separated from the granite by a fault. This interpretation is expressed graphically in figure 12. The position of this probable fault should be regarded as the local western boundary of the Chigmit Mountains as a structural province.

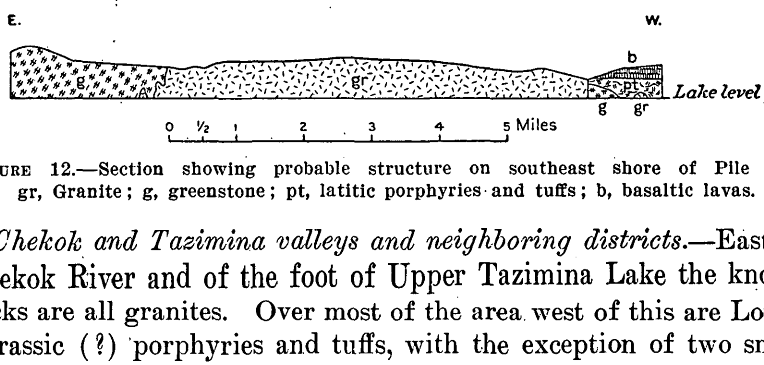


FIGURE 12.—Section showing probable structure on southeast shore of Pile Bay. gr, Granite; g, greenstone; pt, latitic porphyries and tuffs; b, basaltic lavas.

Chekok and Tazimina valleys and neighboring districts.—East of Chekok River and of the foot of Upper Tazimina Lake the known rocks are all granites. Over most of the area west of this are Lower Jurassic (?) porphyries and tuffs, with the exception of two small areas, one 10 miles north of Chekok Bay and the other south of the foot of Lake Clark, in which there are late Paleozoic slates and cherts. These rocks may occur also in other undetected areas. The relation of the granite to the porphyries and tuffs is unknown, but the granite is presumably intrusive into the porphyries and tuffs, as it is on Iliamna Bay. The present contact may, however, be either an intrusive or a fault contact or, in places, may be both. Except on Chekok Bay, where they are within a few hundred feet of one another, these rocks were seen only at the distances of a mile or more from each other. The probable positions of their contacts are believed to be largely in alluvial areas. The porphyries and tuffs, where structure was discernible, as on the mountain 8 miles north of the mouth of Chekok River and in the mountains 5 miles south of Tanalian Point, constitute a series of interbedded flows and pyroclastics, which are moderately flexed, being nearly horizontal at the first locality and dipping 25° N. 35° E. at the second locality. North of the foot of Lower Tazimina Lake the tuff beds are slightly undulatory, but in a broad way appear to be horizontal. The slates, which show only poorly developed cleavage, and the cherts associated with them have been crumpled and tilted at high angles. The strikes recorded are N. 10° E. (magnetic), dip 80° SE., and N. 30° E. (magnetic), dip 90° in the area north of Chekok Bay and N. 70° E. (magnetic), dip 90°, on the hill east of the foot of Lake Clark. The slates and cherts are either unconformably overlain by the porphyries and tuffs, and exposed by the erosion of the latter, or are faulted against them. The former relationship is believed to be the more probable and is expressed in the hypothetical structure section on figure 13.

Kontrashibuna Valley.—The upper part of Kontrashibuna Valley is believed to lie within the area of the granite. Across the central part of the lake is a belt of crystalline limestone and calcareous schist. West of the limestone on the north side of Kontrashibuna Lake are schistose, quartzitic, and slaty rocks. On the south side of the lower half of the lake, and west of the limestone are Lower Jurassic (?) porphyries and tuffs surrounding a small area of late Paleozoic (?) slates and cherts which strike N. 10° E. (magnetic) and dip 80° SE. The relation of these slates to the surrounding porphyries and tuffs is not known. At and below the falls of Tanalian River there is granite. The structural relations of these formations within the Kontrashibuna Valley are supposed to be in general the same as in the neighboring districts to the north and south. The probable structure is indicated in figure 14, page 106; also in figure 17, page 108.

Upper end of Lake Clark.—The rocks of the mountains bordering the upper end of Lake Clark are all igneous or metamorphic. They occur in rudely parallel belts trending approximately north and south. The following structural observations are presented in the order of the geographic position of the localities at which the observations were made, from northeast to southwest. The rock at the head of Lake Clark, and for at least 6 miles up the valley of Chokotonk River, is granite. This granite mass is considered as being a

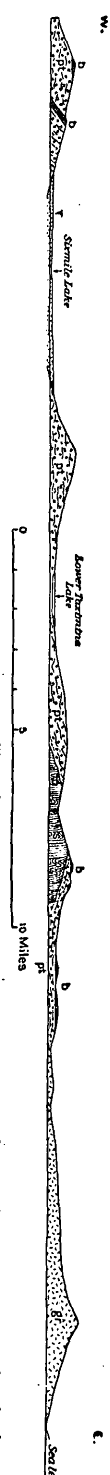


FIGURE 13.—Hypothetical structure section from mountains east of Chekok Valley to hills west of Sixmile Lake. T, Terrace gravels; b, basalt; s, slate; gr, granite; pt, porphyries and tuffs.

great batholith which has invaded the sedimentary beds. It shows foliation in an apparent arch structure centering about a mile below the head of the lake on the west shore. West of this granite is an area of slates and cherts. The contact is concealed on the east shore of the lake, but is well exposed on the west side of the lake, where the granite shows a thick marginal facies of coarse granite porphyry in contact with a zone of rock having a somewhat gneissic appearance, which is the altered and invaded part of the slates and cherts. The slaty rocks have a uniformly northwest strike (N. 46° W., magnetic), and steep southwest dip (70°–73° SW.). They are cut by numerous faults, having planes lying at about right angles to the bedding, on none of which could the amount or direction of movement be determined.

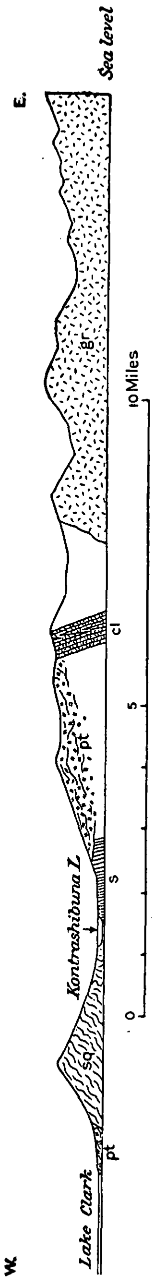


FIGURE 14.—Hypothetical structure section in Kontrashibuna Valley. pt, Porphyries and tuffs; sq, schist and quartzite; cl, crystalline limestone; gr, probably granite; s, slate.

The rocks lying west of the slates and cherts on the west shore of the lake are the tuffaceous beds described on page 55. The attitude of these beds and their relation to the slates was not determined.

These tuffaceous rocks do not cross the lake, their relative position on the east shore of the lake being occupied by a large mass of granite upon which the slates and cherts are overthrust, as is shown on figure 15. The latter beds have steep or vertical dips and rest directly upon coarse granite. The contact is well exposed where it cuts the beach and clearly establishes the fault relationship. At this point the two rock masses are separated by a 4-foot zone of soft, much crushed, and weathered material, consisting of the disintegration products of the slaty rocks above and of the granite below. About midway of this zone the contact surface between the disintegration products of the two kinds of rocks shows sharp and smooth. This surface strikes N. 10° W. (magnetic) and dips 59° NE. No sign of alteration was seen in either rock, except crushing and weathering. The weathered granite is of coarse grain to the very contact.

Areas of somewhat altered igneous rock probably to be classed as greenstone (p. 39) were seen on the east shore of the lake a short distance west of the granite mass just described, and on the west side of the lake west of the Tlikakila Valley. The structural relationship of this rock to the granite is not known.

An area of metamorphic rocks, consisting of a central mass of mica schist and quartzite flanked on either side by calcareous schist and limestone, is exposed on the west shore of the lake just below the area of greenstone. Anticlinal structure is inferred, as is shown in figure 15, because the calcareous rocks appear to dip away on either side from the quartzite schists, although a fan-shaped syncline or one of several fault relationships is possible.

Crystalline limestone, calcareous schist, and quartzite outcrop on the east shore of the lake from about 1 mile above to 7 miles below

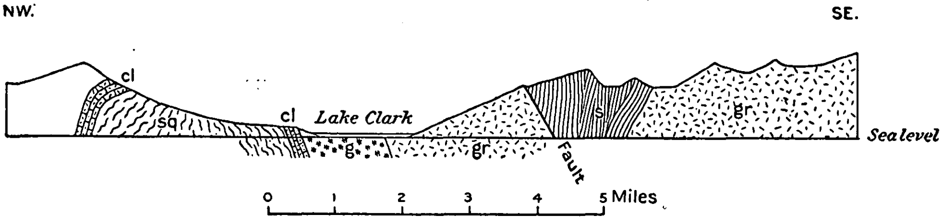


FIGURE 15.—Structure section across Lake Clark below mouth of Tlikakila River. sq, Mica schist and quartzite; cl, crystalline limestone; gr, granite; g, greenstone; s, slate.

Currant Creek. The limestone, which is the easternmost and presumably the uppermost of these rocks (fig. 17, p. 108), extends southward without interruption to the limestone locality on Kontrashibuna Lake (p. 105). It is believed also to be the same structural belt as that noted above on the west shore of Lake Clark.

These schistose rocks are apparently everywhere closely and intricately folded, minute plication being noted in many of the beds. In general the axial planes of the folds as well as the bedding stand

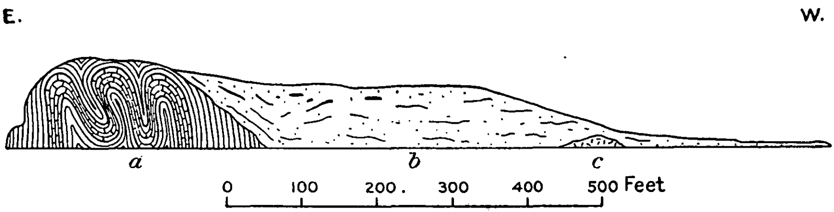


FIGURE 16.—Diagrammatic sketch showing folding of calcareous schist on island 2 miles northwest of Currant Creek, Lake Clark. *a*, Interlaminated thin limestones, sheared argillites and quartzites; *b*, soil; *c*, gabbro.

vertical. The closely appressed, nearly isoclinal folds in the calcareous schist on the island 2 miles northwest of Currant Creek are shown in figure 16. The strong internal deformation of these rocks is evidenced by their crystallinity, especially of the limestones, and by the well-developed schistosity of the other beds. These rocks were invaded by small dikes prior to the folding and by granitic intrusives after the folding.

The contact of the poryphyries and tuffs with the schist east of them is not exposed on the lake shore, and the structural relations are not known. The porphyries and tuffs are continuous with those of the Tazimina Valley. Near their eastern boundary on Lake Clark there are some small detached areas of granitic rocks which are probably intrusive into them. The summit of the hill on the south shore of the lake above Tanalian Point is of basalt provisionally correlated with the Tertiary basalts of the Iliamna Basin and hence supposedly unconformably overlying the porphyries and tuffs, as is indicated on figure 17.

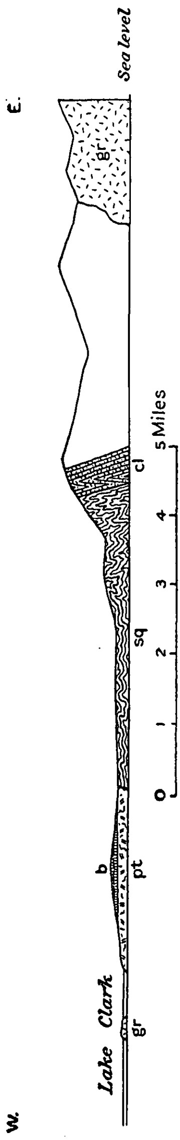


FIGURE 17.—Sketch showing probable structure of mountains east of Lake Clark, 5 miles south of Currant Creek. gr, Granite; pt, porphyries and tuffs; sq, schist and quartzite; cl, crystalline limestone; b, basalt.

ILIAMNA BASIN.

GENERAL FEATURES.

The Iliamna Basin as a structural province includes the essentially nonmountainous part of the area drained by the tributaries of Iliamna Lake. It is dominantly an area of bedded volcanic flows and tuffs of Tertiary age, which have been folded to a comparatively small degree. Older sedimentary and volcanic rocks of complex structure are present only along the rather indefinite eastern boundary of the province and at two other restricted areas on the south shore of Iliamna Lake.

LOCAL OBSERVATIONS.

Along the south shore of Iliamna Lake, from a point 15 miles below the head of Pile Bay to a point 12 miles farther west, the Tertiary basalts and tuffs cap the hilltops, resting unconformably upon older igneous rocks, and dipping westward at about 140 feet to the mile. These facts are shown diagrammatically in figures 12 and 18. The eastern termination of these volcanic rocks is at a contact with granite and greenstone and this point should probably be accepted as the local boundary between the Iliamna Basin and the Chigmit Mountains as structural provinces.

The westward dip of the Tertiary volcanic rocks brings them down to lake level at a point about 20 miles below the mouth of Iliamna River. The shores and islands of Intricate Bay are made up entirely of these rocks which here are in general flat, although a few islands show gentle monoclinal structures.

The shores and islands of Kakhonak Bay are likewise made of these same rocks in horizontal attitude, except at the east end of the bay, where the Tertiary lava sheets are folded and where the older volcanic rocks are also exposed.

Tertiary lavas with prevailingly gentle dips make up the south shore of the lake from near the head of Kakhonak Bay to a point 25 miles east of the outlet of the lake, except for one short interval, where the older volcanic rocks are exposed. At the point 25 miles east of the outlet of the lake a fault cuts the shore, separating gently dipping Tertiary volcanic rocks on the east from steeply dipping older volcanic rocks on the west. The latter are overlain unconformably at an elevation of several hundred feet above lake level by gently dipping Tertiary lavas.

All the exposures on the north shore of the lake from a point 3 miles west of Chekok River to 8 miles west of Newhalen River are Tertiary volcanic beds, which are in places horizontal and in places steeply inclined.

The hills west of Roadhouse Portage in the Newhalen Valley are capped by horizontal Tertiary basalts, resting on tuffaceous beds whose structure was not determined. Similar conditions exist in the hills west of Sixmile Lake (fig. 13, p. 105), where there are also basaltic ridges along the eastern face of the hill which may be either inclined intrusive masses or folded sheets.

The exposures on the lower part of Lake Clark are of volcanic rocks, at least part of which are the Tertiary basalts. The character of the exposures is not such that any structural details have been made out.

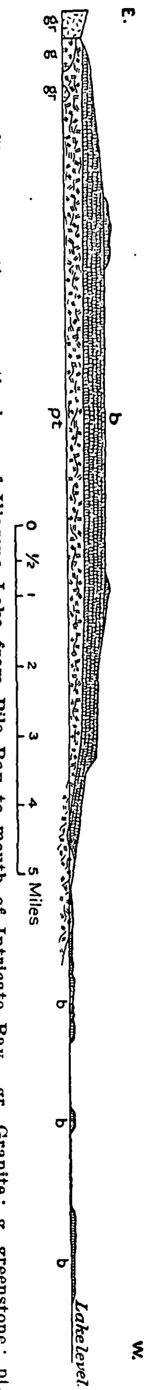


FIGURE 18.—Structure section on south shore of Iliamna Lake from Pile Bay to mouth of Intricate Bay. gr, Granite; g, greenstone; pl, latitic porphyries and tuffs; b, basaltic lavas.

BERING SEA COASTAL PLAIN.

The Bering Sea coastal plain as a geologic province is characterized by the absence, at the surface, of all consolidated rocks, so that its structure is of the simplest kind. The beds of which it is composed are exclusively unconsolidated Quaternary deposits, all of which are believed to lie in nearly or quite their original attitude of deposition. They have been uplifted several hundred feet since their deposition, and this uplift may have been accompanied by tilting or by gentle folding, but of this there is no proof.

HISTORICAL GEOLOGY.

The oldest records of geologic history in this region are believed to be found in the gneisses exposed in the heart of the Chigmit Mountains west of Iliamna Bay. Next in intensity of the metamorphism which they have undergone, and therefore presumably also next in age, are the schists and quartzites which are associated with the gneisses, and the quartzitic and calcareous schists and crystalline limestone of Lake Clark.

There is every reason to believe that all of these rocks were formed and suffered at least part of their deformation during Paleozoic time. It is highly probable that all of them, except the limestones, originated as clastic sediments, and that the gneisses are older than the schists, and owe their coarser grain to more intense metamorphism, or to a greater number of periods of metamorphism. In the latter case the gneisses must have been partly metamorphosed prior to the deposition of the sediments from which the schists were made. The clastic origin of the gneisses is not, however, clearly established. They are granitoid in texture, and may be granitic in origin. They may consequently have had their origin from the deformation of granite rocks intruded into the now schistose sediments.

The slates of the mountains west of Cottonwood Bay, and the slates and cherts of the Lake Clark valley were derived from fine-grained clastic sediments deposited after the schists were metamorphosed. Their date of deposition was in Paleozoic time, probably toward its end. They probably underwent part of their metamorphism during the Paleozoic.

The rocks described as greenstones were derived by alteration from basic igneous rocks, which were at least partly extrusive, and seem to include some waterlaid deposits, and possibly also some rocks originally intrusive. The extrusive and bedded rocks were probably laid down in late Paleozoic time, probably not long after the deposition of the beds now appearing as slates. Their metamorphism, and possibly part of their deposition, may have occurred in the early Triassic. There is no evidence as to the age of such of these rocks as may be intrusive.

From the foregoing it is seen that the record of Paleozoic history in the region is very incomplete. Four periods of subaqueous deposition are recognizable, but the establishment of the first of these is doubtful, and it may be that the rocks referred to it were formed by intrusion after the close of the second (as outlined above) period of sedimentation. The last and closing Paleozoic period of rock making in this region was one of volcanicity. Each of these periods was followed by periods of deformation and metamorphism, or, in other words, by orogenic movements. The erosion cycles which these early movements determined, and the ultimate effect of these movements upon the present physiography of the region, can be only conjectured.

The stratigraphic record begins to be more complete in Upper Triassic time when a great thickness of limestone followed by shaly and cherty beds was laid down. These rocks were intruded by basic masses and were intensely folded near the beginning of Jurassic time. Volcanic outbursts, in early Jurassic time, covered much of this region with lavas and tuffs. There is no local evidence that oceanic waters covered any part of this area while this was going on, but the similar and probably contemporaneous Lower Jurassic volcanic beds on the east coast of Cook Inlet were, in part at least, laid down in marine waters.

At some period after the end of Triassic time and after the folding of the Triassic beds, and probably near the end of the Lower Jurassic, the great granitic masses of the Chigmit Mountains were intruded.

In Middle Jurassic time the present Cook Inlet region became the site of marine sedimentation, and the Tuxedni and Chinitna formations were deposited. If these conditions extended into the present position of Iliamna and Clark lakes, subsequent sedimentation has buried or subsequent erosion has removed the sediments. The waters in which these beds were laid down are known to have extended north along the present site of the Alaska Range and east into what is now the Matanuska Valley.

At the beginning of Upper Jurassic time erosion had probably proceeded far enough in the present Chigmit Mountain area to unroof the granites and furnish detritus from them to the waters in which the Chisik conglomerate was laid down. The deposition of this coarse material was apparently restricted to small areas.

The deposition of the Naknek formation was in a sea of broad extent which apparently reached westward along the present Pacific coast as far as Chignik, and eastward into the present Matanuska and Chitina valleys. The waters were probably shut off from the present area of the Chigmit and Alaska ranges and from the country north and west of them. These areas were probably a region of uplift and vigorous erosion which furnished the fresh detritus which makes up the great thickness of the Naknek sediments. Volcanic agencies were apparently active from time to time along the coast, since many beds of the Naknek formation are tuffaceous and others appear to be lava flows.

The absence of Cretaceous beds within this region indicates land conditions during Cretaceous time, although the possibility of the deposition and subsequent erosion of beds of that age can not be denied.

The area described above as the Iliamna Basin was probably lowered by structural depression or by vigorous erosion during the late Mesozoic and early Tertiary. In Eocene or Miocene time it received large quantities of volcanic detritus from unknown sources and was largely filled with basaltic lavas and tuffs. These beds were subsequently gently folded, and in them were eroded the present lake valleys. These were afterward occupied by large glaciers which doubtless contributed a great share toward the deepening and broadening of the valleys into their present form. On the retreat of the glacial ice the valleys were occupied up to a height of about 150 feet above the present sea level by estuarine waters by which broad terraces were built. The present lakes have been little modified since the uplift which terminated this estuarine occupation.

The Cook Inlet basin probably originated as a down-folded or down-faulted area in a broad sheet of Mesozoic sediments, sometime after the close of the Jurassic. The immense thickness of the Jurassic deposits suggests that important movements along the position of the present west shore of the Cook Inlet were in progress during the deposition of these beds. These movements probably continued during much of the Cretaceous. By Tertiary time the depression had been somewhat enlarged by erosion of part of the Mesozoic rocks and by the uplift of the granitic and other crystalline areas on the margins. It was then partly filled with Eocene or Oligocene fresh-water sediments. These were afterward slightly folded and uplifted and the present water-filled depression was cut in them. This was then invaded by glaciers and on their retreat was overfilled with ocean or brackish water in which were deposited the gravels which now cover the terraces.

The volcanic activity now in evidence at the volcanic peaks of Augustine, Iliamna, and Redoubt is probably but the local survival of activities which began at least as far back as the early Mesozoic and has continued intermittently until now. The periods of greatest volcanic activity were the late Paleozoic or early Triassic, the early Jurassic and late Tertiary.

The more or less approximate accordance of mountain summits (Pl. VIII, *A*, p. 86) throughout much of the region, as well as the presence of fairly mature open valleys (p. 85) above the limit of general glaciation, suggest that there was a period, prior to the more widespread glacial occupation, in which the land surface was reduced to considerably less relief than it now possesses. The evidence at hand is not precise enough to warrant the conclusion that this old surface was a peneplain whose present broader differences of relief are due to warping. The existing features are capable of many possible explanations, none of which can now be positively demonstrated. The detailed interpretation of the physiographic history of this region will accordingly be left for future study.

MINERAL RESOURCES.

GENERAL STATEMENT.

The prospective mineral resources of the Iliamna region are copper, silver, gold, and petroleum. For about a decade prospectors have been attracted to this and adjoining regions in search for copper lodes, gold placers, and oil fields. The first discoveries seem to have been the petroleum seepages at Oil Bay (see p. 127), and later the Dutton copper lodes were located. The attempts to develop these fields brought to the region men who have made a number of other mineral locations.

There has been no production of mineral wealth in the region save for a few dollars won from the gold placer prospects and less than a ton of copper ore shipped out for a smelter test. The present development warrants no statement as to the future of the region.

The descriptions which follow are necessarily not exhaustive. The time available for examination of the properties was too short for detailed study, and, furthermore, none of the prospects had been developed to an extent which would have assisted appreciably a detailed investigation. Inasmuch as the unequal development of the several claims and the varying amount of time spent in examining them bear no relation to the importance of the claims, the space devoted to the discussion of the various properties is to be taken as an index not of their relative importance but merely of the extent of information obtained about them. It should be stated that it is impossible in work of this kind to attempt to collect samples for assays. Consequently, where values are stated in the following pages, they are as reported by the owners of the claims.

GEOGRAPHIC DISTRIBUTION.

With the exception of the oil seepages in the foothills bordering Cook Inlet and one prospect on the southern shore of lower Iliamna Lake, all the prospects so far located in this region are in the Chigmit Mountains. As has been pointed out (see p. 27), this is the area of oldest rocks of the region and the area of the great granitic intrusions.

The prospects are in three areas—between Iliamna Bay and Pile Bay; on the north shore of Iliamna Lake; and on Kontrashibuna

Lake. To some extent this distribution is governed by the geographic distribution of the limestones and by the established routes of travel.

GEOLOGIC OCCURRENCE.

Under this heading the possible economic features of the several geologic formations of this region are discussed. The areal distribution, lithologic character, stratigraphic relations, and structure of these formations are described in the preceding pages. The table opposite page 31, and the geologic map (Pl. II) summarize most of the more important geologic information.

The Paleozoic gneisses, schists, and marbles are known to be mineralized at one locality, about 1⅓ miles west of the head of Iliamna Bay. Here the mineralization is by contact metamorphism of one or more small detached marble masses. At this place hornblende granite is the immediately adjacent rock and greenstone is near by. Elsewhere in the region these Paleozoic formations are of interest because they occur in close association with the limestones described below, which are mineralized. In the Lake Clark region quartzitic schists lie west of the limestone belt. South of Iliamna village, the schists and gneisses limit the limestone belt on the east.

On the Paleozoic and Triassic limestones (pp. 32–35, 41–47) are located four important prospects. Copper deposits have been discovered on each of the areas of limestones recognized in the geologic mapping and on one of them there is also a silver-bearing galena-sphalerite lode. Two of these copper deposits appear to be of contact-metamorphic origin. The one south of Iliamna village is at the contact of greenstone or altered diabase or diorite, and the one on Kontrashibuna Lake is probably near the contact with granite or diorite. The copper deposit at Millet's is near the contact of a basaltic rock with limestone, but this association has not here been shown to be of significance with respect to the mineralization. The silver-bearing lode is in the limestone paralleling the contact-metamorphic copper lode south of Iliamna village. At this locality the important rocks areally associated with the limestone are andesitic porphyry dikes of unknown age.

The greenstones (pp. 38–41), which are metamorphosed basic igneous rocks, are of economic importance for two reasons—first, because within them quartz veins carrying chalcopyrite and pyrite have been discovered; and secondly, because a copper lode has been located along their contact with the limestone south of Iliamna village.

The Kamishak chert (pp. 47–50) is not known to contain or to be associated with mineral deposits of economic interest.

The porphyries and tuffs (pp. 50–59) have been noted in several places to contain quartz veins with pyrite, or to be impregnated with pyrite along fracture zones. One of the latter occurrences has been located as a mineral claim (p. 125).

The granite, quartz diorite, etc. (pp. 74–77), which occupy most of the high mountain area may, at one locality, near the head of Iliamna Bay, and possibly at another, near Kontrashibuna Lake, be the intrusives to which are due the contact-metamorphic developments at the copper lodes. This formation has further interest to the prospector because in it on Iliamna Bay a pyritiferous fracture zone, rumored to contain a little gold, has been found, and, furthermore, because there are copper-bearing quartz veins in it near Knutson Bay on Iliamna Lake.

Small porphyry dikes were seen on Iliamna and Cottonwood bays, at many points on Iliamna Lake, and at the southern end of Lake Clark. They cut the greenstone, granite, and the porphyries and tuffs. At nearly every dike which was studied the country rock is impregnated with pyrite. So constant is this association that the presence of finely disseminated pyrite was regarded in the field as a reliable indication of a near-by dike, which in most places was actually found. It is not known that any of the pyritiferous zones of this class carry valuable minerals, but, nevertheless, these dikes have evidently contributed toward the mineralization of the region, and they may yet prove to be of importance as a guide to the discovery of valuable deposits.

The unaltered Mesozoic formations of Cook Inlet (Tuxedni sandstone, Chinitna shale, Chisik conglomerate, and Naknek formation), described on pages 59–74, can not be expected to contain ore deposits. They are, however, the locus of the oil seepages described on pages 126–130, which some years ago attracted a good deal of attention.

The Tertiary sediments, which in adjoining regions of Alaska contain important coal and lignite beds, are very meagerly developed in this region (pp. 77–82), and are without coal. The Tertiary here consists chiefly of basaltic volcanics, which so far as known are devoid of mineral wealth.

The Quaternary sands and gravels have on a few streams yielded sufficient placer gold to incite a few men to further search (p. 126).

Broadly speaking, it may be said that three rather definite loci of mineralization have been found in this region—limestones at or near the contact of igneous rocks; greenstones, in which there are mineralized quartz veins; and granite or granodiorite, in which there are mineralized quartz veins and also pyritized fracture zones. Pyritized fracture zones, some of which are also quartz healed, occur in various other rocks, chiefly in the volcanic rocks.

The most promising of the present locations are those in the limestones. Though generalization regarding ore occurrence in this region is hardly warranted by what is known of the few prospects so far located, yet it is perhaps indicated that the limestone belts, and especially the contacts of the limestones with the greenstones and the granites and granodiorites, will be the more fruitful fields for prospecting. The larger of the known copper deposits and the silver-bearing lead and zinc lode are restricted to the limestones. These limestones, it should be noted, have not a very wide distribution, but they have not been prospected throughout their known extent. It seems probable, from such data as are at hand, that some of the mineralization of the limestones is genetically related to the intrusion of igneous rocks, at some places of granites or granodiorites, at another of diorite or diabase altered to greenstone, and at another place perhaps of andesitic porphyries.

One of the purposes of this paper is to furnish the knowledge of this region thus far gained which may serve as a guide to further prospecting and development of its mineral resources. The geologic formations above enumerated have been separately delineated on the map and their areal and structural relations are discussed in preceding sections of this report. In using this report, however, it must be recognized that the work upon which it is based was a reconnaissance, and that therefore the mapping and the discussion are in many instances generalizations or are inferential. For the most part the extent and distribution of the several formations are probably well indicated, so that the prospector may pick out the areas of those formations which he deems worthy of further investigation because of what has been heretofore learned of them.

DESCRIPTION OF MINERAL DEPOSITS.

COPPER.

OCCURRENCE OF THE ORES.

The copper deposits of this region may be referred to two classes: (1) Chalcopyrite deposits in limestone—(*a*) associated with minerals of contact-metamorphic origin, and (*b*) without evidence of contact-metamorphic origin. (2) Chalcopyrite in quartz veins in greenstone and in granite.

Only the deposits in the limestone have as yet developed any prospective value. These are known at four localities—2 miles west of the head of Iliamna Bay; 9⅗ miles west-northwest of the head of Cottonwood Bay; on Kasna Creek near Kontrashibuna Lake; and at Millet's, on Iliamna Lake, 22 miles west of Iliamna village. At each of these localities the mineralization is in limestone near its contact with an igneous formation. At the last-mentioned place the contact is not exposed and there is no evidence as to its nature. At the other localities there are diorites or diabases intrusive into the limestone. The limestones are metamorphosed by coarse recrystallization of the calcite and the development of garnet, epidote, magnetite, hematite, and quartz, besides the sulphides, pyrite, and chalcopyrite. These developments in general are close to and parallel with the igneous contacts, but from place to place along these contacts they vary considerably in mineral association, in shape, and in size. They are irregular and nonpersistent. In all their features, their geologic position, mineralogy, and outline they have the characteristics of contact-metamorphic deposits.

COPPER MINERALS.

There are only three copper minerals known from this region. Of these chalcopyrite alone is important; the others, malachite and azurite, are scanty in amount and are products of weathering of the chalcopyrite. Some of the iron pyrites associated with the chalcopyrite is cupriferous.

Chalcopyrite.—Throughout the region chalcopyrite ($CuFeS_2$, 34.6 per cent copper) is the ore mineral of the copper prospects.

It is found in limestone accompanied by pyrite, calcite, and quartz. In some limestones that have been affected by contact metamorphism, quartz, epidote, chlorite, pyrite, and calcite, or epidote, calcite, hematite, quartz, and pyrite accompany the chalcopyrite. Here the association with the calcite or part of the calcite, quartz, and pyrite seems to be always more intimate than with the other minerals. In one place in limestone chalcopyrite is associated with garnet, epidote, calcite, and magnetite.

At other localities chalcopyrite is found in veins of quartz cutting granites and greenstones. Two such veins have been reported to carry gold. The only other (primary) mineral in the veins, so far as known, is pyrite.

Malachite.—The green copper carbonate ($Cu_2(OH)_2CO_3$, 57.5 per cent copper) forms thin crusts on the ores and is a very prevalent stain on the copper minerals and country rock, not only at the prospects, but also where quantities of copper sulphides too small to attract notice of themselves are present, as in the greenstone bluff just west of the mouth of Tlikakila River.

Azurite.—The blue copper carbonate ($Cu_3(OH)_2(CO_3)_2$, 55.3 per cent copper) is not commonly found in this region. It was noted as a thin coating on the sulphide ores at Kasna Creek and at Millet's, and in the quartz veins on the prospect 2½ miles below the mouth of Iliamna River.

DESCRIPTIONS OF CLAIMS.

Dutton prospects.—The claims of the Dutton Mining & Development Co. are about 9⅜ miles west-northwest from the head of Cottonwood Bay and about 6 miles south-southwest of Iliamna village. (See fig. 19.) The prospect is reached from Cottonwood Bay by a good trail, 14 miles long, on easy grade. Part of this (about 9 miles) has been made into a wagon road. There is also a steeper 6-mile trail from Iliamna village.

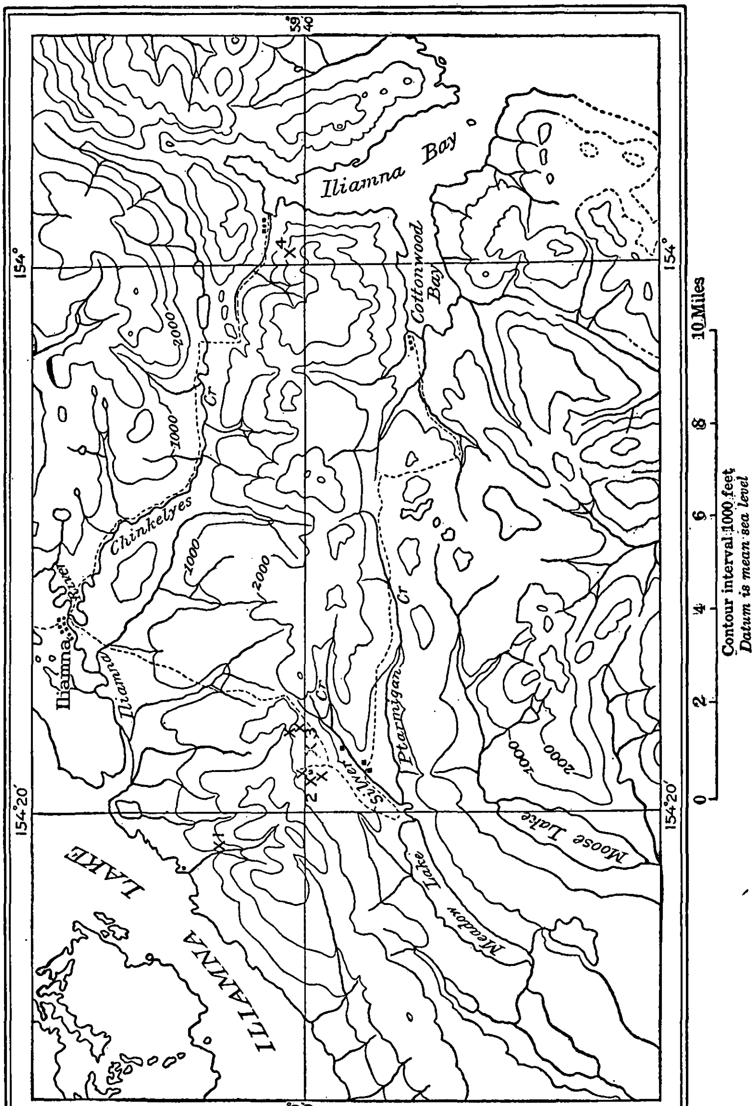


FIGURE 19.—Sketch map showing position of prospects near Iliamna Bay. 1, Durand prospect; 2, Dutton prospect; 3, Duryea prospect; 4, Keyes prospect.

The region is one of bold relief; the neighboring mountain peaks rise abruptly from near sea level to about 4,000 feet. The 12 claims, comprising 203 acres, lie along the flank of one of the higher peaks and extend from a point in a col on the Iliamna village trail, at an elevation of 1,900 feet about 2½ miles southwestward to an elevation of approximately 1,200 feet.

The discovery was made in 1901 by Silas J. Goodro, and the claims were located the following year by the discoverer, Pierce Thomas, and George W. Dutton. The property is now owned by the Dutton Mining & Developing Co. and application has been made for patent. Considerable money was spent on exploratory work, equipment, trails, and buildings during 1904 and 1905, but since then little has been done. The underground workings were inaccessible at the time of the Survey party visit.

The claims are staked along the contact (Pl. II) of limestone with greenstone. This greenstone is an altered igneous rock, originally diabase or diorite. It is a fine-grained rock which in thin section is seen to be composed of plagioclase feldspar, fibrous secondary amphibole (uralite), magnetite, ilmenite, chlorite, epidote, calcite, and quartz. In some areas which are less altered than the greater part of the rock there is a suggestion of original diabase texture.

The limestone, the stratigraphic position of which is described on pages 43–44, is intricately plicated, as is shown in figure 11 (p. 103). The minute folds are closely appressed, stand approximately vertical, and strike parallel to the trend of the limestone outcrops. Within the limestone area there are narrow parallel belts of chloritic schist which seem to be folded or faulted in with the limestone. On the surface the limestone exposures are not continuous, but occur in approximately parallel belts of various widths irregularly disposed. Intervening areas, except for the dikes to be mentioned later, are covered with soil and vegetation. This distribution of the limestones may be the result of folding, which affects them and the associated schists, or of faulting, or very probably of both causes. East of the limestone belt are very dense quartzitic schists which are succeeded farther east by gneisses. A number of small dikes of igneous rock cut the limestone and the greenstone. These dikes are very fine granular porphyritic andesites, very considerably weathered where seen, but not altered to any such extent as the greenstone, and probably are much younger. They were seen both in the limestone near the greenstone contact and along the probable contact of the limestone and greenstone.

The prospective ore bodies of the Dutton claims are included within a zone averaging 200 feet and locally 400 feet in width, which lies along the limestone-greenstone contact and is partly in the greenstone, but chiefly in the limestone. As has been said, the claims are staked on about 2½ miles of the contact, but there are only two areas which seem to have warranted or received considerable development. The larger and principal mineralized area appears, so far as can now be seen, to be about 3,000 feet long; it is included in the length of three claims whose "lode lines" follow the contact, and extends laterally into the three adjoining claims on the southeast. About 1,000 feet farther northeast on the "lode" is the other area, which is largely included within the boundaries of one claim. Ore bodies in these areas which may develop commercial importance will probably be found to be in the form of irregularly distributed bands and shoots.

The mineralization in the greenstone and in some of the less altered dikes is not important in amount or extent. It consists of small, irregular, and discontinuous stringers of pyrite and very little chalcopyrite.

In the limestone area there are pyrite, chalcopyrite, garnet, magnetite, calcite, quartz, epidote, and, much less commonly, chlorite, feldspar, and molybdenite. These are not uniformly developed, but are rather irregularly distributed in bandlike masses paralleling the contact. Garnet and magnetite are not intimately associated with the copper ore. They constitute lenses of nearly pure "garnet rock" or "magnetite rock" and, less abundantly, "garnet-magnetite rock." The magnetite rock is composed preponderantly of minute closely packed crystals of magnetite, with very few small interstices into which they project with crystal outline. The interstices are filled with diopside, fibrous blue-green hornblende, chlorite, calcite, feldspar, and pyrite. The hornblende and chlorite are alteration products of the pyroxene. The pyrite may also be a secondary development in the magnetite rock. It is found with the hornblende and chlorite against which it presents crystal faces. Macroscopically the pyrite seems limited to cracks. The pyrite and feldspar are scarce in the rock.

The garnet rock is made up, in order of relative abundance, of garnets, magnetite, quartz, calcite, and a little pyrite. The order of development seems to be garnet, magnetite, pyrite, quartz, calcite. The garnets are pale brownish-yellow in color and are probably andradite. They range in size from a fraction of a millimeter to 1 centimeter.

The "ore rock" is, on the principal claims, an epidotized limestone containing epidote, calcite, quartz, chalcopyrite, and pyrite. It is made up of fibrous epidote in radial or slightly divergent aggregates and fine granular calcite with some quartz. In this are scattered small cubes of pyrite, for the most part in sharp contact with the epidote and calcite, in some specimens with a thin intervening border of chlorite or calcite. The quartz seems younger than the calcite, being itself without crystal outlines where it touches the epidote, which it appears to surround. The epidote is almost everywhere surrounded by a chlorite fringe which in many places extends into the mass of epidote along cracks, having somewhat the appearance of a secondary product derived from the epidote, but it may be a younger product introduced from without the region of the epidote. The above-described base of the ore rock is interlaced by irregular veinlets, a fraction of an inch to 1 inch in thickness, of quartz and of calcite containing radial or vermicular aggregates of chlorite and chalcopyrite and, in some portions of the ore, also pyrite. This vein calcite and the sulphides are intimately associated. Together they are the youngest constituents in the rock. Much of the vein quartz is strained so as to show undulatory extinction, whereas the vein calcite is not strained and appears in large untwinned grains. Locally this calcite surrounds quartz which has crystal outlines and in some places irregularly interrupts the quartz veins, and in other places separates it from the epidotized rock.

On the claim at the northeast end of the group the "ore rock," as seen on the dump at a shaft, is a schistose limestone composed of calcite and some micaceous minerals. It is not epidotized like the above-described limestone. In this are quartz veins interrupted by veins of pyrite, chalcopyrite, calcite, and quartz intimately intermingled. Pyrite is present in preponderant amount. On this claim molybdenite in minute scattered particles is found in the quartz veins with the iron and copper-iron sulphides, and also as a thin scale on some fractures in the "ore rock." In passing, let it be noted that there is here far too little molybdenite to constitute an ore and that which is present is in too small scales to be concentrated. A surface cut on this claim exposed some small masses, 1 to 2 inches thick, of malachite and iron oxides.

Copper King group.—These claims are about 1⅓ miles west of the head of Iliamna Bay and one-third mile south of the main trail to Iliamna village, at an elevation of from 1,000 to 1,500 feet above tide. They lie on the steep mountain slope. Nine claims were located in 1905 by the late Charles M. Keyes.

Little has been done to develop the property except the digging of shallow pits and cuts in the regular performance of assessment work.

The prospects lie near the contact of hornblende granite and greenstone. Within the area of the former are small areas of crystalline limestone, with a maximum observed thickness of 20 feet, and irregular nonpersistent masses of garnet rock and magnetite rock. The rock is cut by veins of quartz and epidote. The prospective ore is magnetite rock impregnated with chalcopyrite. According to report the ore is rich, but is irregularly distributed in bodies of small size.

Kasna Creek claims.—Several claims were located in 1906 by Charles Brooks and C. von Hardenberg along Kasna Creek, about 1½ or 2 miles above Kontrashibuna Lake. Kasna Creek is a small stream with steep grade. Its upper valley, glaciated and hanging about 1,000 feet above Kontrashibuna Lake, is surrounded by steep and ragged ridges and peaks between 3,000 and 5,000 feet high. One small hole has been opened on the prospect.

At the Shamrock Ledge discovery the prospect is in a belt of limestone about 2,000 feet wide where examined. The western portion is made up of interlaminated fine argillaceous and fine-grained limestone layers striking nearly north (magnetic), with vertical dip. East of this is dense, hard, blue-gray limestone 100 to 200 feet thick. These rocks are abundantly studded with minute pyrite grains, and the whole weathers a deep rusty red. East of this is the ore body. Its exact boundaries are masked by soil, vegetation, and talus. East of the ore body is a crystalline, rose-colored limestone and coarse white marble. The marble east of the "ledge" is much shattered, and a vertically slickensided surface was noted.

The prospective ore body is a zone about 75 feet wide paralleling the strike of the limestone. In this zone are specular and micaceous hematite, chalcopyrite, pyrite, quartz, calcite, and fibrous, radial amphibole. To some extent these minerals are segregated in several parallel bands. There are on the "Shamrock Ledge" at least two bands of hematite, each about 7 to 10 feet wide, consisting almost entirely of aggregates of specular hematite with a little quartz. Three or four other bands of similar width contain severely shattered, dense, gray limestone, with bunches of amphibole (actinolite?), hematite, quartz, and chalcopyrite. These bands are cut by irregular stringers of chalcopyrite, pyrite, and quartz. There are some stringers of several inches of solid chalcopyrite. Pyrite is not an abundant constituent in any part of the mineralized zone. It was estimated by the writer that the total chalcopyrite content of the "ledge" is under 5 per cent.

There are no oxidized ores or secondary minerals present except a thin surface film of limonite and copper carbonates.

Millet claims.—The claims of O. B. Millet, located in 1906 and thereafter, are on the north shore of Iliamna Lake about 22 miles west of Iliamna village. The four important claims lie along a "ledge" which runs N. 35°–40° W. (magnetic) up a low knoll from a small bight on the lake shore. The property has been developed by seven open cuts each crossing the entire width of the mineralized body.

The prospect is on a fine-grained crystalline bluish-white limestone and parallels the contact of a dark, fine-grained diabase. This contact is not exposed, and therefore its nature is not known. Near the lake shore both diabase and limestone are overlain by a thin capping of tuffaceous porphyries.

The "ledge" is for the most part covered by soil and vegetation. Where it outcrops it is inconspicuous and was detected only because limonite and a very little copper stain distinguished it from the inclosing limestone. From the northern edge of the tuffaceous capping, that is, about 2,500 feet from the lake shore, the "ledge" has been traced for 3,500 feet. Through this distance it approximately parallels the diabase contact at a distance of about 100 or 150 feet. The "ledge" or "ore body" ranges from 22 feet to 42 feet in width. Both walls are crystalline limestone, grayish blue to white, much shattered and healed by white calcite seams. The limits of mineralization are sharply marked. The ore body itself is a dark bluish, more or less coarsely crystallized limestone. It is traversed at intervals of 1 to 8 or 10 feet by fracture zones in which the limestone is intricately shattered, cemented by calcite and sulphides, refractured, slickensided, and recemented. These fracture zones are a fraction of an inch to 1 foot wide. Although very irregular, they have a general trend N. 35° to 40° W. (magnetic) and dips 75° to 90° NE.

The mineralization is by chalcopyrite, pyrite, calcite, and quartz. The sulphides to some extent impregnate the limestone, but in much larger amounts appear with calcite as vein fillings. These veins are broken, intricately crumpled and slickensided. The calcite in them is coarsely recrystallized and the fractures have been refilled by calcite, quartz, and small amounts of sulphides. Ten per cent copper and small values in precious metals are reported to have been obtained from picked samples.

Durand prospect.—Two claims have been staked on the mountain side about 2½ miles below the mouth of Iliamna River and 1 mile from the shore of Pile Bay at an elevation of 1,000 feet. Two shallow prospect pits have been opened on a 10-foot quartz vein, striking N. 80° E. (magnetic) and dipping 45° NE. The surrounding rock is a schistose greenstone. The vein contains fairly uniformly disseminated masses of chalcopyrite and pyrite. Azurite and malachite in small masses were seen in weathered parts of the vein. The hanging wall is impregnated with pyrite for 4 feet from the vein.

A possible extension of this mineralized zone was seen on the opposite side of the mountain 2 miles south of the Durand prospect, where C. E. Giffin noted a 2-foot quartz vein carrying pyrite and a 40-inch vein striking north with high westerly to vertical dip, which contained quartz, epidote, and chalcopyrite. The country rock is greenstone.

Knutson prospect.—This property was not visited by the Survey party. It is reported to be about 2 miles back from the entrance to Knutson Bay on the north shore of Iliamna Lake, at an elevation of 1,300 feet. The ledge is said to be a vein of white quartz 3 to 8 feet wide, slightly and irregularly mineralized with copper ores and gold. The country rock is granite.

A similar but narrower vein is said to parallel the Knutson vein at a distance of one-fourth mile.

SILVER.

OCCURRENCE OF THE ORES.

Silver prospects are known at one locality only. This is on the limestone belt extending southwesterly from Iliamna village on which the Dutton copper prospects are located. The silver claims have been staked on the eastern part of the limestone adjoining the copper claims and are in the aggregate about 2 miles in length. However, but one group of 8 claims, belonging to W. E. Duryea and E. Duryea, has been developed, so that investigation was possible. The following description, therefore, applies only to the Duryea properties.

SILVER-BEARING MINERALS.

Exploration in the Iliamna region has not disclosed any silver minerals except argentiferous galena (the sulphide of lead) and argentiferous sphalerite (the sulphide of zinc), which are also manganiferous and which occur in veins now being prospected for their silver content. Besides these minerals manganiferous limonite and lead-bearing ocher, small amounts of smithsonite (zinc carbonate) and selenite (lime sulphate) are in the weathered parts of the veins. Pyrite is only locally and sparingly developed. Calcite and quartz, in veins which have been crushed, are found near the metalliferous veins, but do not occur as gangue minerals in them.

DESCRIPTIONS OF CLAIMS.

Duryea claims.—The limestone on these claims, which has the general structure indicated in figure 11 (p. 103), has been cut nearly at right angles to its strike by many small vertical dikes, of which 27 were seen which had widths of 3 feet or less. Several larger dikes and irregular masses were also observed, most of which are parallel to the strike of the limestone.

Small masses and nodules of black manganiferous iron oxide have been found at a number of places on the bare limestone surface, and wherever these localities have been explored by test pits argentiferous galena-sphalerite bodies have been found along fissures in the limestone. The fracture zones appear to be vertical. Along them the limestone is brecciated and some pieces are slickensided. It appears from the material collected that the sphalerite, galena, and small amounts of pyrite filled the fractures. To some extent also the limestone is impregnated with these sulphides. As none of the openings have exposed ore below the zone of weathering the sulphides of the examined material are considerably oxidized and the limestone decayed by solution due to surface waters. Consequently it has been impossible to determine whether there has been replacement of the limestone. From the abundance of limonite and the fact that considerable limonite is present with the least weathered galena and sphalerite it seems probable that more pyrite will be found in the unoxidized ore.

Near the eastern margin of the limestones on the Duryea claims the distribution of patches of manganiferous gossan and the exposures in the various test pits seem to indicate that for about 5,000 feet there is more or less persistent mineralization on a fissured zone in the limestone striking about 20° east of north (magnetic) and approximately vertical. A cliff on a tributary gulch of Silver Creek crosses this zone and exposes, through a height of 50 feet or more, much oxidized ledge matter. The width of this zone was not determinable from what was visible at the time of the examination. The owners estimate it at 75 feet. The distribution of other showings on the surface and in the test pits would seem to indicate that there has been mineralization along various fractures or fracture zones.

The owners of these claims report that samples have yielded from 80 to 196 ounces of silver, 0 to $20 of gold, 35 to 50 per cent lead, and 15 to 20 per cent zinc. The black manganiferous gossan, they report, carries 2 to 6 ounces of silver.

Other silver claims have been staked on the same limestone belt, but no ore was seen on the surface and no development work has been done on them.

GOLD.

LODES.

Claims on Iliamna Bay.—Several lode claims have been staked on or near the shores of Iliamna Bay. One of these is on Diamond Point, near the entrance to Cottonwood Bay. The country rock is granite locally intruded by small dikes of porphyry. Several hundred feet to the north and west the granite is in contact with a large mass of greenstone. The supposed ore body consists of a shattered and much weathered zone 4 to 12 feet wide on Iliamna Bay, and apparently 100 feet or more in width on Cottonwood Bay, in which the granite is thoroughly crushed and impregnated with narrow veins and stringers of pyrite. No other sulphides were recognized and no authentic information could be obtained concerning assay values, although it was rumored that $2 per ton in gold had been obtained.

Aukney claim.—This claim was located in 1908, presumably on account of a supposed gold content. It is situated on the south shore of Iliamna Lake, 23 miles from the outlet of the lake.

The rocks as exposed in the lake cliffs consist of tuffs (quartz latite tuff) striking parallel to the shore (northeast) and dipping from vertical to 75° SE. They contain much fine disseminated pyrite which, where oxidized, gives them a bright yellow stain. No sulphides other than pyrite could be recognized, and nothing is known as to what precious metals, if any, are present.

The only work done on the claim is a little blasting on the face of the cliff.

PLACERS.

The effort to discover placers on the drainage tributary to Lake Clark from the north has not met with encouraging results. Prospects have been found on Caribou Creek, a northeasterly tributary to Chulitna River; on Kellet Creek and Ingersol, Lincoln, and Franklin gulches, which are headwaters of Kijik River; and on Portage Creek which enters Lake Clark about 35 miles above the outlet of the lake and which heads against the last-mentioned streams. These streams were not visited by the Survey party, and little information about them was obtained. Two men are reported to have done considerable work on Portage Creek, which netted a few hundred dollars' worth of coarse gold. It was further reported that they found the alluvium to be about 12 feet deep and composed chiefly of large glacial bowlders.

PETROLEUM.

The lowlands on the coast of Cook Inlet, especially between Chinitna and Iniskin bays, have been quite extensively staked as petroleum land and several wells have been drilled. The geology and indications of petroleum in this district have been already described in several reports [1] from which the facts presented below are taken.

SURFACE INDICATIONS.

The surface indications of petroleum in this region consist of seepages or oil springs and the so-called "gas springs." In the seepages the petroleum may be seen oozing from the cracks in the rock or from the soil. A copious seepage was seen on the east shore of Iniskin Bay, about 1,000 feet below the lower cabin, between high and low tide. The flow is more or less intermittent, and is often so strong that the petroleum collects in large blotches on the pool or even covers its entire surface. At one point in this seepage the oil was seen to issue from a crevice in the shale of the upper part of the Tuxedni sandstone.

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[1] Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905, pp. 37–49; Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139.

A number of large seepages are reported to be near the cabin at Oil Bay. From the bottom of one of these the petroleum rose almost continually, the flow varying, however, from time to time, now almost ceasing, now becoming very strong. It is frequently possible to skim several quarts of petroleum from the surface of the pool, as was done for the test recorded on page 129.

About 2 miles west of the beach at Dry Bay is a so-called "gas spring," in which gas of unknown composition rises in a continuous stream of bubbles to the surface of the water. From the north shore of Chinitna Bay both oil and gas springs have been reported, but they were not seen by the writer.

All these seepages and gas springs are on the outcrop of the Tuxedni sandstone. Their structural position is a short distance northwest of the monocline described above (pp. 96–99) as extending parallel to the coast. A broad flat-topped anticline is believed to lie northwest of this monocline, although there is evidence (fig. 7, p. 99) that the structure may be further complicated by the presence of a fault, which marks the northwest edge of the belt of monoclinal dip. The seepages are situated at or very close to the line on which the dip changes from nearly horizontal to steeply inclined. If the fault is present throughout this belt the seepages are probably situated on or near it and are intimately related to it genetically.

Seepages are also reported from the shores of Kamishak Bay, especially on the south shore at Douglas River. The rocks in this region, as far as seen by the writer, are the shales, sandstones, and conglomerates of the Naknek formation. They are horizontal or have very gentle dips over large areas, and this district would seem to be more promising as a prospective oil field than the district in which the drilling was done. This is, however, a difficult place to land machinery, for the bays are all shallow and filled with rocks, while numerous uncharted reefs extend out many miles from shore into Cook Inlet.

DEVELOPMENTS.

Indications of petroleum are reported to have been first discovered in this region about 50 years ago. The first samples are said to have been taken out in 1882 by a Russian named Paveloff. Claims are said to have been staked by Edelman in 1892. His location was near the divide at the head of the creeks entering Oil and Dry bays, and the claims were subsequently abandoned. In 1896 Pomeroy and Griffen staked claims at Oil Bay and during the next year organized the Alaska Petroleum Co., which began work in 1898. The Alaska Oil Co. was organized in 1901 and in 1902 began drilling at Dry Bay.

The first well at Oil Bay was begun in 1898 and is said to have been drilled to a depth of somewhat over 1,000 feet. No log of this well or any very authentic information can be obtained, as the property has changed management several times. It is reported that gas was encountered all the way below 190 feet and that considerable oil was found at a depth of 700 feet. The flow of oil is reported as estimated at 50 barrels per day. On drilling deeper a strong water pressure was encountered, which shut off the flow of oil. The well is now over 1,000 feet in depth and affords a continuous flow of gas, which at times becomes very strong. Attempts have been made to shut off the flow of water and either recover the lost oil or drill deeper, but without success.

A second well, located about a quarter of a mile west of the older one at Oil Bay, was drilled during the summer of 1904. The log of this well is given below.

Record of well at Oil Bay.[1]

	Feet.
Sandstone	200
Shale	120
Oil and some gas	1
Shale (caving)	129
	450

The well was abandoned at a depth of 450 feet because the shale caved so badly.

A third well, located about 250 feet south of the last, was also drilled during the summer of 1904. The general sequence of strata is reported to be the same as in the second well described above, the shale continuing to the bottom of the hole. The well was cased to a depth of 630 feet. Oil and gas were reported at a depth of 770 feet, there being three small oil sands, each 6 to 8 inches thick and 4 or 5 feet apart. The well was estimated at 10 barrels per day. The caving rock was encountered at 830 feet. Work was stopped at a depth of 900 feet at the end of the season. Considerable gas was encountered at various depths, at times the pressure being strong enough to blow the water up in the derrick to a height of 20 feet.[2]

A well at Dry Bay was drilled to a depth of 320 feet in the summer of 1902 without encountering oil. The tools were then lost and the hole abandoned. In August, 1903, a new well was started in close proximity to the first, but not much was accomplished, and work was discontinued a few months later because of an accident to the machinery.

No information is available concerning operations in 1905 and 1906. No drilling has been done since 1906 and the oil camps are now abandoned.

[1] Reported by August Bowser.
[2] Information in this paragraph furnished by August Bowser.

CHARACTER OF THE PETROLEUM.

A sample of the seepage petroleum from Oil Bay was collected by the writer by skimming the oil from the surface of the water where it was continually rising from the bottom of the pool. An effort was made to obtain as much of the fresher oil as possible. Vegetable and earthy impurities were removed by straining through coarse cloth. Water could not be entirely removed. Oil for lubricating purposes at the neighboring wells has been obtained from these pools in this manner.

The fresher oil is dark green. That which has remained on the surface of the pool for some time is dark brown.

The oil has doubtless lost a large part of its volatile constituents. The analyses therefore do not represent the composition which could be expected of the live oil from wells in this region. Such oil would have a lower specific gravity, higher percentage of the more volatile constituents, and lower percentage of the less volatile constituents, residue, and sulphur. It would certainly be better than these samples in all respects, and would resemble them in having a paraffin base, and would doubtless be a refining oil.

This sample was submitted to Penniman & Browne, of Baltimore, who return the following report on their tests:

Tests of sample of seepage petroleum from Oil Bay.

	Per cent.	Gravity (°Baumé).
Distilation by Engler's method:		
Burning oil (distillation up to 300° C., under atmospheric pressure)	13.2	29.5
Lubricating oils (spindle oils) (120 mm. pressure, up to 300° C.)	39.2	22.6
Lubricating oils (120 mm. pressure, 300-350° C.)	19.6	17.9
Paraffin oils (by destructive distillation under atmospheric pressure)	22.4	20.4
Coke and loss	5.6	....
Total	100.00	
Total sulphur	0.098	....
Specific gravity of crude oil at 60° F., 0.9557, or 16.5° Baumé.		
Initial boiling point, 230° C.		

The distillation of the lubricating oils under diminished pressure, corresponding to refinery practice, was carried on until signs of decomposition set in. The resulting residue was unsuitable for making cylinder stock, and was therefore distilled for paraffin oils. These paraffin oils contain a considerable quantity of solid paraffin. It was not practicable to determine the amount of the material with the small amount of oil at our disposal.

The iodine absorption of the oils and distillates has been determined by Hanus's method (solution standing 4 hours), and is here tabulated:

Iodine absorption of oils and distillates from Oil Bay.

	Per cent of iodine.
Burning oil	17.8
Lubricating oil	26.2
Heavy lubricating oil	35.8

These iodine numbers upon the lubricating oils were obtained upon the samples. For comparison, samples of similar oils were obtained from the Standard Oil Co., and the iodine numbers determined as follows:

Iodine absorption of commercial oils.

	Per cent of iodine.
Light distilled lubricating oil (spindle oil)	32.0
Dark lubricating oil (engine oil)	45.4

The burning oils were tested in a small lamp and found to give a good flame. All the oil was consumed without incrusting the wick or corroding the burner.

The oil has a paraffin base, and the products of distillation are "sweet." We are informed that this sample is a "seepage oil." If a sufficient yield can be obtained by drilling, a very suitable oil for refinery purposes may be expected, containing a very much larger quantity of the more desirable lighter products.

NOTES ON THE MULCHATNA REGION.[1]

INTRODUCTORY STATEMENT.

The Mulchatna Valley lies between the valleys of Lake Clark and of Kuskokwim River, as is shown in figure 20. Mulchatna River rises opposite the south fork of the Kuskokwim River, in

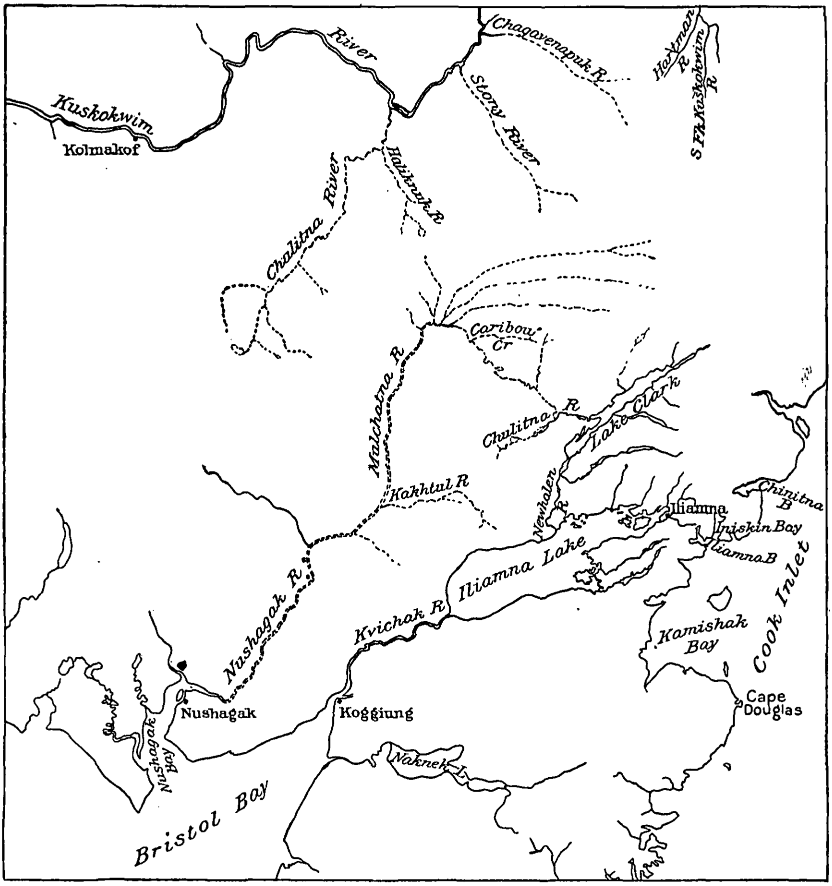

FIGURE 20.—Sketch map showing geographic relation of the Mulchatna district to the neighboring regions.

the mountains north and northeast of Lake Clark, which are the southern extension of the Tordillo Mountains of Spurr. Three

[1] The Mulchatna region has not been visited by Survey parties. The notes here given were obtained from prospectors and traders who are personally familiar with the region.

main branches, known as the Big, the Middle, and the Small Mulchatna, flow southwesterly to a point about 25 miles north of the west end of Lake Clark where they unite to form the main Mulchatna. Thence the stream flows about 60 miles southwest to its confluence with the Tikchik from the northwest, receiving in this interval one important tributary, the Koktalee or Kakhtul. Nushagak River, which is formed by the confluence of the Tikchik and Mulchatna, takes a southwesterly and westerly course for 90 miles to Bristol Bay on Bering Sea. Above the forks of the Mulchatna the country is mountainous with moderate relief; below the forks, it is low with broad gravel-covered, pond-dotted plains and detached hills or mountains.

ROUTES AND SUPPLY POINTS.

Canoes can be taken from Bristol Bay up to the Koktalee and, it is reported, to the forks of the Mulchatna and even beyond in high water. The usual route, however, is from Iliamna, generally from Iliamna Bay on Cook Inlet by portage trail to Iliamna village, thence by boat to Newhalen River and Lake Clark. From Lake Clark the trail is either overland from Portage Bay or by boat up Chulitna River, and thence overland. From Koggiung on Bristol Bay another boat route ascends the Kvichak and crosses Iliamna Lake. There are boats and boatmen for hire at Koggiung, Iliamna, and on Lake Clark, and pack animals or natives are usually available for work on the portages. Supplies of all kinds can be purchased at Iliamna, and the local traders have stocked caches with provisions on Lake Clark and on the Mulchatna. It is reported that the trails are good, that horses can be readily used, and that on the whole the region is more accessible than others in Alaska which have received more attention. During 1910 a company was organized to establish a trading post on the Mulchatna and built a small steamer for service between Bristol Bay and the head of steamboat navigation on Mulchatna River. The ocean steamboat service to Bristol Bay and Iliamna Bay is described on pages 21–23.

It is not known how many men have visited the Mulchatna from time to time. Sixteen were there during the summer of 1909, of whom six planned to remain during the winter, and others were coming in at the time the Survey party was leaving Iliamna. In the summer of 1910 there were some 15 or 20 prospectors in the region. In the fall of 1909 those interested organized the Mulchatna mining precinct and elected a recorder, though there is and has been for some time a United States commissioner with headquarters and recording office at Iliamna, whose district includes the Mulchatna.

PROSPECTS.

On the Mulchatna, from the Koktalee up, and on the Koktalee, also, fine flour gold is found on all the river bars. Bedrock has not yet been prospected along these larger streams on account of ground water. Only summer work has been attempted so far, and as yet no permanent ground frost has been encountered. It is claimed that after May 15 no thawing is required. Above the forks of the Mulchatna, particularly on the middle fork, the gold so far found is coarser, and there is said to be pay. Some of the smaller tributaries carry coarse gold. On one of them two men opened a hole in 1909 and took out about $8 worth of coarse gold.

The prospecting so far has been confined to the present stream beds. The pay is said to be practically all on bedrock, which is reported by the prospectors to be chiefly slate. Limestone and "porphyry" bedrock also are reported. The gravels prospected are generally from 4 to 12 feet deep; one hole is 16 feet deep.

Water is plentiful, and grades are sufficient for sluicing. Timber is abundant on all the streams.

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