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THE NUSHAGAK DISTRICT ALASKA

BY

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THE NUSHAGAK DISTRICT, ALASKA

By J. B. MERTIE, Jr.

ABSTRACT

The Nushagak district, as here defined, is an area of about 14,000 square miles in southwestern Alaska which extends northward from Nushagak and Kvichak Bays for a distance of about 100 miles. This region is drained by the Nushagak River, and the mapped area includes mainly the western part of the Nushagak Valley. Except in its southern part, little was known regarding this district until 1930 and 1931, when a topographic map was prepared by the Geological Survey. The geologic mapping was done in 1931 and 1935.

The district comprises three rather well-defined geographic units. The first of these is known as the Tikchik Mountains, which form the eastern part of a large mountainous province that constitutes the western part of this district. The Tikchik Mountains form a rugged highland that is isolated from the main mountain ranges of southern Alaska and was the site of extensive Pleistocene ice fields. These mountains are bordered on their east side by a system of 12 more or less parallel deep glacial lakes, which now occupy essentially bedrock basins. The second unit, called the Nushagak Hills, is a group of low rounded hills that form the northeastern part of the district. The third unit is the lowland of the Nushagak River and Bay, which comprises the eastern and southern parts of the district.

The geologic sequence consists of sedimentary and igneous rocks, which range in age from Carboniferous to Recent. The Carboniferous rocks consist of Mississippian (?) and Permian sedimentary rocks and Permian volcanic rocks. The Mississippian (?) strata comprise mainly cherty and quartzitic rocks but include also some argillaceous and calcareous beds. The Permian strata consist of fossiliferous limestone. The Permian volcanics comprise basic lavas, which have developed a greenstone habit. A few fossiliferous Upper Triassic rocks have also been recognized, but such rocks appear to constitute only a very small part of the geologic column. No Jurassic rocks are known to be present, but the Cretaceous system is represented in the Tikchik Mountains by a great volume of rocks, which crop out for more than 60 miles normal to their strike. From lithologic and structural evidence, this sequence has been divided into two unconformable groups, which are correlated roughly with the Upper and Lower Cretaceous epochs. In the Nushagak Hills fossiliferous Upper Cretaceous rocks have also been recognized and mapped. The Tertiary system is represented by marine beds of Pliocene age, which occur only along the seacoast. The Quaternary deposits consist of older sedimentary beds, including glacial, glaciofluviatile, and fluviatile deposits, which were laid down during the period of active glaciation; and younger fluviatile and beach deposits, mainly of Recent age. The Carboniferous and Mesozoic sedimentary rocks are intruded by granitic and monzonitic rocks of Tertiary age.

No metalliferous deposits of commercial value have yet been found in the Nushagak district, but the presence of small bodies of granitic rocks suggests that the country rock is probably more or less mineralized. The occurrence of gold in small quantities at widely separated localities materially strengthens this probability. It is concluded that the Tikchik Mountains, because they have been extensively glaciated, are not a favorable site for the occurrence of commercial placers, though lode deposits may be present. The northeastern part of the district and contiguous areas to the north and east are regarded as more favorable sites for prospecting for gold placers.

INTRODUCTION

LOCATION OF AREA

The Nushagak district lies in southwestern Alaska and takes its name from the Nushagak River, which flows southward through this district, draining a considerable part of it. Beginning at Nushagak and Kvichak Bays, which are arms of Bristol Bay, the Nushagak district as the name is used in this report, extends northward for about 140 miles to the headwaters of the Holitna River, a tributary of the Kuskokwim River. The width of the district, as shown on the accompanying topographic and geologic maps, is about 100 miles, so that its area is about 14,000 square miles. The approximate geographic limits of the Nushagak district are meridians 156°40′ and 159°20′ west longitude and parallels 58°40′ and 60°40′ north latitude. Figure 1 shows the location of the Nushagak district in Alaska.

PREVIOUS WORK

EARLY EXPLORATIONS

The mainland of Alaska was discovered by the Russians in the first half of the eighteenth century, but the first white man known to have visited the Bristol Bay region was Captain James Cook,[1] an English explorer, who entered Bristol Bay in July 1778 and gave it the name it now bears, in honor of the Earl of Bristol. Lieutenant Williamson, one of Cook's officers, also named Cape Newenham, the rocky promontory that separates Bristol Bay from Kuskokwim Bay.

After the discovery of Alaska the Russians probably visited much of the southwestern coast, but so far as can be ascertained no permanent settlement was made in the Bristol Bay region during the eighteenth century.[2] In 1818, however, Korasakovsky, probably acting under orders given to him by Baranof, organized an expedition on Cook Inlet, crossed to Lake Iliamna, descended the Kvichak River to Kvichak Bay, the head of Bristol Bay, and followed the coast around to the mouth of the Nushagak River. At this point Korasa-

[1] Cook, James, A voyage to the Pacific Ocean, 1776–1780, 2d ed., pp. 429–433, 1785.

[2] Bancroft, H. H., History of Alaska, 1730–1885, pp. 520–522, San Francisco, Calif., 1886.

kovsky left a part of his men with instructions to build a fort. Returning after a visit to Kuskokwim Bay, he found the fort nearly completed, and named it Alexandrovsk. This station, which was the first settlement established in the Nushagak Bay district, was near the present post office of Nushagak.

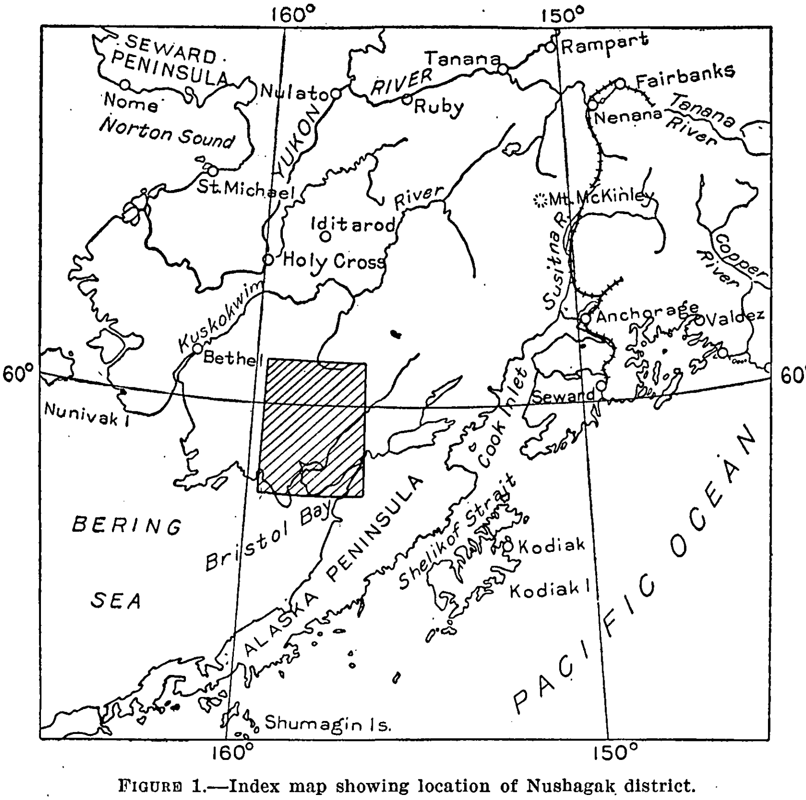

FIGURE 1.—Index map showing location of Nushagak district.

The first survey of the Bristol Bay region was made sometime during the years 1822–24, by an expedition under the command of Khromchenko, Etolin, and Vasilief,[3] who charted the coast from Bristol Bay westward to the mouth of the Kuskokwim. Five years later[4] another expedition, led by Vasilief, departed from Kodiak Island and, after crossing the Alaska Peninsula, entered Nushagak Bay, ascended the Nushagak River to the region of the lakes, and continued northward to the Kuskokwim. This was the first recorded visit of white men to the Tikchik Lakes. In succeeding years other parts of the Nushagak district were doubtless visited by the Russians, but the complete records of these explorations are not available.

[3] Bancroft, H. H., op. cit., p. 546.

[4] Idem, p. 547.

After the purchase of Alaska by the United States, in 1867, this district was also visited by Americans, but only a part of these explorations have been recorded. In 1881 a meteorologic station was established by the Signal Corps of the United States Army at Fort Alexander. C. W. McKay, in charge of this station, is reported to have made numerous trips into the country surrounding Nushagak Bay and on one of these trips to have ascended the Wood River to Lake Aleknagik, the southernmost of the Wood River Lakes. In 1884 McKay was drowned in the Nushagak River, and J. W. Johnson succeeded him in charge of the meteorologic station. Both McKay [5] and Johnson were interested in natural history, and together they sent several hundred specimens of birds and mammals to the United States National Museum in Washington.

A further contribution to the geographic knowledge of this region was made in 1891 by A. B. Schanz, under the sponsorship of Frank Leslie's Magazine. Schanz, accompanied by J. W. Clark, the agent of the Alaska Commercial Co. at Nushagak, and by several natives, made a winter trip from Fort Alexander up the Nushagak, Mulchatna, and Kakhtul Rivers and thence across the divide to Lake Clark. In the same year W. C. Greenfield, compiling information for the eleventh census of the United States, came up the Holitna River from the Kuskokwim, portaged to the Chichitnok, a headwater tributary of the Nushagak, and descended the Nushagak River to Fort Alexander.

LATER SURVEYS

By the end of the nineteenth century the general character of the coastal part of the Nushagak district was fairly well known, for in the meanwhile Bristol Bay had come to be recognized as one of the best sites for red-salmon fishing in Alaska. As the fishing industry grew, settlements of white people had been established at numerous localities from the Alaska Peninsula to Kuskokwim Bay. The inland region, north of Bristol Bay, however, remained comparatively unknown, as it was visited only by occasional traders, trappers, and prospectors.

The first survey of this inland region was undertaken by the Geological Survey. J. E. Spurr,[6] geologist in charge of this expedition, accompanied by W. S. Post, topographer, and six others, made an exploratory trip from Cook Inlet northwestward into the valley of the Kuskokwim River, down that river to Kuskokwim Bay, thence overland to Togiak Bay and eastward along the coast of Bristol Bay to the present site of Naknek,

[5] Osgood, W. H., A biologic reconnaissance of the base of the Alaskan Peninsula: U. S. Dept. Agr., Biol. Survey, North Am. Fauna, No. 24, pp. 25–26, 1904.

[6] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Geol. Survey 20th Ann. Rept., pt. 7, pp. 31–264, 1900.

and on across the Aleutian Peninsula to Shelikof Strait. In the course of the overland part of his traverse, Spurr ascended the Kanektok River to Kagati and Nenevok Lakes, portaged to Togiak Lake, and descended the Togiak River to Togiak Bay. On this part of his trip he saw the west side of the Tikchik Mountains and obtained the first accurate geographic and geologic information regarding this inland mountainous province.

In later years members of the United States Bureau of Fisheries visited the Wood River Lakes, the Nushagak and Nuyakuk Rivers, and the lower Tikchik Lakes, in connection with studies relating to salmon spawning. Thus, in 1908 and 1909 M. C. Marsh,[7] of this organization, visited Lake Aleknagik for the purpose of making counts of the red salmon escaping up the Wood River. In connection with this work Marsh made a sketch map of Lake Aleknagik and also made the first recorded soundings in this lake. Similarly in 1923 A. T. Looff[8] made a trip to the Tikchik Lakes, and as a result of this and other concurrent investigations by the Bureau of Fisheries he published a sketch map of the Nushagak and Nuyakuk Rivers and of the Tikchik and Wood River Lakes. In 1925 and 1926[9] Looff also explored the Snake River and Lake Nunavaugaluk, which discharges into the Snake River. In 1928 F. H. Waskey[10] made an examination of the spawning grounds of the Wood River Lakes system for the Bureau of Fisheries; and as a result of this work, Waskey prepared a sketch map of all four of the Wood River Lakes.

Nushagak Bay and its approaches were first accurately surveyed by the United States Coast and Geodetic Survey. Most of the coast line of Nushagak Bay was mapped, and the bay was sounded for purposes of navigation. The resulting map was published on a scale of 1:150,000, as chart 9050, in 1911.

After Spurr's expedition in 1898, no further work was done in the Nushagak district by the Geological Survey until 1930, but other reports were prepared which dealt with nearby or contiguous regions.[11]

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[7] U. S. Bur. Fisheries Doc. 951, pp. 41–50, 1929.

[8] U. S. Bur. Fisheries Doc. 992, pp. 108–112, 1925.

[9] U. S. Bur. Fisheries Doc. 1023, pp. 259–261, 1927.

[10] U. S. Bur. Fisheries Doc. 1064, pp. 248–251, 1929.

[11] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Geol. Survey 20th Ann. Rept. pt. 7, pp. 31–264, 1900.

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

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Smith, P. S., The Lake Clark-central Kuskokwim region: Geol. Survey Bull. 655, 1917.

Mertie, J. B., and Harrington, G. L., The Ruby-Kuskokwim region: Geol. Survey Bull. 754, 1924.

Harrington, G. L., Mineral resources of the Goodnews Bay region: Geol. Survey Bull. 714, pp. 207–228, 1921.

PRESENT INVESTIGATION

SCOPE AND ITINERARIES

The present report is a description of the geography, geology, and mineral resources of the Nushagak district and is accompanied by a topographic and a geologic map (pls. 1 and 2). The topographic map was made by Gerald FitzGerald, topographic engineer, during the field seasons of 1930 and 1931 but has been amplified from a sketch map of the country around Lakes Chikuminuk, Upnuk, and Nishlik, made by Nelson Sallee, a mining engineer and prospector. The shore line of Nushagak and Kvichak Bays and also the geodetic placement of the map are based upon the work of the United States Coast and Geodetic Survey. The geology of the Tikchik and Wood River Lakes is based largely upon a geologic survey made by the writer in 1935, but the geology of the Nushagak River and the Nushagak Hills is based entirely upon the observations of P. A. Davison, assistant geologist, who accompanied FitzGerald on the expedition of 1931. A brief account of the organization and work of the expeditions of 1930, 1931, and 1935 is given below.

On June 5, 1930, FitzGerald left Anchorage by airplane for Snag Point (Dillingham post office), where he purchased a river boat, an outboard motor, and supplies for part of the summer. With two camp assistants, also hired at Snag Point, he began work at once, and by the end of July he had completed the mapping of Nushagak Bay, Wood River, and the four Wood River Lakes. Returning to Snag Point on August 1, he obtained more supplies and began a traverse of the Nushagak River, which he carried upstream to Koliganek, at the mouth of the Nuyakuk River. On August 24 FitzGerald again returned to Snag Point, and from that time until September 8 he mapped the Snake River, the Weary River, and Lake Nunavaugaluk, after which he returned by airplane to Anchorage.

The members of the expedition of 1931 were Gerald FitzGerald, topographic engineer in charge, P. A. Davison, assistant geologist, and two camp assistants. The party left Anchorage by airplane early in June and, as before, went to Snag Point, where the expedition was outfitted. A large part of the summer's supplies was then transported by airplane to Tikchik Lake, where a cache was made. The party then started from Snag Point in two river boats, with outboard motors, and ascended the Nushagak and Nuyakuk Rivers to Tikchik Lake, where topographic and geologic mapping were begun on June 26. From that time until July 29 Lakes Tikchik, Nuyakuk, and Chauekuktuli and the surrounding country were surveyed, and from July 30 to August 2 the Nuyakuk River was traversed, the survey thus being tied to the work of 1930 at Koliganek.

The party then ascended the Nushagak River to the mouth of the King Salmon River, and from August 7 to August 29 the topographic and geologic mapping of the Nushagak Hills was completed. The Nushagak River, from the mouth of the King Salmon River to Koliganek, was traversed on the return trip. Returning to Snag Point on August 30, the party then visited the three lower Wood River Lakes, in order to give the geologist an opportunity to see this area and also to expand the topographic work of the preceding year. On September 13 the party returned to Anchorage from Snag Point by airplane.

The geologic mapping of the Nushagak was not completed in 1930, and therefore in 1935 the writer was directed to visit the area and to complete this work. The personnel of this expedition consisted of J. B. Mertie, Jr., geologist in charge; R. J. Roberts, field assistant; and two camp assistants. The party with its equipment and half the summer's supplies left Anchorage on June 14 in two Bellanca airplanes and flew directly to Lake Chauekuktuli, where field work was begun on the following day. Gasoline and oil were freighted from Snag Point by airplane, and in the next month, with a folding canvas canoe and a small outboard motor, a geologic map of the country surrounding Lakes Chauekuktuli and Nuyakuk was prepared. Returning after a month, by prior arrangement, one airplane then transported the party and its equipment to Lake Beverly, where a base camp was made. Leaving the cook at this base camp, the writer, together with the other two members of the party, then went to Snag Point by airplane, where a river boat equipped with an outboard motor was hired. The two men then took the boat back to Lake Beverly, and the writer returned by airplane. The rest of the season was spent in conducting geologic surveys in the neighborhood of the Wood River Lakes. The party returned to Anchorage from Snag Point on September 5.

METHODS OF WORK

The topographic survey of the Nushagak district was begun in 1930 from control established on Nushagak Bay in 1902 by the United States Coast and Geodetic Survey. The field scale of the main survey was 1:180,000, and the contour interval was 200 feet. The Nushagak, Nuyakuk, and Snake Rivers and several smaller streams were traversed on a scale of 1:96,000, with a contour interval of 100 feet. The standard methods adopted for reconnaissance plane-table surveys in Alaska were used. Triangulation points on the coast and several sharp mountain tops located by triangulation were plotted on the field sheet. This control was expanded graphically over the Wood River Lake region to include the mountains on the north edge of

Lake Kulik. In 1931 a base line 3,600 feet long was measured on the north side of Tikchik Lake. On this base line three stations were occupied with a theodolite, and four flagged points from 3 to 6 miles distant were observed and the angles measured. The triangles were computed, and the positions obtained were plotted on the field sheet. These computed positions gave several bases from 3 to 8 miles long for the expansion of plane-table control. From this first expansion several of the peaks on the north side of Lake Kulik were located. As these peaks had been located in 1930 from the Wood River Lake control, the Tikchik Lake survey was tied to the Coast Survey triangulation on Nushagak Bay. Solar observations were made for latitude and azimuth on the Tikchik Lake base line.

For the survey of the upper Nushagak River a base line of 2,800 feet was measured about 2 miles below the mouth of the King Salmon River. From the expansion of this base several points near the east end of Tikchik Lake were located, thus tying the Nushagak survey with the Tikchik Lakes control. Ketok Mountain, a prominent landmark 6 miles southeast of Koliganek village, was also located from both the Tikchik base and the Nushagak base. Solar observations for latitude and azimuth were made on the Nushagak base line.

For the river traverse a 14-foot stadia rod was used with the micrometer eyepiece attachment for the alidade. Sights ranged in distance from a few hundred feet to nearly 2 miles. The topographer and rodman traveled in separate boats and traversed from 15 to 40 miles in a day, as the traverse was practically all downstream. Wherever possible a three-point location was made, and every 30 or 40 miles a solar observation for azimuth and latitude. The three main traverses, covering the lower Nushagak below Koliganek village, the upper Nushagak above Koliganek village, and the Nuyakuk River, were tied to Ketok Mountain. The total area mapped on the 1:180,000 scale was 5,000 square miles. The river traverse on the 1:96,000 scale was more than 250 miles.

Geologic observations were made by P. A. Davison in 1931 and by the writer in 1935. Davison, however, was attached to a topographic party, and therefore his observations were of necessity made along a common line of travel, determined for the most part by the exigencies of topographic mapping. The writer, on the other hand, was free to go or to remain at such places as the geologic study demanded and was therefore in a better position for obtaining data at critical localities. Both Davison and the writer utilized the compass, barometer, and notebook for geologic mapping, but the writer had the additional advantage of having a completed topographic map on which to plot results. About 600 specimens of rocks were collected by Davison, Mertie, and Roberts, and many of these have been studied in thin section under the microscope by the writer.

ACKNOWLEDGMENTS

For Mr. FitzGerald, acknowledgment is made herewith to Chester Bakke and Olaf Ophiem, the temporary members of the party of 1930, and to E. J. FitzGerald and Robert Acheson, the temporary personnel of the party of 1931. The writer takes this opportunity to acknowledge with thanks the faithful field services rendered by R. J. Roberts in 1935 and also to thank the other temporary members of the party, E. J. FitzGerald and J. B. Acheson.

The residents of Dillingham and the Wood River Lakes assisted all three of these expeditions in many ways. Special thanks are due to Frank H. Waskey for much local information regarding the whole region; B. H. Polley for information concerning the Wood River Lakes, and adjacent country; and Butch Smith and Fred McGarry for information on the Nushagak and Mulchatna Rivers. Among those residing or temporarily stationed at Dillingham and the Wood River Lakes, the writer wishes to acknowledge courtesies and assistance extended by Mr. and Mrs. A. H. Bradford, Eric Fenno, Hosea Sarber, Ray Smith, and numerous trappers and prospectors. For Mr. FitzGerald, acknowledgment is also made to Noel Wein, of the Alaskan Airways, and for the writer to Messrs. McGee, Neese, and Mills, of the Star Air Service.

A rough draft of his observations was prepared by Mr. Davison. The writer has had the use of this manuscript, together with Mr. Davison's notes and specimens, in the preparation of the present report and has used the information they afford to supplement his own observations. In particular, these records have been utilized in the description of the geography and geology of the Nushagak Valley and the Nushagak Hills, as these areas have not been visited by the writer.

GEOGRAPHY

DRAINAGE AND RELIEF

For descriptive purposes the Nushagak district may conveniently be divided into three geographic units—the lowland of the Nushagak River and Bay, the Nushagak Hills, and the mountainous province of the Tikchik and Wood River Lakes, here designated the Tikchik Mountains. The Nushagak River, the master stream of the district, heads in the Nushagak Hills and flows generally southward to tidewater at the head of Nushagak Bay. A large tributary of the Nushagak, the Nuyakuk River, drains the six northern lakes, or Tikchik Lakes, of the mountainous province; the Wood River drains the four southern lakes, or Wood River Lakes, of the mountainous province; and the Snake and Igushik Rivers drain respectively Lakes Nunavaugaluk and Amanka, southwest of the Wood River Lakes. (See pl. 1.)

LOWLAND OF NUSHAGAK RIVER AND BAY

The Nushagak lowland may be subdivided into two subordinate units—the flat, nearly treeless area around Nushagak and Kvichak Bays and the alluvial flats of the Nushagak River. According to current usage the mouth of the Nushagak River is considered to be directly east of Dillingham, just south of the mouth of the Wood River; but only from Black Point, about 20 miles to the southeast, does the river begin to maintain a continuous downstream current. The effect of the tides, however, is recognized on the Nushagak River as far upstream as the Keefer Cutoff. Similarly, in the Wood River the tides are apparent as far upstream as the lower end of Lake Aleknagik, for at times of very high tide the normal current out of the lake into the Wood River is reversed, and at such times the water level at the lower end of the lake may be raised as much as 8 inches. These effects are due to the fact that the tidal waters, though having maxima of only 19 and 21 feet, respectively, at Clark Point and Dillingham, pile up in the narrow waterways of the lower parts of the Wood and Nushagak Rivers and raise the water levels upstream several feet higher.

Nushagak Bay is a great, shallow tidal embayment, about 20 miles wide where it opens into Bristol Bay, but it narrows to about 2½ miles off Dillingham. From Etolin Point northward there are many shifting channels and shoals in the middle of the bay, with extensive tide flats and shoals along the west side up to Coffee Point. The ship channel lies west of the center of the bay and ranges in depth from 8 fathoms off Coffee Point to about 4 fathoms at Dillingham. The tidal currents are strong, the ebb being the stronger on account of the current from the Nushagak and Wood Rivers. At Dillingham, according to the United States Coast and Geodetic Survey,[12] the mean velocity of the current at full strength is 2.3 knots on the flood and 3.2 knots on the ebb.

The country bordering upon Nushagak and Kvichak Bays is a desolate, nearly treeless, swampy lowland, with the tundra type of vegetation. Along the beach are pearl-gray to dark-gray silts, which form the tidal flats. At some places where the bordering cliffs of alluvial material are close at hand the beach is gravelly. From Cape Constantine to the mouth of the Snake River the land bordering Nushagak Bay on the west is a low, tundra-covered area bordered by silt flats; and the Snake River is little more than a tidal slough from its mouth to Lake Nunavaugaluk. Northeast of the Snake River sand and clay appear along the shores, the eastern border of the foreland ranges from gentle slopes to bluffs 60 to 100 feet high; and in the area back of Dillingham a scattering growth of spruce

[12] United States Coast Pilot, Alaska, 1st ed., pt. 2, p. 242, 1916.

begins to appear. These higher plains of silt, sand, and gravel extend 12 to 15 miles northward to the mountains and eastward to and beyond the Nushagak River. On the east side of Nushagak Bay, however, the foreland rises in gently rolling benches to a height of more than 200 feet, and the village of Nushagak stands on one of the higher parts of this plain. The coast south of Nushagak consists either of gravelly bluffs or of less abrupt declivities farther back from the water, with a silt plain fringing the shore.

The lowland of the lower Nushagak River is about 90 miles long in a northerly direction and 60 miles from west to east. The estuarine part of the river, from Black Point to the mouth of the Wood River, has a length of about 20 miles and an average width of 2 miles. Both sides of this estuary are bordered by dark-gray mud flats that rise only slightly above the level of high tide. These low flats have an average width of 2 miles but wedge out toward Black Point. Treeless, lake-dotted plains of gravel, sand, and clay, ranging from 100 to 250 feet in altitude, lie beyond the mud flats.

Upstream from Black Point the Nushagak River is a moderately swift, shallow stream, which in its tidal reaches is braided with old channels and sloughs from 3 to 10 miles long. From a point about 10 miles east of Black Point and continuing upstream for about 18 miles in an air line the Nushagak flows in two large channels, about 2 miles apart, in which the water is almost equally divided. The eastern of these two channels is known as the Keefer Cutoff. Above this split the river to its source is fairly well confined to one major channel, though numerous small islands, gravel bars, and sloughs occur upstream nearly to the mouth of the King Salmon River. The Nushagak River is navigable at an average stage of water for small boats for more than 250 miles upstream, measured along the course of the river to a point about 30 or 40 miles above the Chichitnok River; and in May and June, when the water is high, a scow capable of handling a field party, its equipment, and about 8 horses could be taken upstream to a point 6 to 8 miles above Ekwok (Hurley's).

The west bank of the Nushagak, from the Iowithla River upstream to a point 10 miles above the mouth of the Mulchatna River, is bordered by an abrupt bluff that ranges from 40 to 200 feet in altitude. This bluff is the eastern limit of an undulating plain, composed of gravel, sand, and clay, which forms the surface of the country between the Nushagak and the Wood River and Tikchik Lakes. The eastern extremities of these lakes show many croppings of hard rock, but the gravel plain nevertheless extends westward to the main hills. This plain is covered with moss and brush, but scattering spruce and poplar occur along the main Nushagak River. Muklung Hills and Kemuk Mountain, with elevations respectively of

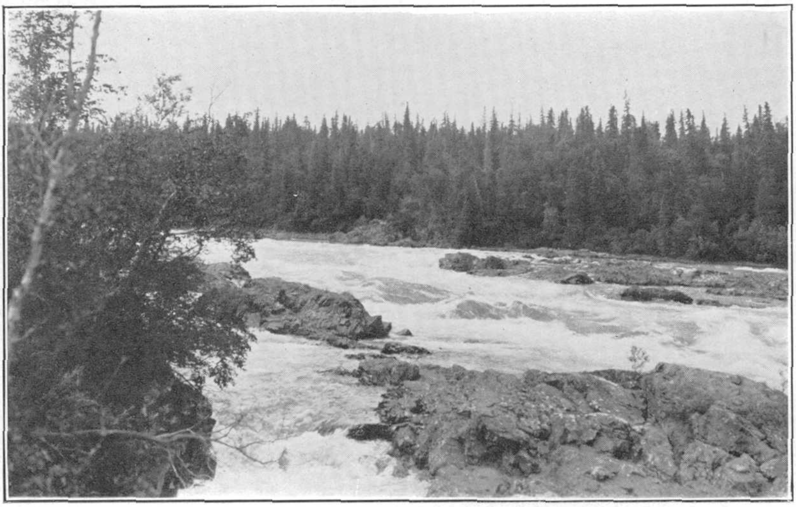
2,800 and 1,800 feet, are two groups of low, rounded hills that rise above this plain. The Kokwok River, a tributary of the Nushagak, drains most of the area between the Muklung Hills and Kemuk Mountain. This stream drains many small beaver lakes and is said to be navigable by canoe for 30 miles above its mouth.

The country adjacent to the east bank of the Nushagak River from Portage Creek northward to the mouth of the Nuyakuk is lower than that west of the river and rises only 5 to 20 feet above the level of the river. The first well-defined bluffs along the river above its mouth appear about 4 miles above the mouth of the Mulchatna River, the largest eastern tributary of the Nushagak. From the Mulchatna southward to Kvichak Bay this low plain is an undrained country dotted with hundreds of small lakes, which constitute an impressive sight from an airplane. About 4 miles south of the village of Inakpuk a low ridge runs northeastward for an undetermined distance, more or less parallel with the Nushagak, and this ridge, which is the first hilly country on this side of the river above its mouth, may be a possible route of entry into the Mulchatna country with pack horses.

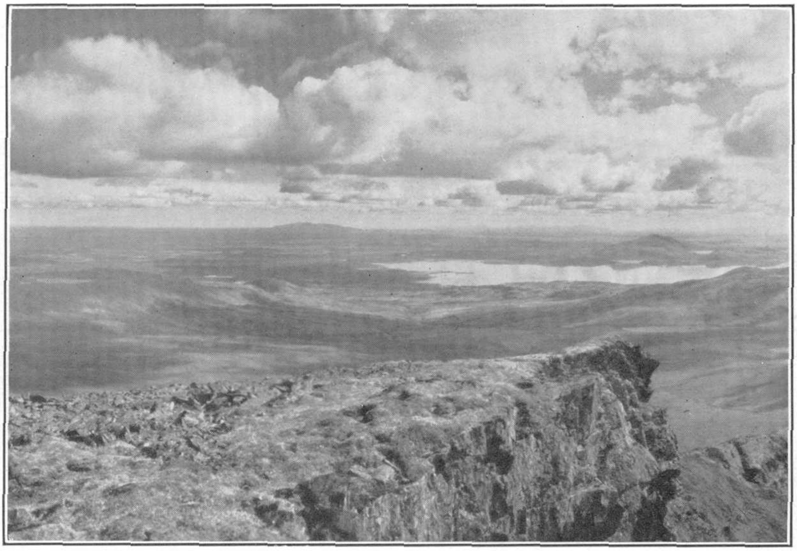
About 5 miles east of the confluence of the Nuyakuk and Nushagak Rivers is a low rounded two-peaked mountain, rising 1,600 feet above the wide expanse of the surrounding plain. This prominence, known as Ketok Mountain, is a prominent landmark when approaching the Tikchik Lakes by airplane from Clark Lake or Iliamna Lake. It marks the southwest end of the divide that separates the drainage basins of the Mulchatna and upper Nushagak Rivers.

The Nushagak River from the mouth of the Nuyakuk upstream flows across a gravel plain of unconsolidated alluvial material and has numerous gravel bars and stretches of shoal water. As a rule the banks are low, but at two places, one just below the mouth of Harris Creek and the other just below the Nushagak Hills, 200-foot bluffs of gravel and sand border the east bank of the river.

The Nuyakuk River is the principal western tributary of the Nushagak. It flows from Tikchik Lake and has a length of about 40 miles, flowing in an easterly direction. This stream is deep and clear and has a moderate current. Just below Tikchik Lake is a short stretch of swift water, and about 3½ miles below the lake is a small waterfall. (See pl. 3, *A*.) A third stretch of swift water occurs 6 miles below the lake. At all three of these places the river cuts bedrock. River boats may be lined through the two stretches of swift water, but a portage of a third of a mile must be made around the waterfall. With these exceptions the river is well confined and is favorable for navigation by small boats. The Nuyakuk River flows through a plain of unconsolidated materials, which at many places have been carved into distinct terraces, from 10 to 100



A. SECOND RAPIDS OF NUYAKUK RIVER, JUST UPSTREAM FROM THE FALLS.



B. VIEW LOOKING SOUTHEAST FROM TIKCHIK MOUNTAIN.

Shows Nushagak lowland. Kemuk Mountain to left of center.

A. MOUNTAINS NORTHWEST OF THE UPPER END OF LAKE CHAUEKUKTULI.

B. VIEW SHOWING NORTHEAST SIDE OF LAKE ALEKNAGIK FROM THE MOUTH OF AGUTOWAK RIVER TO MOSQUITO POINT.
Marsh Mountain to right of center. At left is the deepest part of the lake.

feet above the river. At about 24 miles by river below Tikchik Lake, along the north side of the river, is a low ridge which rises about 500 feet above the river, but other than this the country close to the river shows little relief. The river banks are well wooded with spruce, poplar, and willow. The general appearance of the Nushagak lowland, as viewed from Tikchik Mountain, is shown in plate 3, *B*.

NUSHAGAK HILLS

The Nushagak River heads somewhat to the east of the northeast corner of the mapped portion of the Nushagak district and flows in a general westerly course for about 30 miles (in an air line) to the point where it is joined by the Chichitnok River, a tributary about 20 miles long entering from the north. About 10 miles below this confluence the King Salmon River enters the Nushagak from the west. The King Salmon River has not been surveyed but is believed to have one branch that heads against the Holitna and flows southward and another branch that heads against the Tikchik River and flows eastward. Its maximum length is probably about 40 miles. Between the mouth of the King Salmon River and the mouth of the Nuyakuk River the Nushagak receives several smaller tributaries both from the east and the west.

Above the mouth of the Chichitnok the Nushagak River flows over a gravelly bed and is split into numerous small channels. It is swift in places, and this, together with numerous sweepers, snags, and log jams, makes it a dangerous stream for navigation with small boats. The valley floor is an abandoned flood plain sloping southward and is dotted with hundreds of small lakes. A pronounced change in its course, near the limits of the area shown on the accompanying map, gives rise to a feature known locally as the "Big Bend." Below the mouth of the Chichitnok the Nushagak flows in an open valley with a floor about 2 miles wide until it leaves the hills and flows out onto the gravel plain above described. The Chichitnok River is a swift, clear-water stream that also flows over a gravelly floor. It is characterized chiefly by the fact that it follows closely along the base of the hills on the west side of its valley.

The Nushagak Hills are considered to include all the country drained by the upper Nushagak and its headwater tributaries, but only that part of these hills that is drained by the upper Nushagak and the Chichitnok River has yet been surveyed. The Nushagak Hills, so far as they have been surveyed, are low, smooth hills that are devoid of distinctive landmarks and represent a mature type of topography. The higher summits in the mapped area rise to altitudes of about 2,400 feet above sea level, but the region as a whole perhaps has an average altitude of about 1,500 feet and is covered with the common

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vegetation of the tundra. Recent fires have burnt over much of the area east of the Chichitnok River.

TIKCHIK MOUNTAINS

HIGHLAND AREA

The Tikchik Mountains, as the term is used in this report, constitute the eastern part of a large mountainous province, the southern limit of which lies about 20 miles north of the head of Nushagak Bay. This province is bordered on the north by the rolling hills that lie at the heads of the Holitna and Aniak Rivers. On the east it is delimited by the lowland of the Nushagak River. On the south it is bounded by the nearly treeless coastal plain that lies north of Bristol Bay, but on the west the limits of this province are not yet definitely known. From north to south these mountains extend for 100 miles. The width of this high country, from east to west within the Nushagak district, is about 30 miles, and it is probable that country of the same type extends at least that far to the west of the Nushagak district. It seems reasonable, therefore, to believe that the whole of this mountainous region occupies an area of not less than 6,000 square miles. The general character of the Tikchik Mountains is shown on plate 4, *A*.

The Tikchik Mountains are bordered on the east by a system of more or less parallel lakes. Togiak Lake and perhaps others lie along the western side of this range. All the higher parts of the Tikchik Mountains have been glaciated, and some small glaciers still persist in the central part of these mountains. Except the Coast, Alaska, Aleutian, and other ranges of southern Alaska and the Brooks Range of northern Alaska, these mountains show signs of more extensive past glaciation than any of the other Alaskan highlands. The Tikchik Mountains are therefore of special interest in that they constitute an isolated alpine province of considerable magnitude.

The higher parts of the Tikchik Mountains are composed of sharp, ragged divides, or comb ridges, pinnaclelike peaks or horns, and high alpine valleys that show all the marks of severe and long-continued glaciation. This mountainous province during the glacial epoch was clearly the site of an extensive ice field. Where this range meets the bordering lakes the mountains are lower but still exhibit oversteepened slopes and related features of glacial origin. Still farther east, in the interlake areas, the mountains are less abrupt and their tops are either flat or rounded in outline. At many places these more rounded hills occur as isolated buttes, or groups of several buttes, separated from one another by broad, low alluviated valleys. Similar broad valleys occur at the heads of the various lakes but extend only short distances into the mountains, giving place within short distances to higher valleys of the alpine type. The easternmost spurs of the hills project outward into the lowland of the Nushagak River and finally plunge below the great outwash plain that borders these mountains.

The two highest mountains so far mapped within the Tikchik Mountains are Konarut Mountain and Mount Waskey, both of which are about 5,000 feet above sea level, but it is definitely known that there are still higher peaks farther to the west, in the heart of the range. Near the heads of the lakes the mountains rise to altitudes averaging close to 3,000 feet, but still farther east, in the interlake country, the average height of the hills ranges from 1,500 to 2,500 feet. The lakes that border this highland region and in fact lie within its eastern part have altitudes ranging from 30 to 300 feet. Hence the maximum relief is more than 5,000 feet and the average relief close to 2,000 feet.

LAKES AREA

All of the eastern front of the Tikchik Mountains drains into 12 lakes, which in turn discharge into rivers that flow into Nushagak Bay. The six northernmost lakes are known as the Tikchik Lakes, and these named from north to south, are Lakes Nishlik, Upnuk, Chikuminuk, Chauekuktuli, Nuyakuk, and Tikchik. Lake Nuyakuk, with an area of 66 square miles, is the largest of this group. Tikchik Lake is really the lower end of Lake Nuyakuk, but on account of a bedrock peninsula that almost separates them it has been given a separate name. Lakes Nishlik and Upnuk discharge into the Tikchik River, which empties into Tikchik Lake. Lake Chikuminuk discharges into the Allen River, which empties into Lake Chauekuktuli. Lake Chauekuktuli discharges through a short stretch of swift water into Lake Nuyakuk; and Tikchik Lake, which therefore takes the water from all five lakes, drains into and is the source of the Nuyakuk River.

South of the Tikchik Lakes is another group of four lakes known as the Wood River Lakes, which, named in order from north to south, are Lakes Kulik, Beverly, Nerka, and Aleknagik. These four lakes are connected with one another by short rapids, and Lake Aleknagik, which finally receives the water from the other three, discharges into the Wood River. Of the Wood River Lakes, Lake Nerka is the largest, with an area of 78 square miles. Lake Aleknagik is shown in plate 4, *B*.

Southwest of Lake Aleknagik are Lake Nunavaugaluk and Amanka Lake, discharging respectively into the Snake and Igushik Rivers, both of which enter Nushagak Bay. In the following table the areas of these lakes are given and also, for purposes of comparison, the areas of Lakes Clark and Iliamna:

Areas of lakes in or near Nushagak district, in square miles

Tikchik Lakes:		Wood River Lakes:	
Nishlik	14±	Kulik	24
Upnuk	25±	Beverly	37
Chikuminuk	35±	Nerka	78
Chauekuktuli	31	Aleknagik	34
Nuyakuk	66	Nunavaugaluk	28
Tikchik	25	Amanka	13
		Clark	143
		Iliamna	1, 226

From these figures it will be seen that the Tikchik Lakes have a total area of 196 square miles, that the Wood River Lakes have a total area of 173 square miles, and that all 12 lakes, taken together, have an area of 410 square miles, which is about one-third the area of Lake Iliamna.

Soundings were made in Lakes Chauekuktuli, Nuyakuk, Beverly, Nerka, and Aleknagik, and these lakes in general were found to be deep. On Lake Chauekuktuli a sounding was made 8 miles down the lake from the lower end of Shadow Bay and about 600 yards from the south shore. The depth was 700 feet, which places the bottom of the lake at this point about 376 feet below sea level. On Nuyakuk Lake a sounding was made about 4½ miles east of the promontory that separates Portage Arm from Mirror Bay and about half a mile from a prominent point on the south shore. Here the depth was 930 feet, making the bottom of the lake at this point about 618 feet below sea level. On Lake Beverly two soundings were made. About half a mile east of the lower end of the Silver Horn, near the middle of the lake, the depth was found to be 400 feet, but about half a mile east of the mouth of the Golden Horn a depth of 500 feet was recorded. The fiordlike heads of most of these lakes are also deep, and some of them are as deep as or deeper than the main lakes. Thus, on Lake Nerka, two soundings, about a mile northwest of Elbow Point, each gave a depth of 350 feet; but two soundings in Amakuk Arm, one of them 1 mile and the other 2 miles from the head of the arm, showed depths respectively of 400 and 475 feet. The two main arms of Lake Nerka were found to be relatively shallow, one sounding in the south branch about 2 miles south of Elbow Point giving a depth of only 225 feet. Little Togiak Lake was also sounded in two places, one about a mile above the outlet and the other about midway of the lake. These soundings were 215 and 210 feet, respectively, or nearly as deep as the main part of Lake Nerka. On Lake Aleknagik 18 soundings were made at intervals from one end of the lake to the other, closer together in the western part of the lake. From these observations a longitudinal profile of Lake Aleknagik was prepared, which is shown in figure 2. The greatest depth recorded was 330 feet, about midway of the lake and south of the islands that lie offshore from Jack Knife Ridge. Even between these islands and the mainland shore fairly deep water was found, as one sounding in this narrow channel showed a depth of 110 feet.

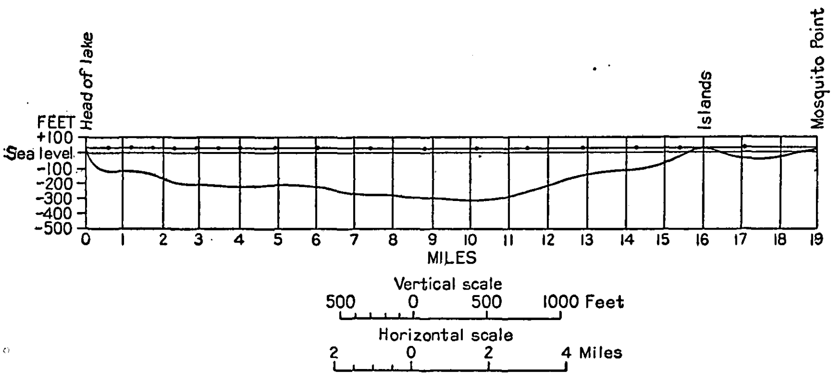


FIGURE 2.—Longitudinal profile of Lake Aleknagik.

For purposes of comparison a tabulation has been made of the deep lakes of the world that occur in glaciated regions.

Deep lakes of glaciated regions

	Depth (feet)	Altitude (feet)		Area (square miles)
		Surface	Bottom	
Scandinavian province (mainly Norway):				
Hornindalsvandet	1,594	167	−1,427	20
Salsvandet i Fosnaes	1,460	43	−1,417	17
Tinnsjøen	1,460	623	−837	17
Mjøsen	1,453	397	−1,056	139
Øvrevandet	1,073	7	−1,066	4
Lundevandet	1,033	134	−899	11
Storsjøen i Odalen	988	426	−562	18
Storsjøen i Rendlen	988	843	−145	20
Tynfjorden	922	207	−715	52
Bredheimsvandet	896	184	−712	9
Ladoga (Russia)	820	16	−804	7,019
Røsvandet	820	1,227	407	73
Totak	820	2,247	1,427	15
Bandak	725	236	−489	24
Hornavan (Sweden)	725	1,394	669	94
Bygdin	705	3,484	2,779	18
Strynsvandet i Nordfiord	650	82	−568	9
Aardalsvandet	610	16	−594	4
Jølstervandet	600	722	122	15
Norsjø	577	49	−528	23
Siredalsvandet	558	131	−427	7
Torneträsk (Sweden)	538	1,081	543	126
Ekern	518	62	−456	11
Scotland:				
Morar	1,018	31	−987	10
Ness	755	52	−703	22
Lomond	623	25	−598	27
Lochy	531	94	−437	6
Ericht	512	1,154	642	7
Tay	509	346	−163	10

Deep lakes of glaciated regions—Continued

	Depth (feet)	Altitude (feet)		Area (square miles)
		Surface	Bottom	
Alpine province:				
Como (Italy)	1,345	650	−695	56
Maggiore (Italy)	1,220	636	−584	82
Garda (Italy)	1,135	213	−922	143
Geneva (Switzerland)	1,017	1,230	213	224
Lugano (Italy)	945	899	−46	19
Brienz (Switzerland)	850	1,846	996	11
Constance (Germany)	827	1,296	469	208
Iseo (Italy)	823	610	−213	24
Thun (Switzerland)	713	1,838	1,125	18
Lucerne (Switzerland)	702	1,434	732	44
Zug (Switzerland)	648	1,367	719	15
Gmundner (Austria)	646	1,385	739	10
Walchen (Germany)	643	2,631	1,988	6
König (Germany)	617	1,975	1,358	2
Atter (Austria)	560	1,538	978	18
Neuchatel (Switzerland)	505	1,400	895	83
Cordilleran province:				
Tahoe (California)	1,645	6,247	4,602	195
Chelan (Washington)	1,419	1,079	−340	58
Adams (southern British Columbia)	1,190	1,380	190	58
Slocan (southern British Columbia)	925	1,772	847	23
Trout (southern British Columbia)	765	2,395	1,630	12
Upper Arrow (southern British Columbia)	>722	1,421	699	97
Mabel (southern British Columbia)	650	----------	----------	----------
Atlin (northwestern British Columbia)	630	2,200	1,570	344
Shuswap (southern British Columbia)	555	1,150	595	77
Lower Arrow (southern British Columbia)	>537	1,378	841	62
Great Lakes province:				
Superior	1,290	602	−688	31,820
Michigan	923	581	−342	22,400
Ontario	774	246	−528	7,540
Huron	750	581	−169	23,010
Great Slave (Northwest Territory)	>656	390	−266	11,583
Seneca	618	444	−174	68
Temiscaming (Ontario)	607	613	6	116
New Zealand and Tasmania:				
Manapouri (New Zealand)	1,460	597	−863	56
Hawea (New Zealand)	1,286	1,060	−226	44
Wakatipu (New Zealand)	1,243	1,001	−242	114
Wanaka (New Zealand)	1,086	971	−115	71
Te Anau (New Zealand)	951	656	−295	139
Waikare-Maona (New Zealand)	846	2,014	1,168	21
Kanieri (New Zealand)	650	423	−227	6
St. Clair (Tasmania)	525	----------	----------	17
Argentina:				
Argentino	>1,063	656	−407	502
Nahuel Huapi	689	2,336	1,647	207
Alaska:				
Nuyakuk	930	312	−618	66
Chauekuktuli	700	324	−376	31
Clark	>606	220	−386	143
Crillon	600	300	−300	2
Beverly	500	100	−400	37
Nerka	475	70	−405	78
Aleknagik	342	34	−308	34

The data shown in this table have been taken largely from the more complete compilation by Halbfass[13] but have been supplemented by some later observations on the Canadian lakes, supplied by the Director of the Geological Survey of Canada. The figures given for the Great Lakes are those published by the United States Coast and Geodetic Survey, instead of those published by Halbfass. The soundings of Alaskan lakes, with the exception of Lakes Clark and Crillon, have not hitherto been published. For greater brevity

[13] Halbfass, Wilhelm, Die Seen der Erde: Petermann's Mitt., Ergänzungsband 40, Heft 185, pp. 1–169, 1922.

this compilation has been restricted to lakes with a depth of 500 feet or more, except for Lakes Nerka and Aleknagik, which, though shallower than 500 feet, were included because the data on them are new. Not all the lakes shown in the table are entirely of glacial origin, though all occur in glaciated regions. The basins occupied by some of the Scottish lakes are due in part to faulting and in part to glacial action. Lake Tahoe, of California, is known to be largely of volcanic origin. With regard to the Tikchik and Wood River Lakes, it should also be noted that the greatest depths of some of these lakes have not been found. On Lakes Chauekuktuli and Nuyakuk, for example, only one sounding was made in each lake; and, although the writer sounded where he believed these lakes were deepest, it is altogether improbable that the deepest places were thus located.

Glacial lakes may be classified in several ways, depending upon their mode of origin. One simplified system of classification is as follows:

1. Glaciotectonic lakes, in the formation of which faulting or surficial warping had some important part.
2. Rock-basin lakes, exemplified by the tarns, or small lakes, found in cirques, and the glint lakes, or larger lakes, occupying bedrock basins in glaciated valleys.
3. Pit lakes, formed by the melting of moraine-covered bodies of ice, thus causing subsidence within a moraine.
4. Barrier lakes, impounded by barriers of moraine, ice, or landslide material. Barrier lakes may be variously subdivided.

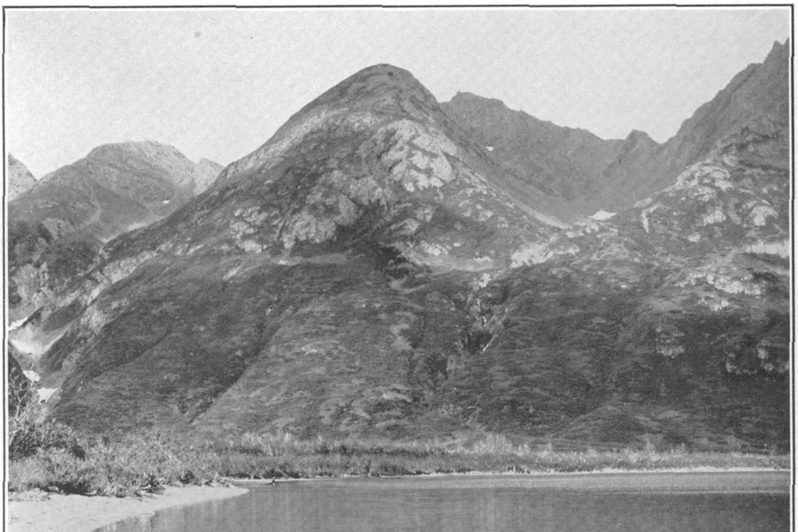
Some of the Scottish lakes are partly of tectonic origin and are therefore glaciotectonic lakes. Most of the Alpine lakes of Europe are barrier lakes. Many of the Scandinavian lakes, however, occupy bedrock basins and are therefore classified as glint lakes. One excellent example of a large lake of this sort is Lake Torneträsk, in Sweden. The Tikchik and Wood River Lakes, as will appear from the following descriptions, are also essentially glint lakes, comparable with many of the Scandinavian lakes.

The soundings and other features observed regarding the Tikchik and Wood River Lakes bring to light some interesting facts. These lakes lie partly within mountainous valleys but also extend outward beyond the mountains into the Nushagak lowland. Thus it might appear that such lakes might be barrier lakes, impounded by unconsolidated deposits of glacial origin, which lie beyond the valleys proper, comparable with Lake Iliamna and also with Lake Constance, Lake Lucerne, and others of the Swiss lakes. Examination of these lakes, however, shows that croppings of hard rock occur intermittently around their lower ends and that the islands and shoals that are so characteristic of these lower ends are bedrock. Moreover, the two main outlets of these lakes, namely, the Nuyakuk and Wood Rivers, cut bedrock at their upper ends, and the Nuyakuk River has two rapids and one waterfall over bedrock. The terraces on all these lakes, however, show that their water surfaces were once much higher than at present, and in these earlier stages they were probably barrier lakes, impounded by morainal material at their lower ends. But the interlake drainage system of the Wood River Lakes and the lowering of the level of Lake Aleknagik, which occurred in postglacial time, have so lowered the water levels in all the Wood River lakes that they now occupy essentially bedrock basins and are therefore best regarded as glint lakes. The same is also true of the Tikchik Lakes, although they have not developed to the same degree the interlake type of drainage system.

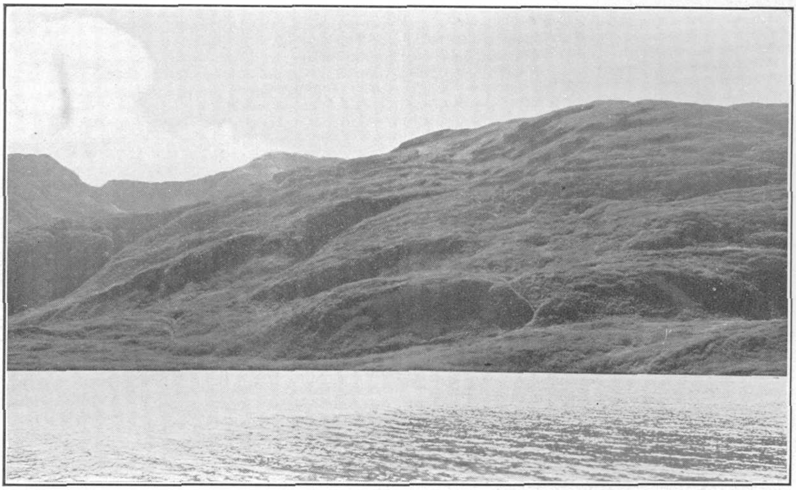
The bedrock constrictions in these lakes are also features of considerable significance. On Lake Chauekuktuli, for example, the head of the lake is separated from the main lake by two bedrock headlands, which almost make Shadow Bay a separate small lake. The same is also true of Amakuk Arm, one of the heads of Lake Nerka; and Little Togiak Lake, the other head of Lake Nerka, is completely isolated from the main lake, being connected with it by a short stream. A still better illustration is the bedrock basin occupied by Lake Elva. This little lake, lying between Amakuk Arm and Little Togiak Lake, occupies a well-defined glacial valley but is connected with Lake Nerka by a stream 3 miles long. Though no soundings were made at the mouths of the Golden Horn and Silver Horn, the same condition is believed to be present there, as the water appears to be shallower than either within the two Horns or in the lake below them. Even on Lake Aleknagik, the shallowest of these lakes, the profile of figure 2 shows a slight rise in the bottom at the constricted part of the lake below the Fish Camp. The constriction in the lower end of Lake Chauekuktuli is of another type, as it appears to have resulted from the dumping of morainal material.

The narrow bodies of water at the upper ends of many of these lakes have some peculiar characteristics. At their heads they end abruptly in a straight line, normal to the bedrock walls, a feature which is shown on the topographic map (pl. 1) and also in plate 5, *A*. These headwater shores are beaches of sand and gravel, deposited by clear-water streams from the mountains. Along the beaches these deposits are clearly foreset beds, with a steep angle of inclination, so that the water becomes very deep a short distance from shore. Bedrock, however, is not far below these beds, as it is exposed at most places as rounded glacier-ridden hummocks a short distance back from the beaches. The walls of these headwater bays are steep, U-shaped, and at many places rough and irregular, due to glacial plucking. The last-named feature is well illustrated in the walls of

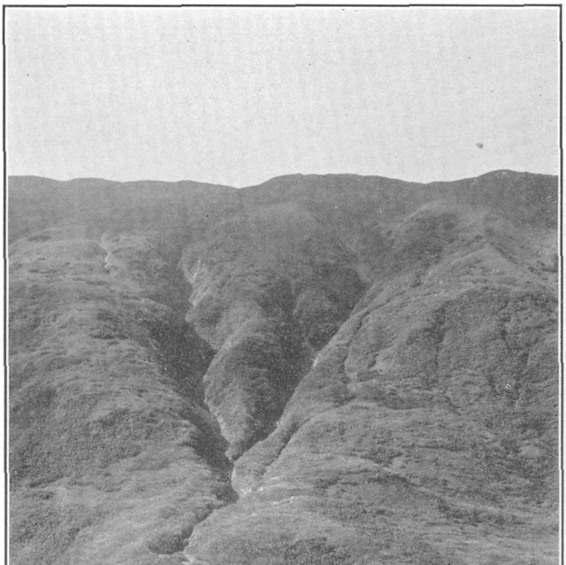
A. HEAD OF AMAKUK ARM, SHOWING TYPICAL SQUARE END OF THESE FIORDLIKE HEADWATER BAYS.



B. GLACIAL CIRQUE IN HANGING VALLEY AT HEAD OF LITTLE TOGIAK LAKE.



A. SOUTHWEST WALL OF LITTLE TOGIAK LAKE, SHOWING ROUGH SURFACE PRODUCED BY GLACIAL EROSION AND PLUCKING.



B. POSTGLACIAL EROSION IN SOUTHWEST WALL OF LITTLE TOGIAK LAKE.

VIEW LOOKING DOWN AMAKUK ARM, SHOWING FIORDLIKE CHARACTER AND STEEP SOUTHWEST WALL.

Little Togiak Lake. (See pl. 6, *A*.) These walls also commonly have cirques or corries high above the water level, forming distinct hanging valleys. This is well exemplified by the cirque at the upper end of Little Togiak Lake (see pl. 5, *B*) and that along the northeast side of Amakuk Arm. The steep walls of these headwater bays also show well the effects of postglacial erosion, by the presence of many small, closely spaced gullies cut in the bedrock. (See pl. 6, *B*.) Below the water level these valley walls are extremely steep. At many places the submerged walls are practically vertical, as far down as one can see in the clear blue-green water, and at some places they are obviously undercut, forming great subaqueous caverns. The water quickly becomes deep down these arms from the headwater beaches, but after the maximum depth is reached the soundings vary little from one another until the lower constrictions are approached, where the bottom gradually rises.

A fiord is ordinarily defined as an arm of the sea that lies in a long, deep glaciated valley, with steep parallel or subparallel sides and with a comparatively flat floor, so that the cross section is trough-shaped or U-shaped. A fiord has also been defined by Johnson [14] as "a partially submerged glacial trough." In this definition "flooded" might perhaps be a better word than "submerged," as it is now a well-recognized fact that glaciers may erode below sea level, so that flooding may subsequently occur without any subsidence. The headwater bays of the Tikchik Lakes, though they are bodies of fresh water, obviously have all the characteristic features of fiords, except that they are not arms of the sea. (See pl. 7.) Their altitude above sea level, however, is so slight, that a coastal subsidence of about 300 feet would make fiords of all of them. For such bays some authors have used the designation "fresh-water fiords," and there seems to be considerable justification for this term.

The main lakes have certain resemblances to their headwater bays but also differ in some important respects. The longitudinal profile of most of them is similar in that the depth increases rapidly down the lake from the bedrock constrictions that form their upper ends, and the maximum depth is soon attained. In the upper third of the lakes this maximum depth does not change materially, but farther down the lakes the depth decreases gradually, and the lower ends of all these lakes are characterized by irregular coast lines, numerous shoals and islands, and, in general, by shallow water. The walls of the valleys that enclose the upper ends of the lakes are much less steep than those of the headwater bays, and at most places there are short forelands between the hills and the lakes and intermittent

[14] Johnson, Douglas, The New England-Acadian shore lines, p. 91, John Wiley & Sons, 1925.

sand or gravel beaches. Farther down the lakes the hills are farther back, the hummocky foreland attains a width of a mile or two, and the beaches become almost continuous. The lower ends of the lakes project outward into lower country, composed either of low, hummocky bedrock hills, such as those surrounding Tikchik Lake, or of outwash deposits that form a thin veneer over the bedrock, as at the lower ends of Lakes Beverly and Nerka.

The valleys that lead from the hills bordering the lakes likewise differ according to their position. Near the upper ends of the lakes these side valleys were the sites of former tributary glaciers and are therefore U-shaped in general outline, but they also show pronounced V-shaped incisions made by postglacial erosion. The streams occupying these postglacial valleys are swift, clear-water streams, which head mainly in cirques, and either cut bedrock throughout their length or else flow in their lower courses over narrow flood plains composed of coarse gravel and boulders. The spurs between these valleys have been truncated by glacial action. In the upper part of the zone of truncation, at altitudes of 1,000 to 2,000 feet, ice-cut terraces are also present at some localities—for example, along the south side of the northern arm of Lake Nerka. Here and there cirques lie along the face of the hills at the rear of the foreland, and some of these in the upper or middle reaches of the lakes are well defined—for example, one in the Frog Mountains, facing north on Lake Nerka. Farther down on the lakes these cirques are less perfect, partly because the ice action was less potent and partly because they have been longer exposed to postglacial erosion and are therefore more dissected. An example of such an imperfect cirque is one along the north side of Lake Aleknagik, near its lower end.

Another interesting geomorphic feature is well marked on Lakes Chauekuktuli, Nuyakuk, and Kulik. From the topographic map, and also from the distribution of alluvium indicated on the geologic map, it will be observed that the valleys occupied by these three lakes are decidedly asymmetric in cross section. The forelands and alluvial deposits occur mainly on the north sides of these lakes, whereas on the south sides, particularly on Lakes Chauekuktuli and Kulik, the valley walls are abrupt and steep. The bottoms of these three lakes are also believed to slope southward, so that the deepest water lies closer to the south sides. These features are probably due to the general southward dip of the rocks, which in this area of the most severe glaciation caused the erosional action of the glaciers to be accentuated along the south walls of the valleys.

Much of the country surrounding the lower ends of the lakes is an undrained region of morainal material, dotted with small lakes. The glacial action is believed to have been most severe in the latitude of

Lakes Chauekuktuli and Nuyakuk, and it is here that the presence of morainal material is most marked. The lowland in the valley of the Tikchik River is an outstanding example of a pitted plain, formed by the dumping of detritus by a melting glacier. Parenthetically, it may be added that the hills that bound Tikchik Valley on the east are believed to mark the eastern limit of active glaciation in this area. The glaciers may indeed have overridden these hills, as they appear to have overridden Tikchik Mountain, but certainly they had little erosive power east of these hills, and it is not believed that they reached the present site of the Nushagak River. In the country closely examined by the writer few of the more distinctive forms of glacial debris were seen, though along the foreland north of the lower end of Lake Chauekuktuli there is a well-defined drumlin-shaped moraine. Similar ridges were observed along the lower end of Lake Kulik.

Gravel terraces, which at places give place to bedrock terraces, are also present along most of the lakes, and near some of the lakes, these terraces are rather conspicuous topographic features. They are composed mainly of sand and fairly well rounded gravel, of the same type now visible on the present beaches. These terraces are discontinuous and occur at levels ranging from 5 to 65 feet above the present lake surfaces and indicate that the lakes formerly stood at higher altitudes than at present. On Lakes Chauekuktuli and Nuyakuk two such terraces, 6 and 20 feet above the water level, were seen at a number of localities, and remnants of less well developed terraces of intermediate height were also observed. Similarly on Lake Kulik a low terrace at 5 feet and a higher one estimated at 15 feet were noted. Between Lake Kulik and Lake Beverly is a water passage consisting of the Wild River, which empties into a little lake known as Lake Mikchalk, which in turn discharges into the Peace River. On the lower end of Lake Mikchalk is a well-defined gravel terrace, 55 feet high, and along the west side of the Peace River is a similar terrace that varies in height from 10 to 35 feet, apparently becoming lower downstream. A low terrace, perhaps 6 or 8 feet high, is well developed at places on Lake Beverly, and on Lake Nerka a similar low terrace and two higher ones, at 25 to 30 feet and 36 feet, were also recorded, as well as a single remnant of a still higher terrace, about 60 feet high. Lake terraces are probably best developed along the lower end of Lake Aleknagik, where four are present, approximately 6, 25, 40, and 65 feet above the present water level. The highest terrace on Lake Aleknagik also continues down the Wood River, where it is well exposed along the west side of the upper part of the river. Farther down the Wood River this higher terrace retreats from the river bank but may be seen here and there, particularly along the west side. In its lower reaches the

Wood River widens rapidly, and 5 or 6 miles below Lake Aleknagik it changes from a clear-water to a muddy stream. Below the mouth of the Muklung River it has a width of a quarter to half a mile, with low, muddy banks, and is a tidal estuary. At the Wood River Cannery, however, two or three gravel terraces are again visible, and Snag Point also is on a high gravel terrace.

No detailed physiographic study of this district has yet been made, so that it is not possible at the present time to correlate these terraces with one another and to work out in detail the postglacial drainage history of the lakes. The major axes of the Tikchik and Wood River Lakes trend east, veering to the southeast toward Nushagak Bay. It seems evident, therefore, that these lakes occupy old preglacial valleys, which drained eastward or southeastward to the Nushagak Valley, and that the direction of flow of the ice was controlled largely by the form of the preglacial valleys, though locally it was apparently controlled in some measure by the structure of the rocks. These ice streams issued from a large ice field that once occupied this mountainous province, and impelled by constant accretion of ice in the highland, they pushed forward and downward into the relatively narrow preglacial valleys and produced by glacial erosion the great overdeepening now evident in the lake basins. East of the present site of the lakes the old preglacial outlets of the valleys were filled by moraine and outwash deposits to form the present Nushagak lowland. By overflow from the lakes, which resulted from subsequent melting of the old glaciers, the water from these bedrock basins sought new outlets, which have resulted in the present intricate drainage system, particularly of the Wood River Lakes.

SETTLEMENTS AND POPULATION

Snag Point, along the west side of the head of Nushagak Bay, is the principal settlement of the Nushagak district, but there are other settlements, canneries, and trading posts elsewhere on Nushagak Bay, on the Nushagak River, and on Lake Aleknagik. Two other settlements, about 5 miles southwest of Snag Point, are known as Dillingham and Kanakanak, but these villages merge into one another to such an extent that they are not separately recorded in the Fifteenth Census. With regard to Snag Point, Dillingham, and Kanakanak, a curious confusion of nomenclature exists. Snag Point has a fourth-class post office, which is known officially as Dillingham. The village of Dillingham has a similar post office, known officially as Kanakanak, and the village of Kanakanak has no post office. According to the Fifteenth Census,[15] Snag Point and Dillingham-Kanakanak are accredited respectively with 85 and 117 persons, many of whom, however, are natives or half-breeds. About 2½

[15] U. S. 15th Census, Population bulletin, 1st ser., Alaska, p. 6, 1930.

miles north of Snag Point, at the mouth of the Wood River, is the Wood River Cannery, where there is a native village that has a population of 55. On the east side of Nushagak Bay there are also canneries and native villages at Nushagak, Clark Point, and Ekuk Spit, with populations respectively of 43, 25, and 37. Another native village called Igushik, with a population of 28, is located at the mouth of Igushik River. Along the Nushagak River are numerous settlements of natives, of which the largest is Ekwok, or Hurleys (population 40), on the west bank of the river, about 6 miles in an air line above the mouth of the Kokwok River. About 23 miles in an airline above Ekwok, on the east bank of the river, is the village of Nunachuak, which in 1931 had a population of about 25 natives. Akokpak village, with a population in 1931 of about 20 natives and a church, is on the west bank of the Nushagak about 3 miles air line upstream from Nunachuak. Koliganek village is at the mouth of the Nuyakuk River, on the southwest bank of that stream. It also has an old Russian church and in 1931 had a population of about 25 natives. In recent years several white families have established homes on Lake Aleknagik. Most of these families have located at or near Mosquito Point, at the lower end of the lake, and they now number 40 or more persons. A post office, called Aleknagik, has recently been established at Mosquito Point.

Naknek, on the northwest side of the Aleutian Peninsula, is also shown at the southwest corner of the Nushagak map, but in this report it is not considered a part of the Nushagak district. According to the Fifteenth Census, Naknek has a population of 173 persons.

Snag Point is the commercial center of the Nushagak district, for here are located two trading companies, one of which also operates a floating cannery off Dillingham during the summer. Another cannery is located at Snag Point, and the proximity of the Wood River and other nearby canneries also brings business to the town. Snag Point has two restaurants and two small motion-picture halls. There are also stores at Dillingham, Nushagak, Clark Point, and Ekwok, and one man maintains a part-time trading post at Nunachuak (new village). Kanakanak is the site of a Government hospital, a radio station operated by the United States Signal Corps, and the Federal jail. The Government hospital has a staff including a doctor and two professional nurses, aided by several native girls. Three radio operators are maintained at the radio station at Kanakanak, and one of these men records the weather conditions for the United States Weather Bureau. For the Snag Point-Dillingham-Kanakanak area there are also a United States commissioner and a United States deputy marshal.

Schools are maintained by the Territory of Alaska at Snag Point, Dillingham, Nushagak, and Mosquito Point. A Federal school for natives is located at Ekwok, on the Nushagak River. The Alaska

Game Commission also has a game warden who makes his headquarters at Snag Point, and during the summer the Bureau of Fisheries has men in this district for patrolling the fishing grounds of Bristol Bay to see that the fishing regulations are obeyed.

TRANSPORTATION AND COMMUNICATION

Bristol Bay is closed to navigation in winter, but during the summer Snag Point and Dillingham are served by steamships from Seward and from Seattle. Five monthly trips, in May to September, inclusive, are made by the steamship *Starr* of the Alaska Steamship Co., from Seward to Snag Point. The power schooner *Tupper*, which makes two summer trips from Seattle to Bethel, also puts in at Snag Point. The freight rate in 1935 from Seward to Snag Point, via the *Starr*, averaged for general merchandise about $17 a ton, plus lighterage and wharfage. Lumber, imported from Seattle, sells for $50 a thousand feet; fuel oil for 10 cents a gallon; and coal for $22 a ton, or $1.25 for a 100-pound sack.

For rapid transit, particularly for passengers, a weekly airplane service is maintained by the Star Air Service between Anchorage and Snag Point, the one-way trip taking 3½ hours, as compared with 10 days on the *Starr* between Seward and Snag Point. The airplane one-way fare is $75. The steamship fare is $70. Other airplane companies operating out of Anchorage also make occasional trips to Snag Point. In summer the Star Air Service has an emergency air mail contract for the weekly delivery of first-class mail only, but second- and lower-class mail is delivered by the steamship *Starr*. In winter, however, all mail is transported fortnightly from Anchorage to Snag Point by airplane. The airplane companies also handle express and other packages, charging 38 cents a pound from Anchorage.

An automobile road, surfaced with gravel, was built in the summer and fall of 1934 between Snag Point and Kanakanak. The intervening country is swampy, so that some stretches of the road had to be planked, but in general road building in this district is favored by the presence of plenty of available gravel. A gravel pit was opened about halfway between Snag Point and Kanakanak for the building of this road. Another automobile road has been planned between Snag Point and Mosquito Point, by way of the Wood River Cannery. Even if all of this road is not built, the stretch between Snag Point and the Wood River Cannery will be most useful, not only for those residing at Wood River, but also for the inhabitants of Mosquito Point, who often find the water trip in small boats from the mouth of the Wood River to Snag Point to be hazardous and unpleasant, on account of adverse tides and winds.

Most of the local travel between Snag Point and outlying points is done either by boat or by airplane. On Nushagak Bay and the Nushagak River many small boats are used. Airplane travel, however, is rapidly becoming a favored mode of transportation, and trappers, prospectors, and cannery people are now using airplanes to an increasing extent, both for local transportation and freighting and for long-distance travel. The airplanes operating in and out of Snag Point are all equipped with pontoons, as there is no landing field at Snag Point, but it is doubtful if a landing field is much desired, as the airplane operators prefer to be on pontoons, because the presence of so many lakes and other bodies of water between Anchorage and Bristol Bay affords a great number of emergency landing fields in case of motor trouble.

CLIMATE

Climatic records have been obtained by the United States Weather Bureau[16] at Dillingham and vicinity since 1881 and at Naknek since 1917. At neither of these places, however, has a continuous record been maintained since the establishment of the stations, but both series of records are adequate for obtaining good averages of the precipitation, snowfall, and mean temperature. The available data up to and including 1933 have been assembled and averaged, and the table given below represents a summary of these data.

Climatic records at Dillingham[1] and Naknek

Month	Mean precipitation (inches)		Mean snowfall (inches)		Mean temperature (° F.)	
	Dillingham	Naknek	Dillingham	Naknek	Dillingham	Naknek
January	1.75	0.53	11.3	7.6	16.3	14.9
February	1.36	1.14	8.9	13.6	16.7	19.1
March	1.86	1.02	13.7	5.2	21.5	21.6
April	1.22	.81	3.9	1.9	29.2	33.2
May	1.62	1.71	2.3	.0	40.9	42.1
June	1.81	1.52	.0	.0	52.0	50.8
July	2.90	3.63	.0	.0	55.2	54.0
August	4.00	4.55	.0	.0	54.5	54.0
September	4.13	3.86	.2	.0	46.8	48.0
October	2.68	2.65	3.2	.2	35.8	35.9
November	1.78	.99	8.9	4.7	24.4	21.7
December	1.41	1.06	13.0	8.8	15.8	15.2
Annual	26.52	23.47	65.4	42.0	34.1	34.2

[1] Record prior to March 1919 was made at Fort Alexander (the present site of Nushagak), 4 miles southeast of Dillingham.

During the field season of 1935 the writer kept a daily record of the temperature, using a maximum and minimum thermometer, which

[16] Summary of the climatological records of Alaska, by sections: U. S. Weather Bur. Bull. W, 2d ed., vol. 3, 1926; also Climatological data, Alaska section, vols. 8–19, 1922–33.

was read morning and evening when it was practicable to do so. For a period of 76 days, from June 17 to August 31, this record is 70 percent complete, and inasmuch as the daily variations in temperature in this district during the summer are not great, the record is believed to give a fair average of temperature conditions in the lake region during the summer days and nights.

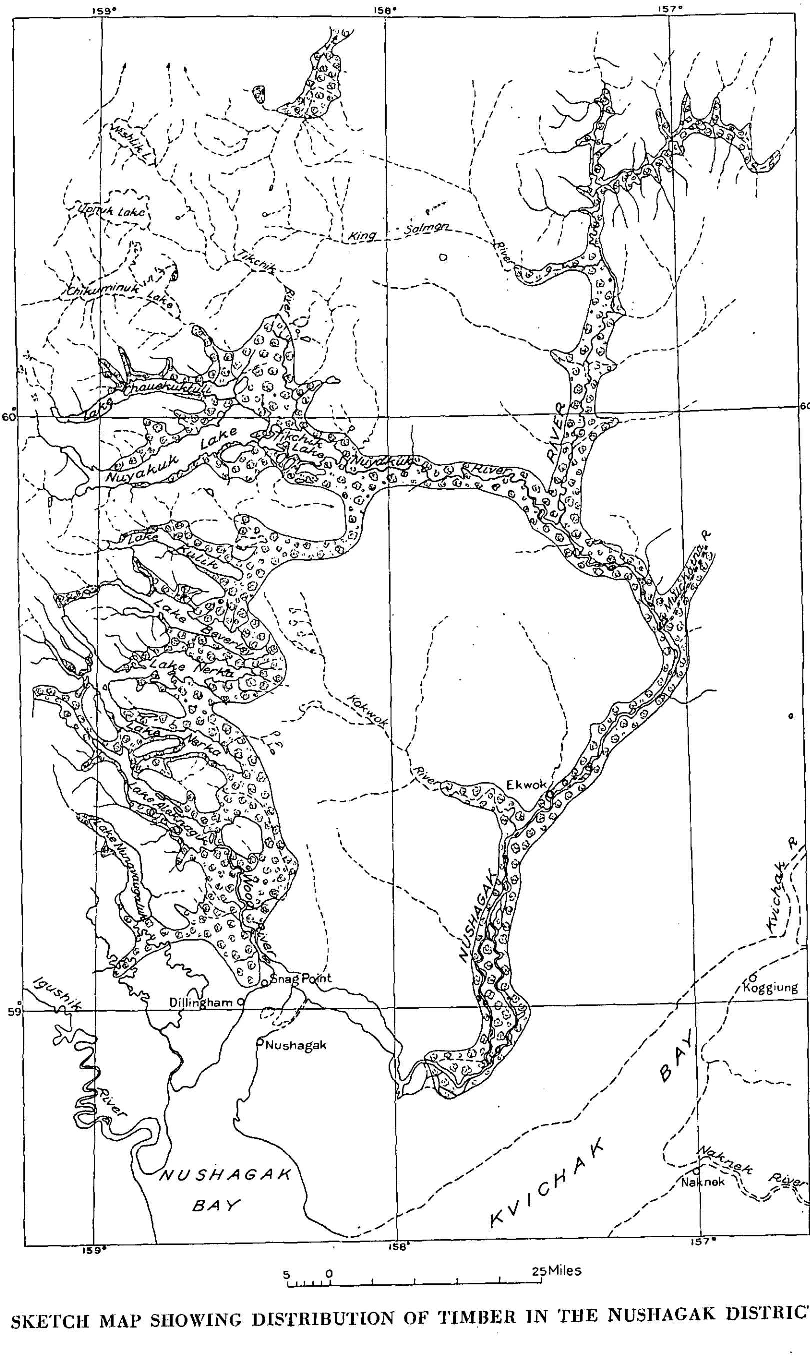
This record is presented below:

Temperature record in Nushagak district, summer of 1935 (° F.)

	June 17-30	July	August	Period
Mean temperature, 7 a. m.	51.6	53.3	51.1	52.0
Mean temperature, 7 p. m.	57.2	57.8	53.8	56.0
Mean maximum, 7 a. m. to 7 p. m.	63.6	62.4	60.5	62.2
Mean maximum, 7 p. m. to 7 a. m.	56.8	57.9	55.0	56.3
Mean minimum, 7 a. m. to 7 p. m.	48.0	52.6	50.1	50.6
Mean minimum, 7 p. m. to 7 a. m.	41.1	46.4	43.9	44.2

From these climatic data it will be seen that the precipitation, though light as compared with that in southeastern Alaska, is more than twice as great as it is in the upper Yukon Valley. Moreover, about half of the precipitation falls in the months of July, August, September, and October, which constitute the rainy season. The smallest precipitation occurs in April. A record kept by the writer during the field season of 1935 shows that there were 30 days in the period from June 17 to August 31 when it rained all or a considerable part of the day. In figure 3 snowfall has been reduced to its equivalent amount of water by the conventional method used by the United States Weather Bureau, regarding 10 inches of snow as the equivalent of 1 inch of water. This method of plotting makes it possible to compare snowfall with total precipitation, and it will be noticed that the curve of melted snowfall in this district though nearly parallel with the curve of precipitation for the months of January, February, and March, lies uniformly below it. Probably most of the precipitation during these three months falls as snow, and therefore the two curves should be nearly identical instead of parallel. This seems to indicate that a conversion ratio of 6½ to 1, instead of 10 to 1, would probably be closer to the truth for this particular district. It is also of interest to learn that the summer period of maximum temperature precedes the period of maximum precipitation by about 6 weeks, and although this is the usual condition in many parts of Alaska, this interval is somewhat longer than the corresponding interval in the upper Yukon Valley.

The curve of mean temperature shows a rather broad, flat peak during the summer season, from the middle of June to the last of August, during which the variation in the mean temperature is slight.



SKETCH MAP SHOWING DISTRIBUTION OF TIMBER IN THE NUSHAGAK DISTRICT

The tabulation of observed temperatures during the field season of 1935 shows the same feature. The summers are cool, with an absence of the occasional warm days of early summer that characterize interior Alaska. Thus, during the summer of 1935 the warmest day noted by the writer was July 3, when the temperature on Lake Nuyakuk rose to 80°; but there were only 8 days when the temperature rose to 70° or more. The summer season is also longer than in interior Alaska, and frost is uncommon after June 1 and before September 1, though during the night of August 12, 1935, the temperature on Lake Nerka dropped to 30°. The greatest extremes of temperature that have been recorded at Dillingham and Nushagak, from 1881 to 1919, are 80° and −54°.

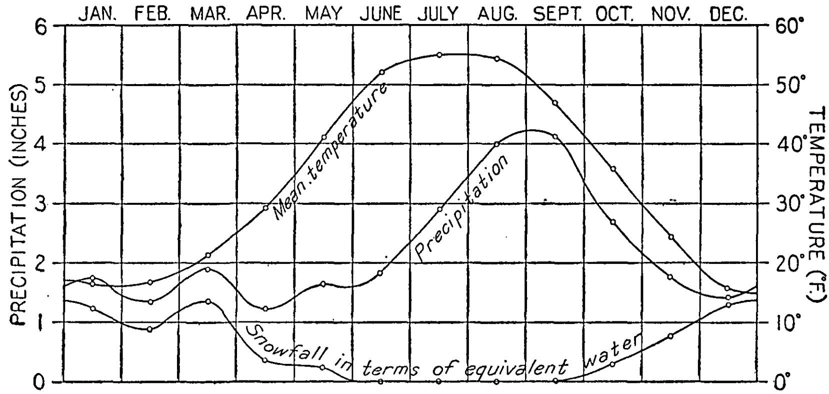


FIGURE 3.—Curves showing mean precipitation, mean snowfall, and mean temperature at Dillingham.

The Wood River breaks up the first or second week in May and freezes in November, but the ice persists on Lake Aleknagik for 3 weeks longer, and sometimes the lake is not entirely free of ice until the middle of June. No data are available for the disappearance of the ice on the Tikchik Lakes, but when the writer landed by airplane on Lake Chauekuktuli on June 14, 1935, the upper third of the lake was still covered by ice, though this ice was honeycombed and rotten and disappeared completely within the next 4 or 5 days. The Nushagak River also breaks up the first or second week in May and freezes anywhere from the first to the third week in November. During the winter thick ice forms along the shores of Bristol Bay and its headwater arms, and this ice, which is dislodged by the tides and wind, mills around in these shallow waterways as dangerous ice floes. Nushagak Bay is therefore closed to navigation about the first of November but is usually reopened by the later part of May, though sometimes not until the middle of June. The same is generally true for Kvichak Bay.

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VEGETATION

Spruce, poplar, and birch are the three common types of trees that grow in the Nushagak district. Plate 8 shows the approximate distribution of timber. The foreland facing on Nushagak and Kvichak Bays is in general timberless, but a scattered growth of spruce begins near Snag Point and continues northward as isolated patches to the lakes. Spruce and poplar grow along the lower shores of all the lakes and on Lake Aleknagik continue to the head of the lake, but the upper arms of the lakes north of Lake Aleknagik are free of timber. Birch is found mainly farther back on the forelands, near the base of the hills. In general, timber in the lake country is approximately coextensive with the distribution of alluvial deposits, where such deposits occur along or close to the lakes. East of the lakes, and also in the low country between the lower ends of the lakes, the area is timberless.

Above the upper limit of timber in the lake region and even on the treeless upper arms of the lakes, a heavy growth of alder and willow brush begins, and continues up to an altitude of about 1,500 feet. Considerable alder and willow also grow in the timber, particularly along stream courses and in marshy depressions. This brush grows to a height of 8 or 10 feet and is so dense that it is hard to traverse on foot, and pack horses could not possibly be led through it without first cutting trails. Also, on account of the rain that occurs in the summer, this brush on the upland is usually wet and affords a continuous shower bath to the traveler.

Below Black Point, on the Nushagak River, only alder brush occurs along the west side of the river. Above Black Point, however, a strip of timber about 3 miles wide grows on the flood plain of the river and continues upstream into the Nushagak Hills. This timber consists mainly of spruce and poplar, with some birch on better-drained parts of the flood plain. The tributaries of the Nushagak, including the Nuyakuk River, are similarly timbered. The heaviest timber in the Nushagak drainage basin occurs in the lower part of the Mulchatna Valley. The Nushagak Hills, except for the main river valleys, are timberless.

Several kinds of wild berries grow in this region, of which the more plentiful and important are the blueberry, the high-bush cranberry, and the low-bush cranberry. The American red currant, though it grows in the region, is not everywhere plentiful. The Arctic red raspberry and a dwarf blackberry, or dewberry, are also found. In a region like this, where fresh fruit is scarce and costly, these wild fruits afford a pleasing and welcome addition to the diet, not only during the summer, when they are picked, but also during the winter as conserved fruits, jams, and jellies.

Bluejoint grass and other kinds of grasses grow luxuriantly in this region. A few of the more common types of grasses are given in the accompanying list of plants.

A collection of flowering plants and some of the lower types of plant life were collected by the writer and his associates in the lake region during the summer of 1935. The plants were submitted to the United States National Museum, where they were examined and determined by specialists under the direction of Dr. W. R. Maxon. The Compositae were determined by S. F. Blake, the grasses by J. R. Swallen, and the remainder of the plants by E. C. Leonard. This collection, which contains 52 genera and 142 species, by no means represents all the plant life that thrives in the lake region, but it does indicate the plants that are more commonly found. The general aspect of this flora is rather different from that of the upper Yukon Valley, as is indicated by the fact that only a third of these plants are the same as those obtained by the writer [17] in a collection of similar size, along the Yukon River near the international boundary. The list of plants collected in 1935 is presented herewith:

Flora of the Tikchik and Wood River Lakes

Pucciniaceae (rust family):
- *Puccinia holboellii* (Hornemann) Rostrup. Northern arabis rust.

Cladoniaceae (Cladonia family):
- *Cladonia uncialis* (Linnaeus) Hoffman. Lichen.
- *Stereocaulon paschale* (Linnaeus) Hoffman. Lichen.

Hypnaceae (Hypnum family):
- *Hypnum cupressiforme* Linnaeus. Feather moss.

Polytrichaceae (haircap family):
- *Polytrichum commune* Linnaeus. Common haircap moss.

Polypodiaceae (fern family):
- *Athyrium americanum* (Butters) Maxon. American lady fern.
- *Dryopteris dilatata* (Hoffman) Gray. Spreading shield fern.
- *Dryopteris linnaeana* C. Christensen. Oakfern.
- *Pteretis nodulosa* (Michaux) Nieuwland.

Equisetaceae (horsetail family):
- *Equisetum arvense* Linnaeus. Field horsetail.

Lycopodiaceae (clubmoss family):
- *Lycopodium clavatum* Linnaeus. Running-pine clubmoss.

Potamogetonaceae (pondweed family):
- *Potamogeton perfoliatus richardsonii* Bennett. Clasping-leaved pondweed.
- *Potamogeton pusillus* Linnaeus. Small pondweed.

Poaceae (grass family):
- *Calamagrostis canadensis* (Michaux) Beauvois. Bluejoint grass.
- *Hierochloa alpina* (Swartz) Roemer and Schultes. Alpine holy grass.
- *Hierochloa odorata* (Linnaeus) Beauvois. Seneca grass.

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[17] Mertie, J. B., Jr., The Tatonduk-Nation district, Alaska: Geol. Survey Bull. 836, pp. 363–367, 1933.

Cyperaceae (sedge family):
- *Carex physocarpa* Presl. Sedge.
- *Carex podocarpa* Robert Brown. Sedge.
- *Carex tolmiei* Boott. Sedge.
- *Eriophorum chamissonis* C. A. Meyer. Russet cotton grass.
- *Scirpus caespitosus* Linnaeus. Tufted club rush.

Melanthaceae (bunchflower family):
- *Veratrum eschscholtzii* Asa Gray. Hellebore.

Liliaceae (lily family):
- *Fritillaria camtschatcensis* (Linnaeus) Gawler. Fritillaria.
- *Lloydia serotina* (Linnaeus) Reichenbach.

Convallariaceae (lily-of-the-valley family):
- *Streptopus amplexifolius* (Linnaeus) De Candolle. Clasping-leaved twisted-stalk.

Iridaceae (iris family):
- *Iris setosa* Pallas. Arctic blueflag.

Orchidaceae (orchid family):
- *Ibidium romanzoffianum* (Chamisso) Daniels. Ladies-tresses.

Salicaceae (willow family):
- *Populus tacamahacca* Miller. Balm-of-Gilead.
- *Populus trichocarpa* Torrey and Gray. Black cottonwood.
- *Salix alaxensis* (Andersson) Coville. Feltleaf willow.
- *Salix barclayi* Andersson. Barclay willow.
- *Salix pulchra* Chamisso. Diamondleaf willow.

Myricaceae (bayberry family):
- *Myrica gale* Linnaeus. Sweetgale.

Betulaceae (birch family):
- *Betula glandulosa* Michaux. Resin birch.
- *Betula occidentalis* Hooker. Western birch.

Polygonaceae (buckwheat family):
- *Rumex acetosa* Linnaeus. Sorrel.
- *Rumex arcticus* Middendorff. Arctic dock.
- *Rumex mexicanus* Meisner. White dock.

Silenaceae (pink family):
- *Arenaria arctica* Steven. Arctic sandwort.
- *Cerastium alpinum* Linnaeus. Alpine chickweed.
- *Merckia physodes* Fischer.
- *Moehringia lateriflora* (Linnaeus) Fenzl. Blunt-leaved sandwort.
- *Stellaria crassifolia* Ehrhart. Fleshy stitchwort.

Nymphaeaceae (waterlily family):
- *Nymphaea polysepala* (Engelmann) Greene. Pond lily.

Ranunculaceae (crowfoot family):
- *Aconitum delphinifolium* De Candolle. Monkshood.
- *Anemone narcissiflora* Linnaeus.
- *Anemone parviflora* Michaux. Northern anemone.
- *Anemone richardsonii* Hooker. Richardson's anemone.
- *Batrachium flaccidum* (Persoon) Ruprecht. Water buttercup.
- *Caltha arctica* Robert Brown. Arctic marshmarigold.
- *Ranunculus reptans* Linnaeus. Creeping buttercup.
- *Thalictrum sparsiflorum* Turczaninow. Few-flowered meadowrue.

Papaveraceae (poppy family):
- *Papaver nudicaule* Linnaeus. Iceland poppy.

Brassicaceae (mustard family):
- *Arabis ambigua* De Candolle. Rockcress.
- *Campe orthoceras* (Ledebour) Heller. Wintercress.
- *Campe planisiliqua* (C. A. Meyer) Heller. Wintercress.
- *Cardamine pratensis* Linnaeus. Cuckooflower.
- *Cardamine purpurea* Chamisso and Schlechtendal. Purple cress.
- *Draba borealis* De Candolle. Northern whitlowgrass.
- *Draba nivalis* Liljeblad. Arctic whitlowgrass.

Crassulaceae (stonecrop family):
- *Rhodiola integrifolia* Rafinesque-Schmaltz. Roseroot.

Parnassiaceae (Parnassia family):
- *Parnassia palustris* Linnaeus. Marsh grass of Parnassus.

Saxifragaceae (saxifrage family):
- *Heuchera glabra* Willdenow. Alum-root.
- *Saxifraga bronchialis* Linnaeus. Saxifrage.
- *Saxifraga nelsoniana* D. Don. Saxifrage.
- *Saxifraga oppositifolia* Linnaeus. Purple saxifrage.
- *Saxifraga serpyllifolia* Pursh.
- *Saxifraga spicata* D. Don.

Grossulariaceae (gooseberry family):
- *Ribes triste* Pallas. American red currant.

Rosaceae (rose family):
- *Dryas octopetala* Linnaeus. White mountain avens.
- *Luetkea pectinata* (Pursh) Kuntze.
- *Potentilla emarginata* Pursh. Arctic cinquefoil.
- *Potentilla fruticosa* Linnaeus. Shrubby cinquefoil.
- *Potentilla monspeliensis* Linnaeus. Barren strawberry.
- *Potentilla palustris* (Linnaeus) Scopoli. Marshlocks.
- *Rubus arcticus* Linnaeus. Arctic raspberry.
- *Rubus chamaemorus* Linnaeus. Mountain raspberry.
- *Sanguisorba sitchensis* C. A. Meyer. Burnet.
- *Rosa nutkana* Presl.
- *Sorbus sambucifolia* Chamisso and Schlechtendal. Mountain-ash.
- *Spiraea steveni* (C. Schneider) Rydberg. Meadowsweet.

Fabaceae (pea family):
- *Astragalus alpinus* Linnaeus. Alpine milkvetch.
- *Astragalus littoralis* (Hooker) Rousseau.
- *Lupinus arcticus* Linnaeus. Arctic lupine.
- *Oxytropis campestris* (Linnaeus) A. De Candolle. Field oxytrope.
- *Oxytropis nigrescens* (Pallas) Fischer. Black oxytrope.

Geraniaceae (cranesbill family):
- *Geranium erianthum* De Candolle. Cranesbill.

Violaceae (violet family):
- *Viola biflora* Linnaeus. Bicolor violet.
- *Viola palustris* Linnaeus. Marsh violet.

Onagraceae (evening-primrose family):
- *Epilobium anagallidifolium* Lamarck. Cottonweed.
- *Epilobium latifolium* Linnaeus. Broad-leaved willow herb.

Haloragidaceae (water milfoil family):
- *Hippuris vulgaris* Linnaeus. Marestail.

Apiaceae (carrot family):
- *Coelopleurum gmelini* (De Candolle) Ledebour. Sea celery.
- *Heracleum lanatum* Michaux. Cow-parsnip.

Cornaceae (dogwood family):
Cornus suecica Linnaeus. Lapland cornel.
Pyrolaceae (wintergreen family):
Pyrola asarifolia Michaux. Liver-leaf wintergreen.
Ericaceae (heath family):
Andromeda polifolia Linnaeus. Bog rosemary.
Arctous alpina (Linnaeus) Niedenzu. Alpine bearberry.
Harrimanella stelleriana (Pallas) Coville. Moss bush.
Ledum decumbens (Aiton) Loddiges. Narrow-leaved Labrador tea.
Loiseleuria procumbens (Linnaeus) Desvaux. Trailing azalea.
Phyllodoce aleutica (Sprengel) Heller. Mountainheath.
Phyllodoce caerulea (Linnaeus) Babington. Purple mountainheath.
Vacciniaceae (blueberry family):
Vaccinium uliginosum Linnaeus. Bog blueberry.
Vaccinium vitis-idaea Linnaeus. Mountain cranberry.
Diapensiaceae (Diapensia family):
Diapensia lapponica Linnaeus. Diapensia.
Primulaceae (primrose family):
Androsace chamaejasme Wulfen. Rockjasmine.
Primula cuneifolia Ledebour. Primrose.
Preimula stricta Hornemann.
Trientalis arctica Fischer. Starflower.
Gentianaceae (gentian family):
Gentiana frigida Haenke. Gentian.
Gentiana glauca Pallas. Gentian.
Menyanthaceae (buckbean family):
Menyanthes trifoliata Linnaeus. Buckbean.
Polemoniaceae (phlox family):
Polemonium acutiflorum Willdenow. Jacob's-ladder.
Polemonium humile Willdenow.
Boraginaceae (borage family):
Mertensia paniculata (Aiton) G. Don. Bluebell.
Myosotis alpestris Schmidt. Alpine forget-me-not.
Labiatae (mint family):
Mentha canadensis L. American wild mint.
Scrophulariaceae (figwort family):
Lagotis minor (Willdenow) Standley.
Pedicularis arctica Robert Brown. Arctic pedicularis.
Pedicularis capitata Adams. Capitate pedicularis.
Pedicularis versicolor Georg Wahlenberg.
Pedicularis verticillata Linnaeus. Whorled-leaved pedicularis.
Veronica wormskjoldi Roemer and Schultes. Wormskiold's speedwell.
Rubiaceae (madder family):
Galium boreale Linnaeus. Northern bedstraw.
Caprifoliaceae (honeysuckle family):
Linnaea borealis Linnaeus. Twinflower.
Sambucus pubens Michaux. Elderberry.
Viburnum pauciflorum Pylaie. Highbush cranberry.
Valerianaceae (valerian family):
Valeriana capitata Pallas.
Campanulaceae (bell-flower family):
Campanula lasiocarpa Chamisso.

Asteraceae (aster family):
- *Achillea borealis* Bongard. Northern yarrow.
- *Antennaria monocephala* De Candolle. Single-headed cat's-foot.
- *Arnica chamissonis* Lessing. Chamisso's arnica.
- *Arnica hyperborealis* Greenman. Northern arnica.
- *Arnica lessingii* (Torrey and Gray) Greene. Lessing's arnica.
- *Arnica nutans* Rydberg. Nodding arnica.
- *Arnica resedifolius* Lessing. Reseda-leaved arnica.
- *Aster sibiricus* Linnaeus. Siberian aster.
- *Erigeron uniflorus* Linnaeus. Arctic erigeron.
- *Solidago lepida* De Candolle. Elegant goldenrod.
- *Solidago multiradiata* Aiton. Northern goldenrod.
- *Taraxacum kamtchaticum* Dahlstedt. Kamchatka dandelion.

ANIMAL LIFE

The larger animals native to this district are caribou, moose, and bear, but none of them are very plentiful. Caribou in small herds were seen by the party of 1935 near Eagle Mountain, south of Lake Nuyakuk; southwest of Akuluktok Mountain, at the head of Lake Nerka; and in the Frog Mountains, between the two branches of Lake Nerka. Moose are scarce in the area of the Wood River Lakes but are more numerous in the country around the Tikchik Lakes; and along the Nushagak River and in the Nushagak Hills they appear to be fairly plentiful, as several were seen by the party of 1931. No bears or signs of bears were seen in the area of the Wood River Lakes, though some have been reported. In the Tikchik Valley and the area around the Tikchik Lakes, however, signs of both black and brown bear were observed, but they are rather uncommon.

Many small herds of reindeer were seen in the Nushagak district. The natives had several herds on the Wood River Lakes and on the Kokwok River in 1930 and 1931. Scattered herds of several dozen were also seen along the Nushagak and Nuyakuk Rivers, and more than a hundred were seen in the valley of the Tikchik River in 1931. These scattered herds were apparently wild and were undoubtedly strays from the native and Lapp herds on the Kuskokwim.

The more common of the smaller animals are beaver, mink, lynx, wolverine, fox, porcupine, land otter, and muskrat, but only certain of these are of much importance as a source of commercial fur. In the lake region mink is the main catch, though some lynx and beaver are also taken. East of the lakes, however, in the Nushagak Valley, and particularly on the Mulchatna, beaver and fox are plentiful and constitute the main source of commercial fur.

Geese and ducks nest in this district and are seen at favored localities. Sea gulls also nest on the islands in the lakes and are very common. On Nushagak Bay and along the larger rivers the

Arctic tern, jager, marsh hawk, kingfisher, whistling swan, and sand-hill crane were noted by P. I. Davison; and in the Tikchik and Wood River Lakes he observed the common occurrence of the golden eagle, bald eagle, crow, magpie, woodpecker, raven, and camp robber, as well as several species of thrush, plover, and loon. Rock and willow ptarmigan and spruce grouse live in this district but do not seem to be plentiful.

The Tikchik and Wood River Lakes afford ideal spawning grounds for salmon, and it is largely for this reason that Bristol Bay and its arms have become the greatest red-salmon fishing grounds in Alaska. The salmon first appear in the lakes in June, but in July and August hundreds of thousands make their way upstream to the lakes to spawn and die, so that by fall the shores of the rivers and lakes are literally lined with dead salmon. The lakes are also the habitat of dolly varden, rainbow, and the large mackinaw trout, though the last-named were seen only in the Tikchik Lakes. As the trout feed upon the eggs of the salmon, the Alaska Game Commission has placed a bounty on each dolly varden that is killed, in order to conserve the salmon. Grayling, whitefish, and pike are also caught in nearly all the rivers and lakes.

Salmon-fishing is the main industry of the Nushagak district. The earliest commercial fishing by whites in the Bristol Bay region was done for salteries, operated by the trading companies, particularly by the Alaska Commercial Co. at Fort Alexander. Later, when the canning of salmon began to be carried on extensively, this region soon became one of the most important fishing grounds in Alaska. At present a large part of the population derives its income directly or indirectly from the fisheries, though considerable trapping is also done. Many salmon are also dried, salted, or canned for local use, and these afford an important source of food for the population of this district.

GEOLOGY

OUTLINE

The rocks of the Nushagak district are predominantly sedimentary rocks, with minor bodies of igneous rocks. On Lakes Chauekuktuli and Nuyakuk, Carboniferous rocks of Permian and pre-Permian age form the country rock, but from Lake Nuyakuk southward to the lowland north of Nushagak Bay a great thickness of Mesozoic rocks is exposed. Along the south shore of Lake Nuyakuk some rocks of Upper Triassic age have been identified, but, for reasons presented below, most of the other Mesozoic rocks to the south are believed to be of Lower and Upper Cretaceous age. The bedrock that forms the Nushagak Hills appears to be dominantly of Upper Cretaceous age. The surface deposits throughout the remainder of the district, and by far the larger part of it, consist of unconsolidated or slightly consolidated deposits, made up of marine Tertiary sediments and Quaternary morainal debris, outwash deposits, and stream-laid alluvium.

The igneous rocks consist essentially of basic volcanic rocks of Carboniferous age and granitic intrusives of Tertiary age. Several varieties of granitic rocks have been identified, and it is considered possible that granitic intrusion took place in two epochs in Tertiary time. There are also a considerable variety of dike rocks, which range in age from Carboniferous to Tertiary and in composition from basic to acidic.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN (?) SERIES

DISTRIBUTION

Rocks that are definitely pre-Permian in age and are believed to belong to the Mississippian series have been found along the shores of Lake Chauekuktuli and in the hills north and south of this lake. These rocks occupy most of the ridge country between Lakes Chauekuktuli and Nuyakuk, except for a narrow strip northeast of Portage Arm, where Permian volcanics and sedimentary rocks occur. North of Lake Chauekuktuli the Mississippian (?) rocks extend for an undetermined distance, as the three northern lakes of the Tikchik group have not been visited.

LITHOLOGY

The rocks of this series consist of chert, cherty grit, and conglomerate; quartzite and quartzitic sandstone, weathering locally to a red ferruginous variety; a group of argillaceous rocks, including shale, slate, and argillite; and limestone and calcareous sandstones and shales. These rocks are cut at places by dikes of basic and intermediate composition. Sheared and semischistose varieties of all these rocks also occur.

No complete stratigraphic section of these rocks can be given, first, because a considerable part of the sequence lies under the lakes, and second, because the slopes of the hills are covered by heavy brush up to an altitude of 1,500 feet. The rocks seen, therefore, are those that crop out along the shores of the lakes and on the upper hill slopes and ridge summits. From the exposures examined, however, it is believed that chert forms a major part of the sequence. These cherty rocks have a considerable variation in color, in the character of the beds, and in their structural features. A large part of the chert is dark gray to nearly black, but light-gray, cream, brown, and red chert was also observed. Much of the chert is massive, with a hackly fracture, so that the thickness and structure of the beds are indeterminate. At some places, however, dark-gray chert occurs in thin beds, but at other localities alternating beds of light- and dark-gray chert were observed to form a banded sequence. Usually the chert is much fractured, and to a considerable extent the resulting cracks are filled with chalcedonic quartz, forming a system of reticulating veinlets. In places, beds of very fine-grained light-colored quartzite are associated with the chert in such a way as to suggest that they have been formed by the recrystallization of chert. Sheared and semischistose phases of the chert were also observed.

To illustrate the dominance of the chert and cherty grits and conglomerates in this series, a partial section is given from the southeast slopes of Ongutvak Mountain, north of the lower end of Lake Chauekuktuli, to the north slopes of the mountain just north of Ongutvak Mountain. The strike and dip in this section are somewhat variable, but in general the rocks dip southward, so that the youngest rocks appear at the south end of the section. On ascending the southeast spur of Ongutvak Mountain, the first exposure above the brush line is shale, cut at one place by a greenstone dike. Chert begins a short distance up the slope from this dike, about 800 feet vertically above the lake, and with an increasing proportion of chert grit and chert conglomerate continues almost to the east summit of Ongutvak Mountain. The chert of this sequence is light to dark gray and is greatly fractured and veined. The gritty and conglomeratic phases consist essentially of subangular to rounded pieces of chert, from some the size of a pinhead up to pebbles 2 inches in diameter, set in a sandy matrix. Up the hill from these cherty rocks, but stratigraphically below them, dark-gray sandy shale and slate, together with some quartzite, appear and continue to the top of the east summit. The chert and chert conglomerate, however, form the west summit of Ongutvak Mountain. North of Ongutvak Mountain both massive and banded chert reappear, but still farther north, on the north slopes overlooking the lower end of the Allen River, a prominent band of fine- to medium-grained recrystallized limestone crops out, followed to the north by more slaty and quartzitic rocks. Still farther north more crystalline limestone occurs, but it is best exposed at the base of the hills to the west.

A possible continuation of this sequence, downward in the section, appears on the ridge west of a creek that enters Lake Chauekuktuli from the north, about 8 miles down the lake from Shadow Bay. On this ridge chert and one band of limestone are poorly exposed in the lower slopes, among some brush-covered irregular knobs. Up the hill, but stratigraphically below these rocks, argillite and intrusive greenstone were found, followed by more chert, which in turn is followed by quartzite and quartzitic sandstone to the top of the spur.

Dark-gray to black massive chert crops out along the steep south shore of Lake Chauekuktuli, southeast of the creek above mentioned, and continues up a spur to the southeast to an altitude of 1,200 feet above the lake. Above this chert, both topographically and stratigraphically, occur quartzites and calcareous sandstones, overlain by calcareous shales. Still farther south black chert reappears and continues to the top of the spur. The general appearance of the country south of Lake Chauekuktuli, where these rocks were seen, is shown in plate 9.

Bands of limestone form the only recognized horizon markers within this sequence of rocks. In addition to the localities already described there is one place along the north shore of Lake Chauekuktuli and another along the south shore, farther up the lake where limestone crops out. From the outcrop on the south shore the limestone was traced eastward for a short distance, and also southeastward intermittently to the Permian limestone.

Along the west side of the creek west of Ongutvak Mountain, one band of limestone is partly exposed in a steep bluff. Here the lower part was found to be a dark-gray massive variety, weathering white. The central part of the limestone band is characterized by thin, discontinuous cherty bands and lenses, interbedded with the limestone. The upper part is an impure limestone, apparently overlain by chert. Finally, the same type of limestone was found along the north shore of Lake Nuyakuk, and also among some islets just offshore, at a locality about 5 miles north of Eagle Mountain and just east of the Permian volcanic rocks. Here the limestone dips northward and is closely associated with chert and chert conglomerate and is itself impure and much silicified. At all these localities the limestone is more or less recrystallized and varies from dark gray to white or cream, the color depending upon its degree of recrystallization. From these descriptions of the limestone, and from its occurrences plotted on the geologic map, it seems probable that two or more well-defined bands lie about midway in the known section of the Mississippian (?) rocks.

STRUCTURE AND THICKNESS

The strike and dip of the Mississippian (?) rocks were observed at numerous localities, but they were found to be highly variable. The strike in particular varies greatly, ranging from N. 20° W. to S. 20° W., but the mean of 27 observations was found to be about N. 77° W. The directions and frequency of these 27 strike observations are shown in figure 4. This mean direction is not exactly that indicated by the general trend of the limestone bands, which seems to run somewhat south of west, though parts of the limestone show an east-west trend. The cropping of the limestone may give a better idea of the general trend of these rocks, but, on the other hand, transverse faults may play an important part in causing the variation between the average observed strike and the regional trend of the rocks. Positive evidence of such transverse faults was observed at one locality along the north shore of Lake Chauekuktuli, about 7 miles below Shadow Bay, where a fault with a sinuous trace but striking in general N. 25° W. and dipping steeply northeast can be seen along the shore and extending out into the hard-rock bottom of the lake. This fault is only a short distance east of a cropping of highly fractured and marbleized limestone along this beach, and it is likely that similar but concealed faults are also present in the near vicinity, marking a zone of transverse faulting. Another transverse fault is indicated in Shadow Bay by the fact that the Permian limestone does not crop out along the south side of Shadow Bay, though it crops out on the north side and in the hills south of Shadow Bay.

Under any interpretation the strike of the Mississippian (?) rocks is roughly east-west, and this direction, or any moderate variation from it, is markedly at variance with the general strike of the Permian limestone and the overlying Permian volcanic rocks, which trend about N. 30° W.

In earlier publications dealing with the geology of interior Alaska the writer has several times stated that no structural unconformity had been definitely recognized within the rocks of the Carboniferous system, nor between the Carboniferous and the overlying Triassic rocks. The sequence of rocks here described, however, shows that a definite structural unconformity exists between the Mississippian (?) and Permian series and raises the question whether similar structural features may not be present at other places in Alaska where the opportunities for structural observations are less favorable.

About 76 percent of the observations of structure in the Mississippian (?) rocks indicate a southward dip that ranges from 20° to 90°. The remainder show a northward dip with a similar range in magnitude. If the southward or dominant dips are regarded as positive and the northward dips as negative numbers, their algebraic sum is found to be about 20° S., which may represent roughly the general tilt of this whole sequence of beds. That is, the folding is such that if no faults were present a stratigraphic section of about 1,800 feet would be exposed for every mile traversed across the strike of this series in the area immediately north and south of Lake Chauekuktuli. Faulting, however, is known to have occurred in

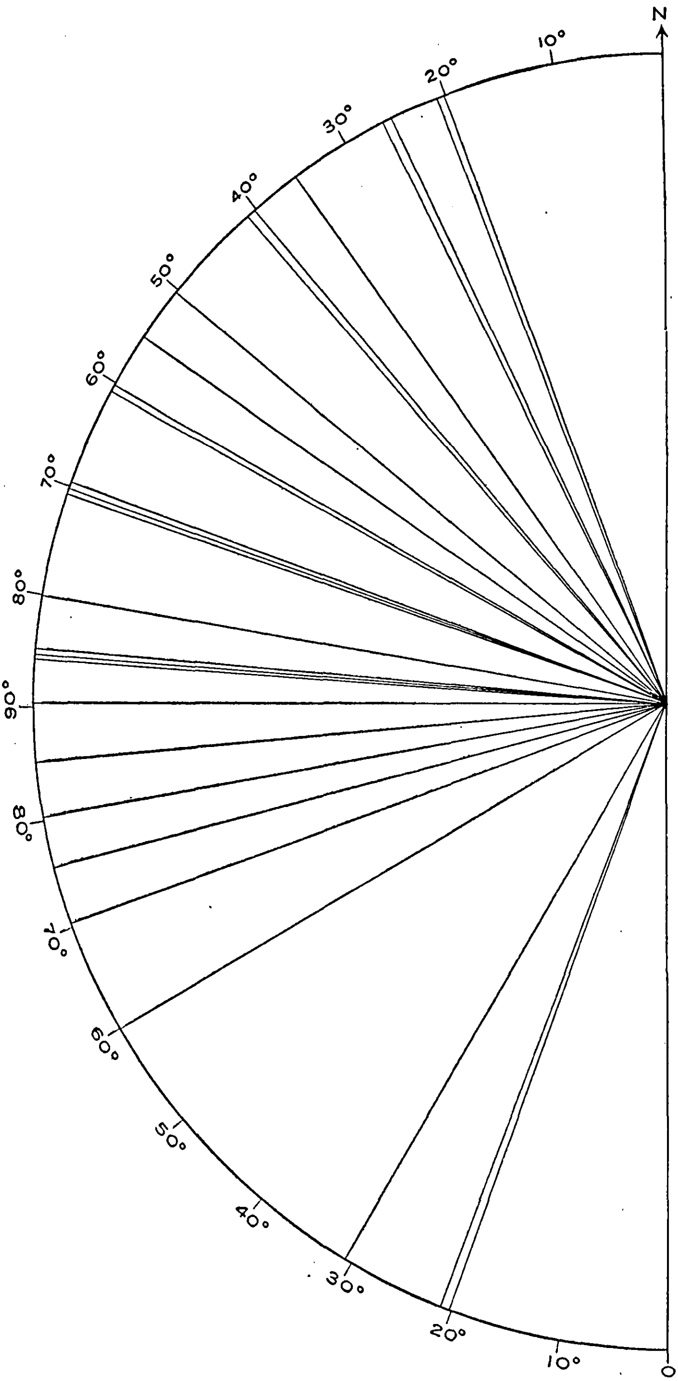

FIGURE 4.—Directions of strike observed in Mississippian (?) rocks.

these beds, though its effects are at present indeterminate. This, together with the fact that some of these rocks adjacent to Lake Nuyakuk have not been studied and the additional fact that the northern limit of the Mississippian (?) series has not been recognized, makes it impossible to give any definite statement regarding the thickness of these rocks; but it seems probable that several thousand feet may be present.

AGE AND CORRELATION

No fossils have been found within the so-called Mississippian (?) sequence, so that on direct paleontologic grounds its age is indeterminate. The structure of these rocks, however, shows that they lie unconformably below the Permian limestone, so that they are definitely pre-Permian in age. That they are not Pennsylvanian cannot be demonstrated, but this conclusion is indicated by the facts that these rocks do not appear to be of terrigenous origin and that marine Pennsylvanian rocks are practically unknown in Alaska, according to the many fossil determinations that have been made by G. H. Girty, of the Geological Survey. It is therefore inferred that these rocks were laid down either during the Mississippian epoch or earlier. Devonian rocks occur at many places in interior and northern Alaska but are almost entirely absent from southern Alaska. For this reason, and also because the lithology corresponds fairly well with parts of the Mississippian sequence exposed at other places in southern Alaska, it has seemed best to designate this series as probably of Mississippian age, the doubt being indicated by the addition of an interrogation point.

PERMIAN SERIES

The Permian rocks of this region are believed to comprise two well-defined formations. The lower one is limestone. This is believed to be overlain conformably and in fact to grade upward into volcanic rocks, which likewise are considered to be, at least in part, of Permian age, though they may range upward into the Triassic system.

LIMESTONE

DISTRIBUTION

Permian limestone has been recognized in this district only at the head of Lake Chauekuktuli and in the hills between the heads of Lakes Chauekuktuli and Nuyakuk. During the season of 1935 this limestone was examined only at two localities, one along the east shore of Shadow Bay and the other north of the head of Portage Arm. These and long-distance observations show that this limestone crops out as a narrow band, whose trend ranges from N. 20° W. to

N. 60° W. but averages about N. 30° W. over its known distribution at the surface. It is mapped for a distance of 12 miles, but it undoubtedly extends farther northwest into the rugged mountains of the highland province.

LITHOLOGY AND STRUCTURE

The Permian limestone is a cream-colored to yellowish limestone, weathering brown, which is more or less recrystallized but nevertheless contains many well-preserved fossil invertebrates. No rocks other than limestone are known to lie at the base of the Permian limestone, but along the west side of Shadow Bay some slaty rocks are exposed between the limestone and the overlying volcanic rock. These slates, however, occur at a locality where faulting is known to have occurred, and their present position may therefore be due to this cause. North of Portage Arm the upper part of the limestone formation includes beds of iron-stained impure limestone, some of which has been found under the microscope to contain laths of feldspar and fragments of basaltic rock, together with secondary minerals, mostly chloritic, which are derived from the alteration of basic volcanic material. Whether these volcanic fragments are ejectamenta that fell into the sea while the limestone was in process of formation, or whether they were transported by streams and distributed offshore, cannot be determined. But evidently Permian volcanism had begun before the epoch of limestone deposition ended. Some of the hematitic limestone, at the top of the Permian sedimentary sequence, has also been found under the microscope to be fossiliferous.

Practically no structural data on the Permian limestone have been obtained, beyond the fact that the main band of this limestone in Shadow Bay strikes N. 20° W. and dips about 30° W., under the rocks that lie west of the limestone. The general trend of the limestone, however, measured from its two ends, as shown on the map, is N. 30° W., but faulting undoubtedly has had some influence in determining this trend.

No measurement of the thickness of the Permian limestone was made, but from its croppings, together with its observed structure, its thickness is believed to be between 500 and 1,000 feet.

AGE AND CORRELATION

Two collections of fossils were made from the Permian limestone, one along the east side of Shadow Bay and the other in the hills north of Portage Arm. These fossils were examined and identified by G. H. Girty, of the Geological Survey. The numbers and localities of these collections, together with Dr. Girty's report thereon, are given below.

35AMt23 (8007). Shadow Bay, at the head of Lake Chauekuktuli. Point along northeast side of Shadow Bay, about 0.9 mile from entrance of bay:

Crinoid stems.
Rhombopora sp.
Productus (Linoproductus) cf. P. schrenki.
Productus (Horridonia) cf. P. timanicus.
Productus cf. P. uralicus.
Productus (Echinoconchus) cf. P. fasciatus.
Productus (Pustula) sp.
Marginifera aagardi?
Marginifera cf. M. typica var. septentrionalis.
Spiriferina cf. S. laminosa.

35AMt536 (8008). Red Hills, a group of hills lying between Portage Arm and the west end of Lake Chauekuktuli. About 1 mile northeast of the northwest end of Portage Arm:

Zaphrentis sp.
Rhombopora sp.
Chonetes cf. C. granulifer.
Chonetes cf. C. geinitzianus?
Productus cf. P. uralicus.
Productus cf. P. gruenewaldti.
Productus (Linoproductus) cf. P. cora.
Productus (Linoproductus) cf. P. koninckianus.
Productus cf. P. mammatus.
Productus (Echinoconchus) cf. P. fasciatus.
Productus (Pustula) cf. P. tuberculatus.
Marginifera cf. M. typica var. septentrionalis.
Camarophoria cf. C. mutabilis.
Rhynchopora sp.
Spiriferella arctica.

These two collections, though generally similar, differ in some minor respects from one another in the genera and species included. This may be due in part to incomplete collecting but is possibly due in some measure to the fact that collection 8007 came from the lower or middle part of the formation, whereas collection 8008 came from the upper part. In all, about 10 genera and 20 species are represented in these two collections, and together these fossils have been definitely identified by Dr. Girty as Permian.

A specimen of the hematitic limestone at the top of the formation was also found in thin section to contain minute fossils, which, according to P. V. Roundy, of the Geological Survey, include echinoids, corals, bryozoans, and foraminifers. These add nothing definite to the determination of the age of the limestone but show the presence of a somewhat different fauna which lived near the end of the period of limestone deposition, when the effects of volcanism in this district may have changed to some extent the chemical composition of the marine waters.

Permian rocks are common in southeastern, southern, and central Alaska, but it seems unnecessary to enumerate the many localities

HILLS ALONG SOUTH SHORE OF LAKE CHAUEKUKTULI, SHOWING GLACIAL EROSION IN THE MISSISSIPPIAN (?) ROCKS.
Nuyakuk Lake in background.

VIEW LOOKING EAST ALONG SOUTH SHORE OF NUYAKUK LAKE.

Shows point and the low cliffs to west which are the site of Upper Triassic rocks. Eagle Mountain at right.

where such rocks have been found. Special mention should be made, however, of the highly fossiliferous Permian limestone found by Moffit [18] and others at the west side of Russell Glacier, in the headwaters of White River, and of the Permian limestones that are interbedded with volcanic rocks, and in fact grade upward into the Nikolai greenstone, as described by Moffit,[19] in the vicinity of Skolai Creek, at the head of the Nizina River. This locality is a specially pertinent one, as it shows the close association of the Permian limestone with volcanic rocks, similar to what has been found north of Portage Arm in the Nushagak district. Maddren [20] has also reported the occurrence of a fossiliferous calcareous tuff at the top of a formation of volcanic rocks in the lower Kuskokwim Valley. For interior Alaska the Tahkandit limestone, of lower Permian age, as described by the writer,[21] is a suitable correlative, but in that area the Permian limestone appears to grade upward into a later Carboniferous formation of terrigenous character. Similar Permian rocks are highly developed on Kuiu, Kupreanof, Admiralty, and Suemez Islands and at other localities in southeastern Alaska.

VOLCANIC ROCKS

DISTRIBUTION

Basic volcanic rocks, classified generically as greenstone, crop out in a belt that begins on the north side of Nuyakuk Lake and extends up the northeast side of Portage Arm and northwestward into the Tikchik Mountains for an undetermined distance. The width of this belt of greenstone is from 1½ to 2½ miles, and its known extent along the strike is about 15 miles. Except in one small area these rocks do not occur along the south shore of Nuyakuk Lake. Greenstone has also been mapped by Davison along the northwest bank of the Nuyakuk and Nushagak Rivers, above and below the village of Koliganek.

STRUCTURE AND THICKNESS

As these greenstones are igneous rocks their lithology and petrographic character are stated in the section devoted to igneous rocks. Few structural data are available regarding this formation, as the lava beds are thick and massive and the structure is not readily discernible. They lie stratigraphically above the Permian limestone and appear to grade downward into the limestone, through the medium

[18] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: Geol. Survey Bull. 417, pp. 21–24, 1910.

[19] Moffit, F. H., Notes on the geology of upper Nizina River: Geol. Survey Bull. 813, pp. 147–152, 1930.

[20] Maddren, A. G., unpublished notes.

[21] Mertie, J. B., Jr., Geology of the Eagle-Circle district: Geol. Survey Bull. 816, pp. 121–130, 1930.

of tuffaceous beds, which are in part of calcareous character. With little doubt this greenstone strikes about N. 45° W. and dips southwestward at about the same angle as the underlying Permian limestone. The upper stratigraphic limit of the greenstone is not known, as it is overlapped conformably by the Mesozoic rocks that lie to the southwest. Judging from the known exposures, however, and assuming a dip of 30°, as shown by the underlying Permian limestone, the writer concludes that the minimum thickness is about 4,500 feet, but the true thickness may be somewhat greater.

AGE AND CORRELATION

It has been shown above that the calcareous beds at the top of the Permian limestone, which grade upward through tuffaceous beds into the greenstone, are fossiliferous. Therefore, the base of the greenstone formation is probably of Permian age, but its upper part may range upward into the Triassic, though no data indicating such a range were found. It is not believed that this greenstone can be of late Triassic or post-Triassic age, because Upper Triassic rocks that have no igneous members are exposed along the south shore of Nuyakuk Lake; and for other reasons, presented on pages 54–56, it is not believed that any large volume of Jurassic rocks is present in this area. In the absence of more definite knowledge the greenstone formation of the lakes area has therefore been mapped as Permian.

The greenstone that occurs along the southwest side of the Nuyakuk and Nushagak Rivers, upstream and downstream from Koliganek, is similar in appearance to the greenstone found at the head of Lake Nuyakuk, but as no other hard rocks occur in the vicinity, its age cannot be substantiated upon stratigraphic grounds. For lack of more definite information, and solely because of its lithologic similarity to the greenstone of Lake Nuyakuk, it is correlated with and mapped as a part of the sequence of Permian volcanics.

This greenstone is similar in many ways to the Nikolai greenstone, which occurs in the Copper River region. The thickness is about the same as that of the Nikolai greenstone, and the lavas comprising the formation are likewise comparable. Moreover, the Nikolai greenstone in the vicinity of Skolai Creek has been found by Moffit [22] to have the same general stratigraphic relation with Permian limestone as is found at the head of Nuyakuk Lake. This formation of greenstone, therefore, is rather definitely correlated with the Nikolai greenstone.

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[22] Moffit, F. H., Notes on the geology of upper Nizina River: Geol. Survey Bull. 813, pp. 147–152, 1930.

TRIASSIC SYSTEM

UPPER TRIASSIC SERIES

DISTRIBUTION

Upper Triassic rocks have been recognized along the south shore of Nuyakuk Lake, a short distance west of the point about 4 miles east of the entrance to Mirror Bay. Limestone crops out here intermittently at four places along the beach for a distance of about 1,000 feet, and the same limestone is imperfectly exposed just back of the beach in some low brush-covered knolls facing the lake. Similar limestone was found at one place on the spur to the southwest. It is not known whether these croppings along the beach represent a single horizon of limestone, but they are too small to be shown individually on the accompanying geologic map. They have therefore been represented diagrammatically on plate 2 as a single, small body, which has been extended southeastward to its known cropping on the spur. The site of the Upper Triassic rocks is shown in plate 10.

LITHOLOGY AND STRUCTURE

The best exposures of the Upper Triassic limestone occur along the beach, where it crops out in place and where also much limestone debris occurs. The limestone at the west end of these croppings is white to cream and is thoroughly recrystallized. At the east end, however, where the limestone crops out for the longest distance along the beach, it is dark gray and only finely crystalline, and it is at the extreme east end of this cropping that fossils were found. Much of this less altered limestone is pebbly, with the general appearance of a limestone conglomerate or limestone grit, but the pebbly material included by the matrix is only in part limestone, the remainder consisting of chert and shale.

The structure of the Upper Triassic limestone and its relation to the adjacent country rock are indeterminate, for its eastern and western contacts are not visible, and it cannot be traced continuously southeastward, as the low spurs are heavily covered by brush. Between the beach croppings some quartzite occurs, but the marbleized condition of most of this limestone, together with the structure of the nearby rocks, indicates that its present position is the result of faulting. The discovery of a similar limestone along the main spur to the southeast suggests a general structure comparable with that of the Carboniferous rocks on the north side of Nuyakuk Lake, but beyond this nothing is known of the structure. The thickness, obviously, is also indeterminate.

AGE AND CORRELATION

The fossils collected from the limestone have been examined and identified by John B. Reeside, Jr., of the Geological Survey. The locality and the identification of these fossils are stated below:

35AMt63 (17080). South shore of Nuyakuk Lake, about 3 miles north of Eagle Mountain and a quarter of a mile west of a promontory along the beach:

Pseudomonotis subcircularis Gabb.
Myoconcha? n. sp.
Placites n. sp.

Mr. Reeside states that these fossils are of Upper Triassic age and that they are correlative with the Noric stage of the Upper Triassic. *Pseudomonotis subcircularis* is a type fossil of the Upper Triassic rocks of Alaska, but *Myoconcha* has not been reported elsewhere in Alaska. *Placites* also, though questionably identified from the shores of Keku Strait in southeastern Alaska and from a locality at the mouth of the Nation River, along the Yukon, has not heretofore been definitely identified from the Upper Triassic of Alaska. These faunal variations, though they do not affect the determination of the age of this limestone, are nevertheless worthy of mention in relation to later work that may be done in this part of southwestern Alaska.

Lower Triassic rocks and, with one possible exception, Middle Triassic rocks have not been found in Alaska, but Upper Triassic rocks have a wide distribution throughout the Territory. The general distribution, character, and fauna of the Triassic rocks of Alaska have been given by Martin,[23] and it will suffice here to state that such rocks are found in southeastern, southern, southwestern, central, and northern Alaska.

CRETACEOUS SYSTEM

Cretaceous rocks constitute a major part of the country rock of the Nushagak district. With the exception of the granitic intrusives and certain dike rocks they form practically all of the hard rock from the south shore of Nuyakuk Lake to Nushagak Bay, and they are also the country rock of the Nushagak Hills.

The Cretaceous rocks have been divided, for purposes of mapping, into two major groups, which, however, may not be mutually exclusive. The first group, designated undifferentiated Cretaceous, includes those sedimentary rocks which occur in the area of the Tikchik and Wood River Lakes. The second group, designated Upper Cretaceous, comprises only the rocks of the Nushagak Hills. This separation of the Cretaceous sequence into geologic units that are perhaps not mutually exclusive arises from the fact that no fos-

[23] Martin, G. C., The Mesozoic stratigraphy of Alaska: Geol. Survey Bull. 776, pp. 3–130, 1926.

sils of diagnostic value have been found in the rocks of the Tikchik and Wood River Lakes, so that they cannot be subdivided into Upper and Lower Cretaceous series, though the Cretaceous age of most of these rocks seems to be reasonably certain. On the basis of lithologic and structural data, however, these rocks may be subdivided into two fairly well defined units, which may or may not correspond to the stratigraphic divisions of Upper and Lower Cretaceous. Therefore, although the Cretaceous rocks of the Tikchik and Wood River Lakes are mapped as a single unit, they are here described as two units. The Cretaceous rocks of the Nushagak Hills, on the other hand, are fossiliferous, and their geologic age has been determined as Upper Cretaceous.

UNDIFFERENTIATED CRETACEOUS ROCKS

OLDER ROCKS

DISTRIBUTION

The older rocks of the undifferentiated Cretaceous assemblage crop out at the south shore of Nuyakuk Lake, and except for the Carboniferous and Triassic rocks that are exposed in two small areas along this shore, they constitute the sedimentary sequence as far south as the north arm of Lake Nerka. More specifically, their southern limit would be a line running the length of the north arms of Lake Nerka and passing westward across the western part of Sunshine Valley.

LITHOLOGY

As a group these older rocks may be described essentially as impure quartzite, quartzose graywacke, and siliceous argillite and slate, with which are interbedded a minor proportion of conglomeratic or gritty beds and a few thin beds of impure carbonate rocks. Some beds of red and green chert and siliceous argillite, which crop out at the west end of Tikchik Lake, are also probably a part of this series.

The quartzite and quartzose graywacke are dark-gray rocks, which occur mainly as massive beds ranging in thickness from a few to many feet. They are resistant to weathering and erosion and are therefore especially prominent on the lower ridges and spurs, where both glacial and postglacial erosion have acted differentially upon the country rock. In some of the U-shaped fiordlike arms at the heads of the lakes these harder rocks are also conspicuous as precipitous bounding walls on one or both sides.

In a petrologic classification these massive rocks are all similar, in that they are composed of a heterogeneous assemblage of quartz and other rock-forming minerals, as well as fragments of various types of older country rock. They are distinguishable from the younger undifferentiated Cretaceous rocks in the relatively large proportion of quartz which they contain. The quartzitic rocks are composed dominantly of grains of quartz, although they also contain so many mineral grains and rock fragments that none of them can be classified as other than impure quartzites. Such rocks, however, have a vitreous quartzose appearance, and even in the hand specimen their generic character can hardly be mistaken. The quartzose graywackes, on the other hand, contain a larger proportion of these constituents called impurities, but still have a much greater proportion of quartz than is commonly found in the younger graywackes farther south or in the graywackes occurring in the region of Prince William Sound and the Susitna Valley, where the name graywacke is so much used as a petrographic designation. Obviously, therefore, the impure quartzites and the quartzose graywackes grade imperceptibly into one another. Most of these massive rocks are composed of rounded to subangular grains, which show plainly their original detrital character, though in most of them there is sufficient evidence of incipient recrystallization to justify the term quartzite or quartzitic rocks. Incipient cleavage is also apparent in some of the massive rocks, but this feature is much more noticeable in the argillaceous rocks of this series.

In addition to quartz the impure quartzites and quartzose graywackes also contain grains of plagioclase feldspar, commonly much sericitized and less commonly albitized; pyroxene, usually augite; fragments of older sedimentary rocks, including slate, chert, and limestone; lavas of glassy and granular types, mainly basaltic, but also some of intermediate and even acidic composition; iron ores, with here and there some pyrite; and, most significant of all, some orthoclase, original biotite and muscovite, and other minerals distinctive of granitic rocks, together with actual fragments of these granitic rocks. These rock-forming constituents are mentioned roughly in the order of their relative abundance, but no quantitative measurements of the various components of these rocks have yet been made, either by crushing and separation into homogeneous fractions or by volumetric estimates based upon areal measurements in thin section, although an intensive study along these lines might yield some interesting results.

These massive rocks are fairly uniform in the average size of their component grains. The mineral particles and rock fragments usually range from 0.05 to 1.5 millimeter in size, and in some of the hand specimens the detrital character is recognizable without the aid of a hand lens, though a lens is useful or necessary for observing individual grains in most of these rocks. As above stated, however, gritty and conglomeratic phases are also present, and it is not uncommon to find massive grits composed of grains several millimeters in diameter. Conglomerates, however, are rare.

One conglomerate worthy of special mention occurs along the south shore of Nuyakuk Lake, about 3 miles north and a little east of Eagle Mountain. This rock contains cobbles and boulders that reach 4 feet in diameter and, as might be expected from its proximity to the Carboniferous rocks, the larger detritus consists mainly of greenstone and limestone, though considerable quartzite and chert also constitute a part of the cobbles. The matrix ranges from grit and graywacke to more argillaceous varieties. Under the microscope samples of the graywacke matrix were found to consist largely of grains of altered feldspar and fragments of sedimentary and basic igneous rocks. This conglomerate lies in or near the same zone of faulting that has affected the Triassic limestone, a short distance to the west, and its stratigraphic position, with regard to the rocks immediately adjacent to it, is anomalous. It appears to overlie well-bedded quartzitic rocks that crop out along the beach just to the east, but its lithologic and petrologic character suggests rather strongly that it may really be part of a well-defined basal conglomerate that marks the beginning of Cretaceous sedimentation.

The siliceous argillites and slates differ from the coarser-grained and more massive rocks in several respects. They occur in both thick and thin beds but also commonly show a lamination along the bedding planes, due to the alternation of light-colored and dark-colored rock. The lighter-colored laminae are at some places harder than the dark-colored laminae and stand out in relief, but at other localities the lighter-colored rock is less resistant to erosion, the darker bands standing out in relief. Some of these rocks, particularly the more argillaceous varieties, have a well-developed slaty cleavage, but others are massive.

Petrographically the argillites and slates have many of the characteristics of the more massive coarse-grained rocks, but they are composed of finer-grained detritus and contain a larger proportion of argillaceous material. All these rocks, however, are more or less siliceous, but the more massive, noncleaving types are the most siliceous. Many of these harder, more siliceous rocks are either visibly laminated in light and dark bands or show lamination on a microscopic scale. Where thus laminated the light-colored bands are composed dominantly of fine quartz, together with a smaller proportion of argillaceous material, altered feldspar, and iron ores. The darker bands are dominantly argillaceous. The average size of the mineral grains is about 0.01 to 0.02 millimeter. All these rocks are thoroughly indurated, and some of them show incipient recrystallization, with the development of fine flaky biotite in the more argillaceous types. Some original grains of biotite, however, probably derived directly from granitic rocks, were found in several specimens of the siliceous argillites. One specialized type of argillite that occurs here and there in this sequence contains hardly any argillaceous material but is essentially a fine-grained quartzose graywacke and differs from the other quartzose graywacke only in the exceedingly fine grain of the component minerals.

Certain red and green cherts and siliceous argillites that are possibly a part of this Cretaceous sequence deserve particular mention. These rocks crop out most conspicuously on the peninsula that divides Tikchik and Nuyakuk Lakes, but some of them have also been found along the south shore of Nuyakuk Lake and in the hills for a short distance to the south, among the more usual types of Cretaceous rocks. One of the red rocks of this group proves, under the microscope, to be an almost opaque red siliceous argillite, in which banding is produced by the variable density of hematite along the bedding planes. This rock and others like it also contain quartz and altered laths of feldspar, which occur in grains that are not only angular but very irregular in outline. It is possible that these rocks are of tuffaceous origin. The green varieties are likewise fine-grained but consist of chalcedonic quartz, chlorites, and carbonates and have the same origin as the red varieties, if they are not actually derived from them.

A few beds of impure limestone occur among the Cretaceous rocks, but they are rare, inconspicuous, and laterally discontinuous. Some of these beds are composed almost entirely of carbonates, but more commonly they have as impurities the other rock-forming minerals of this sequence, so that they grade from limestone into calcareous argillite or graywacke. At most places, but particularly along the water's edge, these impure limestones are lighter in color than the rocks with which they are interbedded and are to a greater or less extent dissolved away. Several beds or lenses of impure limestone from 4 to 12 inches thick, which occur at one locality along the south shore near the east end of Nuyakuk Lake, were found to contain some imperfectly preserved invertebrates. Similarly along the north side of the north arm of Lake Nerka some forms suggestive of small crinoid stems were found at the end of the little peninsula southeast of Akuluktok Mountain. Evidently these calcareous horizons are favorable places to look for fossils in a sequence of rocks otherwise almost devoid of traces of organic life.

In general, the older part of the undifferentiated Cretaceous sequence consists of a monotonous repetition of dark-colored quartzites and siliceous graywackes, argillites, and slates. Lithologically and structurally these rocks can be differentiated from the younger

Cretaceous rocks that overlie them and also from the various Carboniferous rocks that underlie them, but they contain no recognizable horizon markers.

STRUCTURE AND THICKNESS

These rocks are strongly folded, but on account of the absence of prominent beds that can be followed and used as structural indexes, the folding is not very apparent on a small scale. It is believed, however, that the folds, though universally present, are fairly open in type, except locally in zones of faulting and in the vicinity of intrusive rocks. Forty-eight observations of strike and dip were made, and from these data the average strike was found to be N. 83° E. The dips range in magnitude from 20° to 90°, but 67 percent of them are to the north, and the algebraic sum of these dips is 26° N.

The minimum distance across the strike of these rocks is about 22 miles. To estimate the thickness of sedimentary beds by applying such a mean dip is open to several objections. First, it might be questioned whether the recorded observations are really representative of the regional distribution of the rocks, though the means of strike and dip were obtained by two independent observers. One of these observers worked largely along the lake shores, while the other worked mainly along the summits of the hills; and the means obtained by each worker agree surprisingly well with those obtained by the other. Yet even if the use of these mean dips, or the mean sines of these dips, were justified for computing the stratigraphic thickness, a more cogent objection is the fact that such a computation neglects entirely the effects of faulting, of which ample evidence was found at many localities. Most of the observed faults, however, are minor structural features that have caused no large displacements of the rocks; yet their mere presence suggests the possibility that larger faults may also be present. In a similar way, unrecognized effects of close folding may also be of much importance. For these reasons, the mean structural observations may not be used for deriving any accurate estimate of the true thickness of the sequence. But in the absence of any better data they signify grossly that this stratigraphic sequence, though folded and faulted, has a general or regional dip to the north and that it comprises many thousands of feet of strata.

Both the strike and the dip of the lower group of the undifferentiated Cretaceous rocks appear to be markedly divergent from those of the underlying Carboniferous rocks. The difference between the average strike of these rocks and that of the Permian limestone is about 67°, and the average dips, though of the same order of magnitude, are respectively northward and southward, so that the bedding planes of the two series are sharply inclined to one another. These facts indicate that a marked structural unconformity exists between the lower unit of the Cretaceous rocks and the Carboniferous, as well as the Triassic rocks, both of which underlie the Cretaceous series. For reasons given below, no considerable sequence of Jurassic rocks is believed to be present in this area, though some may be infolded in the Cretaceous. The unconformity at the base of the Cretaceous is therefore thought to represent a period of uplift, folding, and igneous intrusion, probably accompanied also by mountain building, all of which took place during the Jurassic period. Subsequently the Carboniferous and Triassic rocks, much deformed and intruded by the granitic rocks, were submerged, and the Cretaceous sediments were deposited on their upturned and eroded edges.

AGE AND CORRELATION

The undifferentiated Cretaceous rocks, both in this district and elsewhere in southern Alaska, contain few traces of organic life, and in the Nushagak district invertebrates were found in the lower part of this series at only one locality. The exact fossils were determined by J. B. Reeside, Jr., of the Geological Survey, as indicated below:

35AMt46 (17079). South shore of Nuyakuk Lake, 6.3 miles N. 15° W. from Agenuk Mountain and 6.75 miles S. 6° E. from Chaufchivak Mountain:

Mytilus sp.
The age is indeterminate.

The genus *Mytilus* is a pelecypod that is known to range stratigraphically from the Triassic to the Recent, and in Alaska has been found in rocks of Upper Triassic, Upper Jurassic, and Upper Cretaceous age. The collection above recorded has therefore little value in determining the age of these rocks, but it indicates the marine character of the sedimentation and also shows that some organic life was present in the water from which these sediments were deposited.

The best evidence for the age of these rocks is found in the character of their component minerals. It has already been shown that minerals derived from granitic rocks, as well as fragments of such granitic rocks, have been identified among the minerals of the quartzites and graywackes. This granitic material cannot be the same as that which constitutes the granite and related rocks of Agenuk and Akuluktok Mountains, as these masses intrude the undifferentiated Cretaceous rocks and are therefore probably of post-Cretaceous age. The granitic minerals and fragments have therefore been derived from some granite body or bodies that existed prior to the deposition of these rocks. The oldest country rock of this district is of Carboniferous age, and even for southern Alaska as a whole the country rock in general is not older than Devonian. Hence any early Paleozoic or pre-Paleozoic granitic rocks are not likely to be the sources of this granitic material. The only remaining granitic rocks from which such granitic debris is likely to have been derived are the Coast Range granitic rocks, which began to be intruded in Middle or Upper Jurassic time. If sufficient time is allowed for erosional processes to uncover such intrusives, which were injected at a considerable depth below the surface, it does not seem probable that the lower rocks of this undifferentiated assemblage of rocks can be as young as Jurassic. On the other hand, they have none of the characteristics of the Tertiary rocks of southern Alaska, but they do resemble greatly the Cretaceous rocks found at many other places in southern Alaska. For these reasons this series of undifferentiated rocks has been considered to be mainly of Cretaceous age.

The younger rocks of this undifferentiated sequence, as shown below, differ both in their lithology and structure from the older rocks of the sequence. In the absence of fossils of determinative value these differences, though significant, do not afford sufficient evidence for dividing the series into two groups of Lower and Upper Cretaceous age. It is probable, however, that the older rocks of the series, above described, are mainly Lower Cretaceous. The really doubtful matter is whether they represent the entire Lower Cretaceous sequence, or perhaps only the lower part of it.

The nearest rocks of definitely known age with which the older rocks of this series may possibly be correlated are those of a formation that lies west of the mountainous province, in the headwaters of the Kanektok River. This group of rocks was called by Spurr [24] the †Oklune series,[24a] and its age was determined on the basis of a large float boulder of sandstone and conglomerate, which contained *Aucella crassicollis* Keyserling, the type fossil of the Lower Cretaceous. This boulder was found on the Kanektok River about 12 miles below Klak Creek and about 65 miles west of the west end of Lake Beverly. The country rock within the area near the site of this boulder is described by Spurr as consisting essentially of sandstone, arkose, conglomerate, and carbonaceous shale, grading upstream into massive fine-grained feldspathic sandstones. Allowing for possible difference in the degree of metamorphism, this lithology corresponds rather closely to that of the older rocks of the undifferentiated Cretaceous sequence in the Nushagak district. Above the mouth of Klak Creek, however, the rocks are dominantly of volcanic character, and as limestones and

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[24] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Geol. Survey 20th Ann. Rept., pt. 7, pp. 163–169, 1900.

[24a] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey.

cherts are also mentioned, it is probable that the †Oklune series, as mapped, contains some rocks that are older than Cretaceous. Nevertheless, the fossils found on the south shore of Nuyakuk Lake, west of the mountainous province, on the strike of the older unit of the undifferentiated Cretaceous rocks, have considerable significance, because they tend to confirm the assignment of these older undifferentiated rocks to the Lower Cretaceous and because they suggest that such rocks continue westward for many miles.

YOUNGER ROCKS

DISTRIBUTION

The younger rocks of the undifferentiated Cretaceous sequence begin at the north arm of Lake Nerka and continue southward for a distance of about 40 miles, to the last hard-rock hills in the vicinity of the Snake and Weary Rivers. They thus comprise all the sedimentary bedrock in the country contiguous to the south arm of Lake Nerka and to Lakes Aleknagik and Nunavaugaluk.

LITHOLOGY

The rocks of this younger group are essentially graywacke, argillite, and slate, which constitute a monotonous sequence of dark-gray rocks without any conspicuous horizon markers. The massive rocks of the older group, as is evident from their vitreous appearance, are rather siliceous. The rocks of the Frog Mountains and of the islands off Elbow Point, however, obviously differ in composition from those to the north and are typical graywacke. The same type of rock continues southward to the lower lakes.

As generally used by Alaskan geologists, the term "graywacke" means a well-indurated dark-colored sandy rock, composed dominantly of plagioclase feldspar, ferromagnesian minerals derived from basic rocks, and fragments of dark-colored country rock, either igneous or sedimentary. Quartz, though usually present, is not one of the principal minerals. The detrital material of such rocks has evidently resulted from a rapid mechanical comminution of the country rock, with a minimum of chemical decay and subsequent transportation. Hence the lime-soda feldspars, ferromagnesian minerals, and fragments of basalt and slate, which under ordinary climatic conditions would have disintegrated to form argillaceous material, have been preserved as detrital grains. The character of the grains shows that these rocks have been derived from a country rock composed mainly of basic lavas and intrusives and dark-colored well-indurated argillaceous rocks.

The graywackes of the younger group of the undifferentiated Cretaceous rocks correspond closely with the typical graywackes of southern Alaska, as defined above. They occur in beds from a few inches to many feet in thickness and are at many places interbedded with thinner beds of argillitic rocks. The hand specimens of graywacke are dark-gray, moderately coarse-grained rocks, in many of which feldspar and pyroxene are visible to the unaided eye. In fact, some of these rocks look so much like basic igneous rocks that unless their fragmental character is recognized by close scrutiny, they may be mistaken for diabase or coarse-grained basalt. Under the microscope they are found to consist essentially of rounded to angular grains of plagioclase feldspar, pyroxene, and fragments of basaltic rocks. Other minerals and rock fragments, however, are also present, among which are quartz, iron ores, hornblende, fragments of fine-grained igneous rocks of intermediate composition, graywackes, argillite, slate, chert, and crystalline limestone. The plagioclase feldspar varies somewhat in composition, but much of it has the composition of acidic labradorite. Most of it is extensively altered to sericite, carbonates, and kaolinic products. The pyroxene is mainly augite, which is more or less altered to chloritic minerals. The basaltic detritus is partly granular and partly glassy and likewise shows alteration of the same type that has affected the grains of plagioclase and pyroxene. At some places the graywackes are greatly fractured, resulting in a network of reticulating veinlets filled by white secondary minerals, among which prehnite and several zeolites were identified. Plate 11, *A*, shows an exposure of graywacke, thus fractured and veined.

The argillite and slate of this group are well-indurated hard rocks and differ only in the fact that the argillite has no secondary cleavage. These rocks occur in beds from a few inches to several feet in thickness and differ from the graywackes in that they are much finer-grained and contain a larger proportion of argillaceous material. Under the microscope, however, it may be seen that they were derived from the same source rocks as the graywacke. Some of the argillites are somewhat siliceous, and such rocks are particularly hard, massive, and devoid of cleavage. One feature seen in these hard argillites is the presence here and there of small rounded to subangular pebbles of the same material as the matrix. These pebbly forms are believed to have originated either as concretions or in the manner of a primary conglomerate, but in either event they were formed apparently at essentially the same time as the including sediments were deposited.

Calcareous rocks also form a part of this group, but such rocks are relatively rare and inconspicuous. They consist of impure limestone and calcareous graywacke, essentially similar to those described as found among the older rocks. They occur as thin beds which pinch out laterally, extending commonly but a few feet, so that they are distinctly lenticular. One variant from the usual type of calcareous rock occurs on a small outlying island in the north arm of Lake Nerka, northeast of Anvil Bay. The rocks at this locality are reddish when viewed from a distance, but the hand specimens are buff to cream-colored rocks composed of grains of calcite, fragments of slaty rocks, iron ores, and quartz, cut by veinlets of calcite and chalcedony. The grains of calcite, however, appear under the microscope to be a secondary mineral derived from the alteration of plagioclase feldspar. Some of these rocks are rather coarse grained, with a conglomeratic aspect.

STRUCTURE AND THICKNESS

The rocks of the younger group of the undifferentiated Cretaceous differ from those of the older group in that they approximate a monoclinal sequence, which dips generally southward. From 57 observations of strike and dip the average strike was found to be N. 88° E. This regional trend, it will be observed, differs only by 5° from that of the older rocks, the average strike of which was found to be N. 83° E. This difference is not sufficiently great to be of any significance, as it is within the limits of accuracy of these averages and may be quite accidental, owing to lack of sufficient data. These rocks, however, are highly tilted, and 91 percent of the observed dips are to the south. By balancing the southward and northward dips, in the manner heretofore described, the average dip is found to be 48° S. In general, therefore, the bedding of the younger rocks lies at an angle of 74° to that of the older rocks, and if the younger rocks were laid down essentially as horizontal beds, the older rocks must have had a much higher tilt to the north at the beginning of the later sedimentation than they do at the present time.

Generalized structural observations of this sort cannot have any such degree of precision as is indicated by the figures above deduced, as many other unknown factors have not been and cannot be evaluated. Faults, for example, are known to be present, and it is very likely that strike faulting on a large scale must have occurred to explain such a tremendous monoclinal sequence of beds. Rather close folds were also observed at a few places, and if many of the folds are of the appressed type, the figures above given might need to be considerably modified. Nevertheless, the structure of the older and young rocks was observed and recorded in the same way, and in fact the observations recorded are the sum of independent observations made by two geologists, which check one another closely. No fortuitous causes are known, therefore, which could account for these differences in structure, and with due allowance for the admitted lack of data sufficiently complete to serve in a statistical analysis, and for unknown and unevaluated geologic factors, it seems evident that the bedding of the younger rocks is markedly discordant from that of the older rocks of this sequence. A pronounced structural unconformity is therefore indicated between these two groups of rocks.

The distance across the strike of the younger rocks is about 40 miles and this distance, if computed with an average dip of 48° S., would result in a thickness of rocks of the order of many miles. It is not believed possible that any such thickness of these rocks can be present, and the probable alternative explanation that suggests itself is block faulting, parallel to the strike, on a large scale. Such major faults, if present, are probably localized in the lake basins, and their presence may in fact have been a potent factor in localizing the old stream valleys that antedated the present glacial valleys and lakes.

AGE AND CORRELATION

No paleontologic data whatever are available for assigning a geologic age to these rocks, and the structural data have already been presented. They lie above rocks that are believed to be of Lower Cretaceous age, and their age is therefore either Lower or Upper Cretaceous, but probably not both. The structural unconformity above deduced suggests strongly that the younger rocks are of Upper Cretaceous age, and their lithology, as compared with that of the Upper Cretaceous slates and graywackes of Prince William Sound, Cook Inlet, and the Susitna Valley, strengthens this probability. In the absence of paleontologic data, however, they have not been definitely assigned to the Upper Cretaceous, but instead have been mapped merely as the younger group of the undifferentiated Cretaceous rocks.

UPPER CRETACEOUS ROCKS

DISTRIBUTION

Rocks that are assigned to the Upper Cretaceous epoch, on the basis of paleontologic evidence, form the bedrock of the Nushagak Hills in the northern reaches of the Nushagak Valley. These hills occupy a roughly circular area with a diameter of about 30 miles. in the northeastern part of the Nushagak district. This part of the district has not been visited by the writer, and the following descriptions are therefore based entirely upon the work done by P. A. Davison in 1931.

LITHOLOGY

The Nushagak Hills are smooth and well rounded and are largely covered by vegetation of the tundra type. Bedrock crops out along the ridges, but the exposures in general are intermittent and are separated by long intervals in which only bedrock rubble can be observed. Better exposures are found here and there in the valleys where the streams have cut against the valley walls. Most of the bedrock exposures, as well as the rubble, consist of graywacke and shale, though a few bands of conglomerate were noted in the upper valley of the Chichitnok River and also in the Nushagak Valley above its junction with the Chichitnok.

Along the rivers, where these rocks are best exposed, graywacke was observed in beds from 2 to 8 inches thick, interbedded with shales ranging from 1 to 12 inches in thickness. Much of the shale is fissile and is broken into pieces as thin as cardboard and from 4 to 6 inches in diameter. On the hills graywacke is more apparent. Here the surfaces of the rocks are much weathered, and when broken some of the graywacke shows small rustry pits about the size of a pinhead, which appear to be the result of solution of some of the rock-forming minerals or rock fragments. Quartz veins, generally about one-sixteenth of an inch thick, though some as large as half an inch were seen, are rather common in the graywacke. Some veins of calcite were also observed, but some of these may also have contained zeolitic minerals.

The graywacke in general consists of angular to subangular grains of detritus, ranging in size from grains as large as three-eighths of an inch in diameter down to particles too small to be resolved with the unaided eye. The constituents of the graywacke are fragments of white and clear quartz, quartzite, fine-grained graywacke, chert, argillite, plagioclase, feldspar, and basaltic rock in various stages of alteration.

STRUCTURE AND THICKNESS

The strike of the bedding is approximately northwest. Fifteen observations of dip were recorded, of which three were 90°, two were to the south, and the remainder showed a dominant northward inclination of the beds averaging 58°. Along the rivers several small open folds were seen, but most of these were broken by normal faults, with throws of 20 to 50 feet. The thickness of these beds is indeterminate from the information at hand.

AGE AND CORRELATION

Fragments of fossil invertebrates were found in the shales of the Nushagak Hills by Davison at three localities within a mile of one another. None of these were found in place, but the absence of glaciation in these hills precludes the possibility that the fossils are of other than local origin. The exact localities of these fossils, together with their identifications by J. B. Reeside, Jr., of the Geological Survey, are given below:

31AD75 and 31AD75–B. Slopes of spur about ¼ mile north of Nushagak River and about 11 miles N. 60° E. of mouth of Chichitok River.

31AD75–A. Gravels of Nushagak River, at base of spur where collections 31AD75 and 31AD75–B were made.

These three collections contain fragments of *Inoceramus* sp. A specimen found in collection 31AD75–A suggests an Upper Cretaceous age, and my best guess is that the material is of that age.

It is doubtful if these rocks should be correlated directly with those of the Tikchik and Wood River Lakes. In lithology they correspond more closely with the younger group of the undifferentiated Cretaceous rocks, but they appear to be much less indurated than either the older or the younger rocks of that sequence. The lithologic differences, however, may possibly be due to differences in the character of the country rock from which the detritus was supplied, or to variations in the conditions of sedimentation; and the difference in degree of induration may be due either to local metamorphism in the lake region or to residual alteration in the Nushagak Hills. For these reasons the Upper Cretaceous rocks of the Nushagak Hills have been separately mapped.

The nearest rocks with which the Upper Cretaceous series of the Nushagak Hills may be directly correlated are the rocks that crop out on both sides of the Kuskokwim River between Sleitmut and Georgetown, about 100 miles to the north. The region between these two localities, however, is largely unmapped, and it is rather probable that the same series of rocks occupies a considerable part of this intervening area. Northeast of the Nushagak Hills, in the headwaters of the Hoholitna River, similar rocks have been mapped by Smith [25] under the designation Mesozoic shales and sandstones, though he considered that most of them were of Cretaceous and Jurassic age.

TERTIARY SYSTEM

NUSHAGAK FORMATION

Unconsolidated or slightly consolidated marine sediments, called by Spurr [26] the "Nushagak beds" and here called the Nushagak formation, have been observed along the east shores of Nushagak Bay and extend eastward around Cape Etolin into Kvichak Bay. These beds have not been seen by the writer, but, according to Spurr's de-

[25] Smith, P. S., The Lake Clark-central Kuskokwim region, Alaska: Geol. Survey Bull. 655, pp. 63–76, 1917.

[26] Spurr, J. E., A reconnaissance in southwestern Alaska: Geol. Survey 20th Ann. Rept., pt. 7, pp. 173–174, 1900.

scription, they consist of stratified gravel, coarse sand, arkose, and clays, which in part are slightly cemented and consolidated by iron hydroxides. Some of the gravel shows striae, which were thought to be of glacial origin. These beds are in places distinctly flexed and folded and dip at angles as high as 20°. These strata are also markedly cross-bedded. They are said to be overlain unconformably by horizontally bedded gravel and clay. There can be little doubt that the Nushagak formation of Nushagak Bay represents near-shore marine sedimentation.

Spurr referred these beds to the Miocene epoch, on the basis of a collection of fossils made sometime between 1881 and 1884 by C. W. McKay, who at that time had charge of the Signal Corps meteorologic station at Fort Alexander. These fossils were found somewhere near the head of Nushagak Bay, probably near old Fort Alexander (now Nushagak), but the exact locality was not recorded. These fossils, as determined by W. H. Dall,[27] are listed below:

Modiola multiradiata Gabb.
Pectunculus patulus Conrad.
Nucula tenuis Lamarck.
Serripes gronlandicus Beck.
Tellina carlottensis Whiteaves.
Macoma middendorfii Dall.
Macoma nasuta Conrad.
Mactra albaria Conrad.
Saxicava arctica Linnaeus.
Teredo sp.
Neverita saxea Conrad.
Natica clausa Broderip and Sowerby.

These fossils were determined by Dall to be equivalent in age to the Astoria shale (Miocene) but were thought to be more nearly representative of the upper part of the Astoria. In a similar determination of some Tertiary fossils found by the writer [28] at Lituya Bay, southeastern Alaska, Dall correlated the fossils with the "Astoria or Etchegoin Miocene," which was interpreted as indicating the equivalence of the Astoria and Etchegoin formations. The Etchegoin sandstone, however, is now considered to be wholly of Pliocene age and is so classified by the Geological Survey. This fact raises a doubt regarding Dall's conception of the upper limit of the Astoria shale, and it is possible that he may have correlated rocks now regarded as Pliocene with the Astoria shale, which is still considered to be of Miocene age. In view of this uncertainty, the writer has designated the Tertiary fossils from Nushagak Bay as Miocene or Pliocene.

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[27] Dall, W. H., Report on coal and lignite in Alaska: Geol. Survey 17th Ann. Rept., pt. 1, pp. 842–847, 1896.

[28] Mertie, J. B., Jr., Notes on the geography and geology of Lituya Bay, Alaska: Geol. Survey Bull. 836, pp. 129–130, 1933.

QUATERNARY SYSTEM

PREGLACIAL CONDITIONS

Prior to the beginning of glaciation, the regional configuration of the Nushagak district was probably considerably different from what it is today. No data are available regarding absolute sea level at that time, but with reference to the Tertiary and older sediments near the coast, the sea level was relatively lower, and the regional baselevel of erosion was therefore also relatively lower than at the present time. Nushagak and Kvichak Bays were probably river valleys, which in their lower courses were carved in the newly elevated Nushagak formation. The Nushagak lowland was probably the site of a wide, open, and maturely dissected valley, but of course it lacked the outwash deposits under which it is now largely buried. Finally, the depressions now occupied by the Tikchik and Wood River Lakes were normal alpine valleys, which opened eastward into wider valleys that drained to the Nushagak River.

The conclusion that sea level was relatively lower before the period of glaciation than at the present time is based upon the fact that the basal glaciofluviatile and fluviatile deposits now visible at the head of Nushagak Bay lie upon the irregular upper surface of the Nushagak formation, which was produced apparently by erosion. At some places these basal beds are entirely above sea level, but at other places, according to Spurr,[29] the contact between the two formations dips below the sea, so that the Nushagak formation is invisible. The folding of the Nushagak formation and the erosional surface at the top suggest strongly that the Nushagak had been uplifted above sea level; that it had been somewhat deformed in that process; and that it had been subjected to erosion and sculpturing by streams before the overlying Pleistocene sequence began to be deposited. As the site of the old Nushagak Valley may not be exactly the present site of Nushagak Bay, the maximum depth below sea level of the surface of the old valley cannot be estimated, although certain data, presented below, indicate that this old erosional surface lies at least 150 feet below the present level of the sea.

The present drainage of the Wood River Lakes constitutes clear evidence of the changes produced by glaciation. Lake Kulik, for example, now drains southward into Lake Beverly through a channel at the upper end of the lake, and a part of this channel cuts bedrock. In a similar way Lake Nerka empties into Lake Aleknagik through a back-hand drainage channel that is 10 miles west of the lower end of Lake Nerka. Tikchik and Wood River Lakes

[29] Spurr, J. E., op. cit., pp. 173–174.

have intermittent croppings of bedrock at their lower ends and are essentially glint lakes, though in their earlier stages they were probably barrier lakes, dammed by morainal material. The present altitudes of the lakes therefore give a rough idea of the minimum levels of the old preglacial stream valleys at the points now marked by the east ends of the lakes. Thus Tikchik Lake has a present water level of about 300 feet, but the fall in the Nuyakuk and Nushagak Rivers from the lake to Snag Point, on account of a lower relative sea level at the beginning of glaciation, may have been considerably greater than it is at the present time.

West of the east ends of the lakes little can be learned of the configuration of the old preglacial valleys, as they have clearly been scoured out and greatly overdeepened by glacial erosion. The Tikchik Mountains were presumably high mountains in preglacial time, possibly higher with regard to the present sea level than they are now, as the sapping effects on high ridges produced by a major glaciation must have been severe. The streams that drained eastward and southeastward from the Tikchik Mountains were probably alpine streams in their upper courses, confined to narrow mountain valleys, which opened up into wider valleys farther downstream, beyond the eastern front of the mountains.

GLACIAL CONDITIONS

It has frequently been emphasized that the Pleistocene and glacial epochs in parts of Alaska are not necessarily synonymous. Little definite information is available regarding the beginning of glaciation in Alaska, because the last stage of glaciation, presumably of Wisconsin age, was so intense that it largely obliterated the evidence of any earlier glacial and interglacial stages. Hence, in the absence of definite data bearing upon this question, most of the effects of glaciation in Alaska are referred to ice of Wisconsin age. The facts show clearly, however, that parts of Alaska have not yet emerged from the glacial stage, so that in geologic terminology some of the glaciation of Alaska is post-Wisconsin and therefore of Recent age.

At some time during the Pleistocene epoch the Tikchik Mountains and the mountainous province of which they form a part began to accumulate extensive ice fields. Beginning in the highest part of this range, the ice gradually extended down the alpine valleys until, in the course of time, these preglacial valleys were occupied by great tongues of thick ice which moved outward from the mountains and in this area eastward and southeastward toward the Nushagak Valley. Eventually these ice tongues became thick enough to fill the valleys to an altitude, in the region of the lakes, of about 2,000 feet and to override the lower hills at the eastern face of the mountains.

The erosional effects of this glaciation are clearly shown by the smoothly worn bedrock surfaces with glacial striae at the lower ends of the lakes; by truncated spurs, particularly on the south sides of the lakes; by the overdeepening that produced the lake basins; by well-developed hanging valleys in the upper ends of the lakes and less perfectly developed ones in the lower hills farther down the lakes; and by the comb ridges and pinnacle summits in the higher mountains. Apparently the maximum effects of this glaciation were produced in the vicinity of Lakes Chauekuktuli and Nuyakuk, for here the ice tongues were sufficiently thick and extensive to override low hills such as Tikchik Mountain and possibly the hills to the north of Tikchik Mountain. This fact is attested by the presence of erratic boulders on Tikchik Mountain and by the character of the valley of the Tikchik River, which from a distance appears to be the site of a great ground or terminal moraine formed when the glaciers were melting and retreating. Notwithstanding the fact that the ice field extended to the hills north of Tikchik Mountain, there is no evidence of glaciation east of these hills, and it is believed that they formed an effective barrier to the main ice field, though some small tongues of ice may have pushed through low divides and drainage channels for a short distance east of these hills. The shallowness of Tikchik Lake is further evidence that the ice had lost its maximum erosive power by the time it had reached the longitude of Tikchik and Agenuk Mountains.

The glaciers that discharged eastward from the Tikchik Mountains probably persisted and maintained their maximum lengths for a long time. During this period, and particularly in its waning stages, a large volume of outwash material was moved eastward and southeastward into the Nushagak Valley. Likewise an even greater volume of such material was moved westward into this valley, as a result of glaciation in the Alaska and Aleutian ranges. The net result was an extensive aggradation of the Nushagak Valley.

The thickness of these ice tongues and the magnitude of the glaciation are also best appreciated in the vicinity of Lakes Chauekuktuli and Nuyakuk. These lakes have depths respectively of at least 700 and 930 feet, and their bottoms are therefore 376 and 618 feet below the present level of the sea. These depths do not necessarily represent the maximum amount of glacial overdeepening—first because these lakes may be in places deeper than the two soundings show, and second because the old gradients of the preglacial valleys, from the heads of these lakes to their eastern extremities, have not been determined. With evidence of ice action 2,000 feet above the present lake levels, the thickness of ice in the Nuyakuk depression was therefore locally as much as 3,000 feet. The Nuyakuk glacier, moreover, had a length perhaps of 40 miles from the ice fields at its head to its lower end. Although in area and in the thickness and length of the ice tongues issuing from it, the central ice field is not comparable in magnitude with the ancient ice fields of the Alaska Range, yet this region certainly ranks as one in which glaciation took place on a large scale.

It seems probable that in their waning stages the glaciers retreated rather rapidly, as otherwise there would be more evidence of morainal material along the lakes. Moreover, the lakes would probably have been more or less filled, at least in places, by morainal material, or outwash deposits, if this retreat had been gradual and of long duration. The two projecting spits of unconsolidated material in the lower end of Lake Chauekuktuli, as seen in plate 12, point to a pause in the retreat of the Chauekuktuli glacier, but little evidence of this sort was found in the lower ends of the other lakes. The deep headwater bays and fiordlike arms that occur in so many of these lakes, however, suggest either a pause in the process of glacial retreat, or perhaps a renewal of glaciation on a small scale after the original valley glaciers had largely disappeared. The fact that the constrictions at the lower ends of these headwater arms consist of bedrock suggests a renewal of glaciation rather than a pause in the retreat of the original glaciers, for in such a renewal the morainal material from the ends of these smaller glaciers could have been dumped into the deep water of the lower lakes, thus becoming effectively concealed. Eventually practically all the ice in this region was melted, but small valley glaciers apparently persisted long after the retreat of the main ice tongues, and in fact a few small glaciers are still preserved in the high alpine valleys west of the lakes.

POSTGLACIAL CONDITIONS

After the retreat of the ice the drainage conditions in this region changed materially but did not revert to those which existed prior to glaciation. The Nushagak River continued to function as the master stream of the region, but under somewhat different conditions. Its principal eastern tributary, the Mulchatna River, ceased to be a glacial stream and there was a corresponding diminution in its flow of water; and as glacial tributaries from the west side of its valley were also eliminated, the Nushagak likewise became a clear-water stream. The aggradation of the Nushagak Valley during the glacial epoch alone was sufficient to raise materially the baselevel of erosion in this region, but it also seems probable from conditions now visible along the coast that, either by subsidence of the land or by elevation of the sea, the relative level of the ocean was raised, thus aiding in the rise of the regional baselevel of erosion in the Nushagak Valley.

Along the west side of the Nushagak Valley the combined aggradation produced by outwash deposits from the east and west was sufficient to close off the old preglacial valleys and to impound the streams that issued from the Tikchik Mountains, so that a system of lakes with more or less parallel headwater arms trending east and southeast was developed in these glaciated tributary valleys. In their initial stages these lakes were probably dammed by unconsolidated material, either moraine or outwash, which resulted from the preexisting glaciation. The system of terraces on these lakes also indicates that their water levels were originally much higher than at the present time, for the detritus now visible along the ruins of these terraces shows from its character and also its level disposition, that these deposits are old beach gravel rather than stream deposits.

With a continuous supply of water from the mountains emptying into these lakes, overflow channels were quickly established. For Lakes Chauekuktuli and Nuyakuk the height of the bounding hills on the north and south was adequate to insure an outlet toward the east, and therefore the present Nuyakuk River was soon established, probably with the same general course as that of its old preglacial valley. (See pl. 10.) In a similar way, Nishlik and Upnuk Lakes overflowed southeastward into the general sites of preglacial valleys, thus establishing the Tikchik River. Chikuminuk Lake likewise began to discharge southeastward, forming the Allen River, which, however, may not necessarily occupy the site of a preglacial trunk valley.

The Wood River Lakes, on the other hand, were evidently barred from the Nushagak Valley by higher land, composed of glacial outwash. The mapping of the country east of the Wood River Lakes is not sufficiently detailed to show the exact site of this ancient barrier, but in the disposition of the higher hills in this area there is a suggestion that a low divide may connect the Muklung Hills with Kemuk Mountain and extend thence northwestward to Agenuk Mountain. The partly drained small lakes in the headwaters of the Kokwok River, the partly drained small lakes that drain westward into the Wood River Lakes, and other, unmapped lakes in this general area, which are visible from the air, all suggest strongly that a much larger lake, connecting the east ends of Lakes Kulik, Beverly, and Nerka, may at one time have extended eastward to the low divide above postulated.

A new postglacial drainage system was soon established for the Wood River Lakes, but in this area the divides between the lakes were relatively low compared with the divide south of Nuyakuk Lake and evidently lower than the barrier that existed to the east. As a result each of the several Wood River Lakes quickly overflowed into the next lower one, thus establishing the present interlake drainage. On account of the aggradation in the Nushagak Valley, the Kokwok River is a sluggish stream that has not been sufficiently active in postglacial time to extend its drainage westward to Lakes Kulik, Beverly, and Nerka. Hence the streams that connect these lakes with one another and with Lake Aleknagik have been able to maintain their courses, in spite of the fact that they now cut bedrock at many places. On the other hand, a lowering of the baselevel of erosion for the Nushagak River, with the consequent rejuvenation of that stream and its tributaries, might subsequently enable the Kokwok to extend its drainage backward, thus tapping some or all of the upper Wood River Lakes.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits of the Quaternary system may be divided broadly into two general groups, based on relative age. The older group of these deposits consists of glacial, glaciofluviatile, and fluviatile deposits that were laid down mainly during the period of active glaciation. They are largely of Pleistocene age, but the latest of these deposits undoubtedly have been formed during the Recent epoch. The younger deposits consist of fluviatile and beach deposits, the latter including both estuarine and fresh-water types. They are largely of Recent age. The separation of these unconsolidated deposits into Pleistocene and Recent groups is not feasible, however, as they doubtless overlap one another in the geologic time scale. They are therefore divided for the purpose of description into two groups, of which the older is more or less contemporaneous with the epoch of major glaciation, whereas the younger for the most part postdates the glacial epoch.

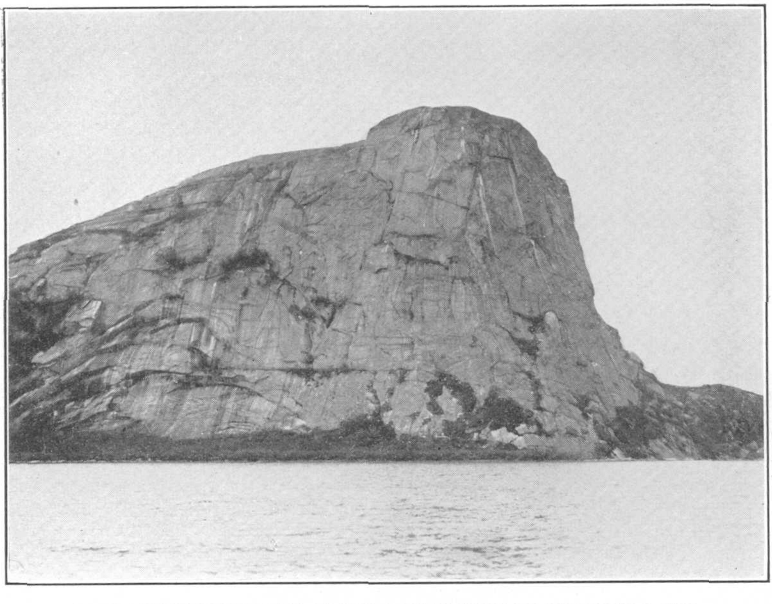
On the geologic map it has not been found practicable to map these two classes of deposits separately. This is due in part to the small scale of the map but in much larger part to the lack of detailed geologic investigation so far done in this region. Moreover, the Nushagak formation cannot be separately mapped because it crops out only in bluffs along Nushagak and Kvichak Bays and even on a detailed map could be represented only by a sinuous line following the beach. All the Quaternary deposits, as well as the Nushagak formation, are therefore shown on the geologic map (pl. 2) by a single pattern, but the heterogeneity of this assemblage is indicated in the explanation.

GLACIAL AND GLACIOFLUVIATILE DEPOSITS

The alluvial deposits that were formed in this district during the glacial epoch consist essentially of morainal, glaciofluviatile, and

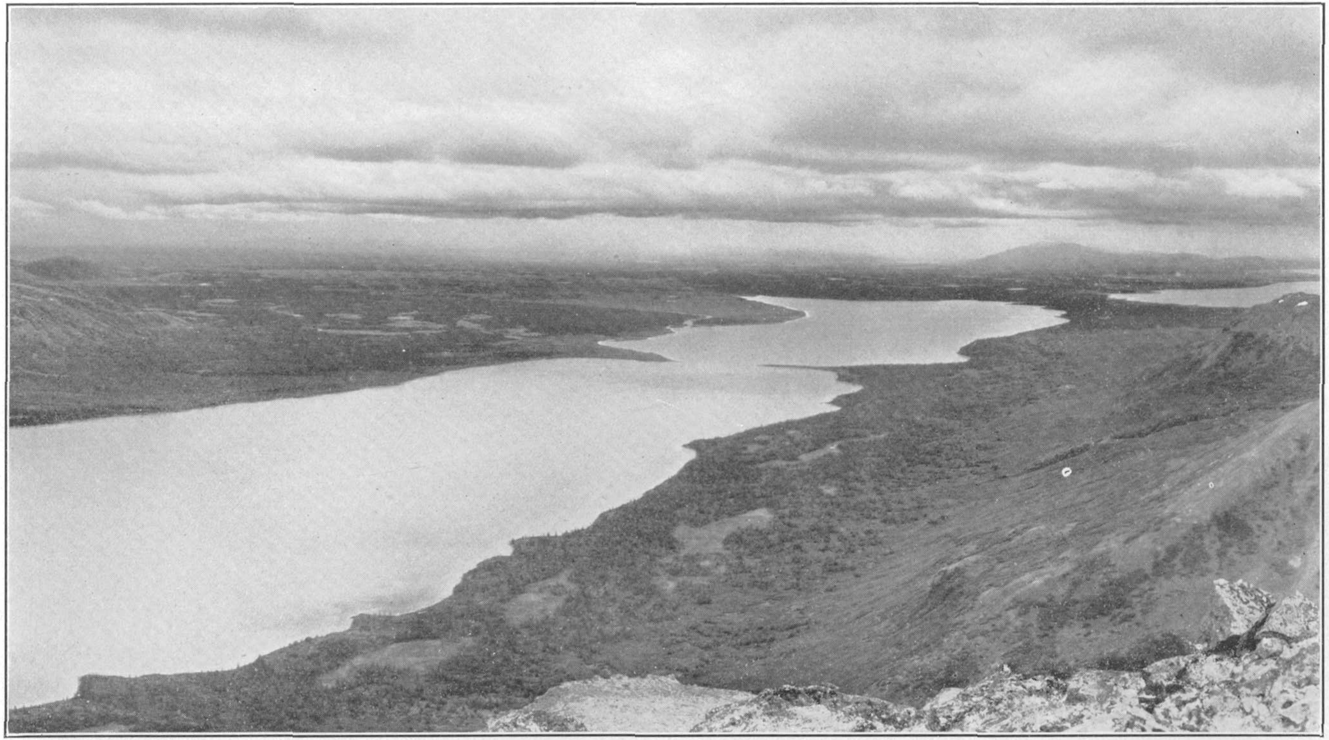
A. FRACTURED GRAYWACKE ON LAKE ALEKNAGIK.

Shows reticulating fissures filled with carbonates and zeolites.



B. GRANITE MONOLITH ALONG SOUTH SIDE OF TIKCHIK LAKE.

Shows sheeting and jointing.



LAKE CHAUEKUKTULI, LOOKING SOUTHEAST.

Shows the two projecting spits that probably mark a pause in the retreat of the Chauekuktuli Glacier.

fluviatile deposits, of which the glaciofluviatile or outwash deposits have the largest surficial area. The morainal deposits are confined largely to the lower ends of the lakes and to the valley of the Tikchik River, but few of these deposits were seen by the writer, and little information regarding them can therefore be given. Glacial till was observed by Davison at the mouth of Tikchik Lake, and the two low spits in the lower end of Lake Chauekuktuli are believed to have been formed of morainal material, though the subsequent action of lake waters has largely obliterated the surficial evidence of the character of this deposit.

The upper portion of the great Nushagak lowland is made up largely of glaciofluviatile or outwash deposits. These deposits originated as debris eroded by glacial action, but they were reworked and more or less sorted by the streams that issued from the ends of the glaciers and were distributed eastward and southeastward into the Nushagak Valley largely as a great outwash plain. Sections of these deposits are not in general visible, as the Nushagak lowland is a gently undulating plain covered by moss or other vegetation, but where such deposits have been dissected by the present streams, they are seen to consist of more or less rounded but poorly assorted gravel, sand, and silt. Such deposits were noted by Davison in a high bluff along the north side of the Nuyakuk River and 17 miles below the mouth of Tikchik Lake. Similar deposits are visible at numerous places in the bluffs along the Nushagak River, but these on the whole are better sorted and grade imperceptibly into fluviatile deposits. Similar bluffs, about 50 feet in height, were observed by Davison on the Chichitnok River and on the Nushagak above the mouth of the Chichitnok. Alluvial terraces and slopes were also noted on both sides of the Nushagak River below the mouth of the Chichitnok, and at the lower end of the valley of a tributary of the Nushagak River about halfway between the Chichitnok and King Salmon Rivers the valley floor is flanked by a terrace that rises about 450 feet above the river level. This tributary stream is rather sharply incised into the terrace, as the width of the valley at the level of the top of the terrace is less than a quarter of a mile. Below Koliganek these deposits, as observed on the river bluffs, consist of yellowish khaki-colored gravel and sand, with some clay, which show bedding and cross-bedding clearly.

In the Nushagak Bay area the glaciofluviatile and fluviatile deposits occur both as bluffs along the coast and also extend below sea level. Just east of the settlement of Snag Point is a bluff about 60 feet in height, which rises abruptly from a low muddy beach. The lower two-thirds of the bluff consists of gravel and sand, above which the sediments are dominantly sandy. At other places along Nushagak

Bay these beds, according to Spurr,[30] consist of gravel, sand, and clay, containing many pebbles and boulders that are polished and deeply scratched by the action of ice. Some of the bluffs in which these sediments are exposed are as high as 200 feet, but many of these higher bluffs consist of the Nushagak formation, overlain by as little as 10 feet of the later deposits. Eastward toward Kvichak Bay the bluffs become lower and are composed entirely of the later deposits. This fact suggests the possibility that the outlet of the Nushagak River, at the time when this gravel was deposited, may have been farther to the east, so that it drained directly into Kvichak Bay.

Some facts that bear upon the character of these glaciofluviatile deposits are available from the records of certain wells that have been drilled in the Nushagak Bay area. These drill-hole data have been furnished in part by Frank Warren, now of Portland, Oreg., and in part by Fred Peterson, of Clark Point. In 1927 a well was drilled by the Alaska-Portland Packers Association at Snag Point for the purpose of obtaining an additional supply of drinking water. This well was driven to a depth of about 213 feet, using an 8-inch casing for the upper 160 feet and a 6-inch casing for the lower part of the hole. For the first 8 or 10 feet the hole was drilled through frozen ground, and lenses of ice were also found at irregular intervals. Water was encountered throughout the drilling operations, at some places in fairly good quantity but at others as mere seepages. The ground drilled consisted of fine gravel, sand, and clay, resembling the sedimentary beds exposed along the Nushagak River and showing clearly its fluviatile character. At the depth of 213 feet a stratum of moderately fine gravel and black sand was found, from which a strong flow of fine, clear water was obtained that rose in the casing within 15 feet of the surface of the ground. This well was used throughout the seasons of 1927 and 1928 but gave trouble because the flow of water was interrupted at times by a heavy run of sand, although the bottom bowl of the pump was 10 feet from the bottom of the well and the lower 10 feet of the hole was lined with a perforated casing. It seemed impossible to pump a basin around the base of the casing large enough to prevent the sand runs, so that finally the well was abandoned. The presence of the flow of water and the black sand at the 213-foot level in this hole suggest strongly that this point marked the top of the Nushagak formation, and therefore the old erosion surface at the time when the glaciofluviatile deposits were first laid down. If so, this indicates a thickness of these beds at Snag Point of at least 213 feet, and assuming an altitude of 60 feet above sea level for the top of the well gives the depth of the Nushagak formation below sea level at Snag Point as probably at least 150 feet.

[30] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Geol. Survey 20th Ann. Rept., pt. 7, p. 178, 1900.

At Clark Point, near Clark Slough (locally known as Combine Slough), only a few hundred yards from the bay, another well was drilled by the Columbia River Packers Association. According to Fred Peterson, of Clark Point, who was present when the drilling was done, this well was sunk to a depth of 186 feet. At from 20 to 30 feet below the surface this hole penetrated a lens of ice from 2 to 3 feet thick, and at greater depth it passed through several thicker bodies of ice. A short distance below the last body of ice, which was found at a depth of 175 feet, a good flow of water was obtained, but it is said to have been coffee-colored, full of mossy detritus, and unfit for drinking. Bedrock was not reached, but gravel was found in the bottom of the hole.

A third hole, drilled at Naknek, yielded an artesian well with a good supply of free-flowing potable water. The depth of this well is not known to the writer. It therefore appears that in the vicinity of Nushagak Bay glaciofluviatile and fluviatile deposits, in places, have a thickness of at least 200 feet.

About 3 miles south of Clark Point is a point of land known as Ekuk Spit. About 6 or 8 miles southeast of Ekuk Spit a 14-foot mammoth tusk has been washed out of a 20-foot clay bluff and at the time of the Survey party's visit lay on the beach. Another mammoth tusk was found on the west side of Nushagak Bay at Coffee Point, about 8 miles southwest of Kanakanak. These two occurrences of vertebrate remains constitute the only available paleontologic evidence bearing upon the geologic age of these deposits, but they suffice to show that the gravel, sand, and clay that lie above the Nushagak formation are of Pleistocene age.

RECENT DEPOSITS

The postglacial deposits may be divided into three types—the fluviatile deposits that form the valley floors of the present streams; the tide-flat deposits that line the beaches and form the bottoms of Nushagak and Kvichak Bays and their estuaries; and the fresh-water beach deposits along the shores of the Tikchik and Wood River Lakes.

The fluviatile deposits are typically exposed in the valley floor of the Nushagak River but require little description. They consist for the most part of fine to fairly coarse gravel and sand but include also some larger cobbles and boulders a foot or more in diameter, which, however, are sparsely distributed. All the pebbles of the gravel, including the largest ones, are well rounded, and no material of distinctly morainal character was observed. From the headwaters downstream there is little variation in the size of the gravel, until the extreme lower end of the river is reached, where the gravel becomes finer, and finally, near Black Point, the coarser alluvium gives place gradually to tidal silts.

The tide-flat deposits consist of silt and mud, which at most places form the beaches of Nushagak and Kvichak Bays. These muddy tidal deposits are so soft and full of water that a man will sink into them for a foot or two at every step when a landing is made from a boat. At places, however, where the bluff of older deposits occurs close to the water, gravel has been washed out of the bluffs and forms good gravel beaches that give firm footing, but at other places the gravel is only a thin veneer over the mud and is by no means firm. A good gravel beach occurs a few hundred yards east of Snag Point, and it is near this beach that hydroplanes commonly land in order to discharge passengers and freight for Snag Point. Similar good beaches were observed at places along the west side of the Wood River within the lower or estuarine zone of the river.

The mapping of the alluvium in the area of the Tikchik and Wood River Lakes, particularly at their east ends, is more or less conventional. These lakes, though originally barrier lakes that were dammed by unconsolidated materials of glacial origin, are now glint lakes, which occupy essentially bedrock basins. The geologic map shows that in their headwater arms the banks of the lakes are composed of hard rock. In their east ends, however, the banks of these lakes are composed largely of alluvial deposits, but bedrock crops out intermittently and at places for considerable stretches. The bedrock, however, occurs mainly at the water's edge, and back from the lakes is immediately overlain by unconsolidated deposits of all kinds, ranging from the shingle of old beaches to outwash and morainal material. Therefore the bedrock cannot be mapped on the scale of plate 2 without gross exaggeration, nor can it everywhere be shown because of a lack of such recorded data. An attempt has been made, however, to show in part the distribution of alluvium and bedrock at the east ends of these lakes by indicating roughly some of the places where bedrock has been seen under the alluvium, along the beaches.

The unconsolidated deposits in the lake region are covered with heavy vegetation and in general are not visible for examination. In the central zone of the Tikchik and upper Wood River Lakes well-defined sand and gravel beaches occur at short intervals, and where such beaches are bordered by low timber-covered terraces excellent camp sites may be found. Such beaches and camp sites, however, are less common on Lake Aleknagik. At the lower ends of all the lakes the shores are low and swampy, with a growth of marsh grass, though even here bedrock crops out in places. The shingly deposits of the present and older beaches consist of well-rounded and assorted gravel and sand, and owing to the presence of slaty and other thin beds in the country rock much of this gravel is inclined to be discoid in outline. At some places along the lake shores and on projecting spits there is coarse debris which represents glacial material that has slumped into the lakes.

The deposits that constitute the lake terraces are made up of a variety of materials. As a rule, the older terrace fronts lie some distance back from the present beaches, and their lake-facing fronts are in general gentle slopes rather than bluffs and are covered with a growth of shrubby vegetation. These terrace fronts were investigated at some places by means of shallow cuts made with a geologic pick, and the material was found to be essentially similar to that found on the present beaches. The rounding and sorting in this material is due to wave action, but probably such material extends for only a short distance back from these old beach lines, beyond which the alluvium is more likely to be coarse and little sorted, particularly on the higher terraces. The higher gravel also occurs along some of the interlake channels, as for example on the Agulowak and Peace Rivers, where these deposits consist mainly of gravel which forms fairly well defined slopes and bluffs close to the river banks.

The present beach deposits are naturally of Recent age, but the same is not necessarily true of all the beach deposits along the fronts of the older terraces. In fact, though these deposits are here described under the heading "Recent deposits," it is by no means certain that all of them are later than the main glaciation, as glacial lakes undoubtedly began to form concurrently with the retreat of the valley glaciers. As the retreat of the ice is believed to have been a fairly rapid process, however, it is unlikely that the original high-water levels of the lakes were much reduced before the ice tongues had retreated to the heads of the headwater fiordlike arms, and in this sense all but the very highest of these water-worked ancient beach deposits may be regarded as essentially of postglacial age.

IGNEOUS ROCKS

The igneous rocks of the Nushagak district may be divided broadly into two major groups, which differ from each other not only in their geologic age but also in their petrographic character and mode of occurrence. The older of these two groups consists of a series of basic lava flows of Permian age, the distribution and stratigraphic characteristics of which have already been described. In the following pages their petrographic character will be stated.

The second group of igneous rocks consists of granitic rocks that intrude the undifferentiated Cretaceous sedimentary rocks and are considered to be of Tertiary age. These rocks at different localities differ in petrographic character to a degree sufficient to warrant their subdivision into two minor groups, which may possibly represent different epochs of Tertiary intrusive activity.

In addition to these two major groups, there are also a variety of dike rocks, most of which are related genetically either to the Carboniferous volcanics or to the Tertiary intrusives. The petrographic characteristics of some of these dike rocks are also described below.

PERMIAN VOLCANIC ROCKS

The distribution, stratigraphic relations, and age of the Permian volcanic rocks have already been stated, and it remains to describe their petrographic character. They are dark-green to almost black massive rocks which occur mainly in thick beds, so that, though distinctly bedded, the attitude of the beds is not easily discernible. At the base of this sequence, as seen along the north shore of Lake Nuyakuk, the lavas are in contact with Mississippian (?) chert and limestone. These basal beds are distinctly agglomeratic and consist of half-rounded to angular fragments and cobbles of greenstone in a matrix of the same general character, though probably tuffaceous. Some of these basal rocks, however, appear to be ellipsoidal, suggesting that the earliest of the lavas were poured out under the sea. The lavas above these basal beds are massive greenstones, which at many places show a columnar structure, but some tuffaceous beds were also seen somewhat higher in the sequence. In the vicinity of the Red Hills, where the basal beds are also exposed, these rocks lie in contact with the Permian limestone and include much tuffaceous material, some of which is more or less calcareous and appears to have been deposited in shallow water shortly after the deposition of the Permian limestone was completed. These rocks are brownish and give to the hills a reddish appearance when viewed from a distance.

The lavas and agglomeratic rocks range from holocrystalline rocks with a considerable variety in granularity to very fine grained and partly glassy rocks. Nearly all these massive lavas originally had gas cavities, which subsequently were filled with secondary minerals, thus developing an amygdaloidal habit. All these rocks have a greenish hue, but where they are in contact with the water of the lake they have acquired a distinctive bluish-green stain that renders their recognition unmistakable even from a boat some distance offshore.

Under the microscope these rocks are found to consist essentially of normal basalt and diabase, the difference being one of fabric only. Some of them are porphyritic, and in such rocks the phenocrysts are usually plagioclase feldspar, or less commonly pyroxene. The groundmass consists essentially of plagioclase feldspar, augite, and iron ores. Both the feldspar and pyroxene are greatly altered, and in the few sections studied the feldspar is too much altered for accurate determination, though its twinning and general appearance indicate that it is probably close to labradorite. Most of the pyroxene is extensively changed to chloritic minerals and other products. The iron ores are also oxidized in considerable part to iron hydroxides. This altered aspect of the minerals of these rocks gives rise to the so-called greenstone habit.

As the Permian volcanics came to the surface they had to pass through the older rocks, and in this process the magma also produced sills, dikes, and small intrusive bodies in these older rocks, particularly in the Mississippian (?) sequence. Such minor intrusives were observed at many places in the country bordering on Lakes Chauekuktuli and Nuyakuk. Most of these rocks are so essentially similar to the lavas, both in texture and composition, that no separate description of them seems necessary. Among them, however, one hornblende basalt was identified. Like the lavas, they are much chloritized, but some of them are sheared and cut by veinlets of quartz, calcite, and other secondary minerals.

TERTIARY GRANITIC ROCKS

DISTRIBUTION

The granitic rocks occur as good-sized intrusive masses at several localities in the area of the Tikchik and Wood River Lakes. The largest body of such rocks occurs north and south of Tikchik Lake, extending about S. 30° W. from the north side of Tikchik Mountain almost to the top of Agenuk Mountain. The bedrock under the eastern part of Tikchik Lake is probably a part of this intrusive body, so that the total length of the mass is about 15 miles. The width ranges from 3 to 5 miles. The appearance of these granitic rocks along the south side of Tikchik Lake is shown on plate 11, *B*.

The second largest body of granitic rocks forms the bedrock of the north end of the Muklung Hills, and though the geologic map shows two main areas and several small croppings at this locality, separated by alluvium, it is probable that these constitute a single large mass with an elongation similar to that of the Tikchik-Agenuk mass. The length of the granite body in the Muklung Hills is about 7 miles, and the width about 5 miles. Because of their petrographic similarity, the Tikchik-Agenuk and Muklung intrusives are described here as a unit.

A third body of granitic rocks constitutes the country rock at and about Akuluktok Mountain, extending from the head of Silver Horn, a headwater arm of Lake Beverly, in the same general southwesterly direction almost to Lake Nerka. This mass is more irregular in outline but has a length of about 5 miles and a width of 1 to 3 miles. A short distance to the west a small outlying mass of granitic rocks of the same type is exposed along the northeast side of Amakuk Arm, extending northward toward the crest of the ridge. Granitic rocks are reported to occur at the north end of Kemuk Mountain; and according to F. H. Waskey granite has also been found in the vicinity of Sleitat Mountain. Smaller apophyses of the granitic rocks, which have not been mapped, may also be present.

A small mass of granitic rock, of somewhat more basic character than those heretofore mentioned, occupies the crest of the ridge between the lower end of Lake Kulik and the upper end of Lake Beverly.

Two small bodies of granitic rocks which are little larger than dikes were found along the ridge top southwest of Sunshine Valley, at the head of Lake Aleknagik. Dikes of acidic and intermediate character, both coarse- and fine-grained, have also been found at numerous localities within this district.

PETROGRAPHIC CHARACTER

The granitic rocks of this district include granite, quartz monzonite, granodiorite, and quartz diorite, and their fine-grained equivalents, but the monzonitic rocks have certain distinctive features which suggest that they may represent a different stage if not a different epoch of intrusion. Though these varieties of granitic rocks have all been recognized, it is nevertheless true that the larger bodies, such as those above mentioned, fall naturally into two general groups, granite and quartz monzonite; and the other types are magmatic variants that occur mainly as dikes and other small intrusive bodies.

The rocks composing the Tikchik-Agenuk mass and the body exposed at Muklung Hills are coarse-grained light-colored granites. Such rocks probably offered less resistance to glacial erosion than the harder, well-indurated members of the sedimentary sequence. Moreover, they disintegrate rapidly under the influence of the weather, so that fresh samples are not everywhere available. The granitic rocks at the east end of Tikchik Lake and those of the Muklung Hills have also been exposed to the weather longer than others farther west, because the glaciers retreated first from the eastern part of the area. For these reasons the eastern hills made up of these rocks are low, smooth, and inconspicuous. Within the main masses most of these rocks are uniformly coarse-grained, but along the edges of the intrusives some finer-grained porphyritic types were seen. In the coarse-grained varieties the mineral particles commonly range in size from 2 to 5 millimeters and with the unaided eye can be seen to consist essentially of quartz, feldspar, and biotite.

Under the microscope the feldspar is found to be dominantly microcline or orthoclase. In some specimens a little albite is perthitically intergrown with the microcline, but in others a small amount of acidic plagioclase is present as separate grains. Dark minerals, of which biotite is the most common, compose a rather small proportion of these rocks. Hornblende, though not common, is also present in some of the rocks from the Muklung Hills, and small amounts of muscovite and diopside were found in the rocks of the Tikchik-Agenuk area. The accessory minerals include some iron ores, apatite, titanite, and zircon.

The granitic rocks of the Akuluktok Mountain area are finer-grained than those above described and show more textural and petrographic variations, but petrographically and chemically the more common types do not appear to be essentially different. Though some porphyritic types are present, most of these rocks are rather uniformly granular, with individual grains that range in general from 1 to 2 millimeters in size, rarely reaching 5 millimeters. They consist essentially of quartz, potash feldspar, and dark minerals, mainly biotite. Perthitic intergrowths of microcline and albite are not unusual, but orthoclase and a small amount of acidic plagioclase are also rather common. In some specimens the quartz shows strain shadows and has an undulatory extinction. In the granitic types the acidic plagioclase is either albite or oligoclase, and hornblende, though present, is less abundant than biotite. The same accessory minerals are present as above noted. Among these rocks, however, numerous specimens were found of types that are best described as granodiorite. These differ from the granites in the fact that plagioclase is the dominant feldspar and potash feldspar is relatively scarce. In several specimens the plagioclase was determined to be andesine, but some of the andesine is zonally grown with more acidic varieties. It is probable that these granodioritic types were intruded somewhat later than the main granitic mass.

The granitic rocks that crop out on the ridge between Lakes Kulik and Beverly were found to be dominantly quartz monzonite, with which are associated, however, some more basic types, classified as pyroxene diorite. The quartz monzonites are granular rocks, comparable in the size of their grains with those of Akuluktok Mountain, but because they contain a larger proportion of dark minerals, they are darker in color. They are made up essentially of orthoclase and plagioclase in about equal amounts, quartz, and much biotite and pyroxene, together with accessory iron ores, apatite, and titanite. In the more acidic types the plagioclase feldspar has been determined to range from oligoclase to andesine, but in the pyroxene diorites the plagioclase lies between andesine and labradorite. In the monzonitic types quartz is less abundant than in the granites, and in the pyroxene diorites it is either scarce or absent. Biotite and pyroxene are present in nearly all these rocks, and hornblende in some of them. Some of the biotite is more or less chloritized. The pyroxene is a diopsidic augite, some of which is also chloritized. Apatite is more common than in the granitic rocks and is particularly plentiful in the pyroxene diorites.

The granitic rocks that occur as small intrusive bodies, dikes, inclusions, and border facies exhibit a wide range of fabric, granularity, and composition. Among the finer-grained types rhyolite porphyry and dacite porphyry have been found, and in the coarser types porphyritic granites and granodiorites are present. Along the north shore of the north arm of Lake Nerka a dike or perhaps a small intrusion of diorite was observed, in which the dark minerals were found to be chloritized biotite and brown hornblende. At a locality along the south shore of Lake Chauekuktuli, about 1½ miles west of the shore cropping of the Mississippian (?) limestone, another igneous rock containing brown hornblende was found as a dike rock. This rock, which is probably dioritic, contained so large a percentage of brown hornblende that it may be considered to belong to the vogesite-spessartite series. At another locality along the west side of the Akuliktok Mountain mass a peculiar granitic type was collected, which consisted of the high-temperature variant of orthoclase, sanidine, together with quartz, much biotite, and a little garnet and iron ores. On account of the high percentage of biotite this rock approaches a minette. Along the ridge southwest of Sunshine Valley a variety of granitic rocks were found as dikes and small intrusive masses. Among these are granite porphyry, porphyritic granodiorite, quartz monzonite, and andesite (?) porphyry. These rocks are not essentially different from those already described, except that in most of them the feldspars are altered by sericitization. It is of particular interest that the monzonitic type here occurs in close association with the granite and granodiorite.

CHEMICAL CHARACTER

To learn more regarding the chemical composition of the granitic rocks, three samples were submitted to the chemical laboratory of the Geological Survey for complete analysis. All three of these samples were composed of a number of specimens, which were taken and mixed with the intention of obtaining composite samples that would represent the average composition of these intrusives. Sample 35AMt41 represents the granite of the Tikchik-Agenuk mass, which appears to be rather uniform in granularity and composition. As the granite of the Muklung Hills was essentially similar, no analysis was made of rock from this intrusive body. Sample 35AMt105 is a composite sample of the granitic rocks of Akuluktok Mountain and included specimens from the northern, central, and southern parts of this mass. Sample 35AMt601 is a composite sample of the intrusive mass that occurs on the ridge between Lakes Kulik and Beverly. In addition to the analytical work, spectroscopic tests were also made for certain metals by George Steiger, of the Geological Survey.

In order to compare the chemical composition of these three samples with that of Alaskan granitic rocks of other types and ages, five additional analyses have also been tabulated. The first of these represents a composite sample of the granodiorite of the Coast Range intrusives, collected by Buddington[31] in southeastern Alaska, and analyzed by J. G. Fairchild, of the Geological Survey. The granodiorite of the Coast Range was considered by Buddington to be of approximately Upper Jurassic or Lower Cretaceous age. The second and third are analyses of granites, collected by the writer from the Ruby and Circle districts of interior Alaska. Both of these granites have been referred questionably to the Mesozoic, with the alternative that they may be of early Tertiary age. The fourth and fifth are analyses of monzonitic rocks from the Iditarod and Nixon Fork districts of southwestern Alaska, considered to be of Tertiary age. The four analyses last named were made by E. T. Erickson, of the Geological Survey. None of these analyses, except the one given by Buddington, have heretofore been published.

Analyses of granitic rocks from Alaska

	1	2	3	4	5	6	7	8
SiO_2	76.32	75.71	66.67	64.87	74.02	75.98	57.16	64.84
Al_2O_3	12.27	12.72	14.95	16.26	12.02	11.70	16.88	15.20
Fe_2O_3	.54	.14	.71	1.51	.92	.39	.26	.73
FeO	1.38	1.50	3.80	2.89	2.72	2.24	5.36	4.18
MgO	.25	.08	1.38	1.72	.69	.30	4.78	2.02
CaO	.81	.90	3.03	4.72	1.46	.58	4.08	3.04
Na_2O	3.54	4.15	3.55	3.82	3.22	2.73	4.67	4.03
K_2O	4.50	4.52	4.07	3.30	4.28	5.46	5.32	4.55
H_2O+	.39	.43	.78	.28	.28	.42	.69	.41
H_2O-	.08	.10	.11	None	.09	.05	.04	.04
CO_2	None	None	None	--------	.04	Trace	.11	.48
TiO_2	.18	.15	.75	.70	.26	.22	.30	.30
P_2O_5	.04	None	.16	.19	--------	--------	------	------
MnO	.05	.03	.07	--------	.05	None	.08	.06
BaO	None	None	None	--------	--------	--------	------	------
SrO	None	None	None	--------	--------	--------	------	------
Total	100.35	100.43	100.03	100.26	100.05	100.07	99.73	99.88

1. 35AMt41 (granite).
2. 35AMt105 (granite).
3. 35AMt601 (quartz monzonite).
4. Granodiorite of the Coast Range (Buddington).
5. 34AMt70 (granite from head of Flint Creek, Ruby district).
6. 34AMt71 (granite from Mammoth Creek, Circle district).
7. 33AMt99, 100, and 101 (monzonite from head of Flat Creek, Iditarod district).
8. 33AMt72 (quartz monzonite from head of Hidden Creek, Nixon Fork district).

[31] Buddington, A. F., and Chapin, Theodore, Geology and mineral deposits of southeastern Alaska: Geol. Survey Bull. 800, p. 216, 1929.

These analyses have been computed into normative molecules, by the methods given by Cross, Iddings, Pirsson, and Washington.[32] To the writer it seems of little practical utility to compute norms to a hundredth of a percent, particularly when the molecular proportions are derived from the analyses in such a way that the last figure of the norm is consistently in error. However, as it is conventional to tabulate norms to a hundredth of a percent, this usage has been followed, but in the computation the molecular proportions have been carried to an extra decimal, in order to insure accuracy in the last digit of the norms. It will be observed that the norm given for the granodiorite of the Coast Range differs from that published by Buddington.[33] This arises, first, from the fact that MgO and FeO were allocated in different ratios to the diopside and hypersthene molecules, and, second, because TiO_2 was allotted to titanite instead of to ilmenite. These eight norms and their symbols in the quantitative classification are given below:

Norms of granitic rocks from Alaska

	1	2	3	4
Quartz	35.67	31.54	20.21	17.60
Corundum	.18			
Orthoclase	26.63	26.74	24.07	19.52
Albite	29.92	35.05	30.03	32.28
Anorthite	3.75	2.70	12.79	17.43
Diopside		1.57	1.03	3.92
Hypersthene	2.51	1.80	8.20	5.29
Magnetite	.79	.21	1.02	2.18
Ilmenite	.33	.29	1.44	1.32
Apatite	.10		.37	.44
Semitotal	99.88	99.90	99.16	99.98
Water and CO_2	.47	.53	.89	.28
Total	100.35	100.43	100.05	100.26
Symbol	I.(3)4.1".3	I."4.1(2).3	I(II).4.2.3	(I)II.4.(2)3.3

	5	6	7	8
Quartz	33.36	35.96		12.56
Corundum		.22		
Nepheline			4.24	
Orthoclase	25.30	32.30	31.47	26.91
Albite	27.20	23.06	31.64	34.06
Anorthite	5.67	2.89	9.34	9.90
Diopside	1.35		8.95	4.34
Hypersthene	4.94	4.19		9.56
Olivine			12.31	
Magnetite	1.32	.56	.37	1.07
Ilmenite	.49	.41	.56	.56
Apatite				
Semitotal	99.63	99.59	98.88	98.96
Water and CO_2	.41	.47	.84	.93
Total	100.04	100.06	99.72	99.89
Symbol	I".(3)4."2."3	I.3(4).1".2"	II.5.2.3	"II.4(5).2.3

[32] Cross, Whitman, Iddings, J. P., Pirsson, L. V., and Washington, H. S., Quantitative classification of igneous rocks, Univ. Chicago Press, 1903.

[33] Buddington, A. F., op. cit., p. 216.

These analyses and norms bring out some interesting facts. First will be observed the marked similarity between the granites of the Nushagak district (columns 1 and 2) and the granites from Ruby and Circle (columns 5 and 6) in the upper Yukon Valley. All four are very siliceous rocks, ranging from 74 to 76 percent of silica and from 31 to 36 percent of normative quartz. The only granular igneous rocks at present known in Alaska that are as siliceous or more siliceous than these are five dike rocks of aplitic character, collected by Spurr,[34] which range in their content of silica from 75 to 77 percent. The siliceous character is also indicated by the low percentage of femic or dark-colored minerals, as a result of which all four of these rocks fall into class 1 of the quantitative system. The feldspars in all four rocks are highly alkalic, as is indicated by the fact that all belong either in rang 1 or in rang 2 veering to rang 1. This feature also shows in thin section by the perthitic intergrowths of microcline and albite, and by the small percentage of plagioclase feldspar as basic as oligoclase. Finally, all belong either in subrang 3 or in subrang 2 veering to subrang 3, showing a general but slight preponderance of potash over soda.

The intrusive rock from the ridge between Lakes Kulik and Beverly (column 3) is distinctly less siliceous, and this feature shows not only in the small amount of normative quartz but also in the higher percentage of dark-colored minerals. On the other hand, it does not conform exactly with the monzonitic rocks of southwestern Alaska, as exemplified by the intrusives from the Iditarod and Nixon Fork districts, though it is not greatly dissimilar to the latter. It resembles the quartz monzonite from Nixon Fork (column 8) in that the ratio of potash to lime-soda feldspars is nearly the same, but it differs in having more normative quartz and less normative diopside and hypersthene. Actually neither the intrusive from the ridge between Lakes Kulik and Beverly nor the intrusive from the Nixon Fork district, if classified on the basis of normative feldspar alone, is a true monzonitic rock, because their ratios of potash to lime-soda feldspar are, respectively, 1:1.6 and 1:1.7, as compared with the theoretical limits of 1:1.5. Both, however, have certain characteristics, such as the constant appearance of augite in their modes, that relate them much more closely to the monzonitic rocks of southwestern Alaska than to the granitic rocks of interior Alaska. Both these rocks have therefore been described by the writer as quartz monzonites, though they might more accurately be designated grano-monzonites. In the quantitative system of classification of igneous rocks the difference between these monzonitic rocks of southwestern Alaska and the

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[34] Spurr, J. E., Am. Geologist, vol. 25, pp. 231–233, 1900. Clarke, F. W., Analyses of rocks from the laboratory of the U. S. Geol. Survey, 1880–99, p. 229, 1900.

siliceous granites of interior Alaska is suggested by their tendency to fall into class 2 instead of class 1, and as the class is based upon the ratio of salic to femic minerals, this tendency indicates their more basic character. Their greater basicity is also shown by the universal assignment of the monzonitic rocks to rang 2 instead of rang 1, a difference that is based upon the ratios of (K_2O+Na_2O) to CaO.

Comparing both the granites and the monzonitic rocks with the granodiorite of the Coast Range, as exemplified by the composite analysis of Buddington's samples (column 4) shows that the latter has some of the characteristics of both the former but also shows certain differences. Though more basic, as measured by normative feldspar, than either the granites or the quartz monzonite (column 3), the granodiorite still belongs in class 1, showing its relatively low percentage of dark minerals. On the other hand, it belongs in the same rang as the quartz monzonite—that is, rang 2—thus showing a similar ratio of (K_2O+Na_2O) to CaO, but the percentage of the anorthite molecule is definitely greater, and as the percentage of albite is much the same as in the monzonitic rocks, a lower percentage of potash feldspar is indicated. This lower percentage of K_2O shows up clearly both in the chemical analysis and in the normative orthoclase.

To summarize these mineralogical and chemical characteristics, it appears that three types of granitic rocks, only two of which occur in the Nushagak district, are represented by the analyses given above. First, there is a highly siliceous granite; second, a group of monzonitic rocks, which are characterized by greater basicity and a much higher percentage of dark-colored minerals, among which augite and biotite are the usual modal types; and third, the granodiorite of the Coast Range, which is less silicic than the granites and comparable in this respect with the monzonitic rocks. It differs from the monzonitic rocks, however, in having a low percentage of dark minerals, which relates it to the granites, and in having a lower percentage of normative orthoclase and a higher percentage of normative anorthite than either the granite or the quartz monzonite.

CONTACT ALTERATION

The larger bodies of granitic rocks have produced considerable alteration of the sedimentary rocks along their peripheries. At some localities these contact effects are noticeable, even at a distance, by the reddish color of the sedimentary rocks close to the intrusives. The rocks bordering the south end of the intrusive mass of Akuluktok Mountain afford a good example of this alteration. On closer inspection this reddish color is found to be caused by the deposition of oxides and hydroxides of iron along the cleavage, joint, and bedding planes of the bordering sedimentary rocks, for a distance of a quarter of a mile or more from the surface outcrops of the granitic rocks. This process has clearly been caused by the deposition of iron salts from heated mineral-bearing solutions that penetrated the sedimentary rocks through connecting crevices. It is also apparent that this process has been most effective in those rocks which, through folding and fracturing, had developed the largest number of cleavage, joint, and bedding planes. The source of the heated water and of the contained mineral salts, however, is not so clear. These waters may have been of either connate or meteoric origin, and the contained minerals may either have ascended with the connate waters or may have been leached from the intrusive or the sedimentary rocks. If the water was of meteoric origin and the intrusive was injected close enough to the surface to affect the zone of underground water, these solutions may have been heated at the time of the granitic injection. But if the water was of meteoric origin and the injection occurred at moderate or great depths, the heated solutions could not have existed until erosion had sufficiently denuded this region, so that the zone of underground water was extended downward to the intrusive mass. The thermal metamorphism of the bordering sediments, as described below, rather favors the idea of intrusion at considerable depth, but the character of the mineral salts does not favor their origin from connate granitic water. Regardless, however, of the absolute depth of the granite of Akuluktok Mountain below the surface at the time of its intrusion, it seems most probable that the reddening of the nearby sedimentary rocks was caused by heated meteoric waters, possibly long after the injection had occurred but before the granitic rocks had thoroughly cooled. The iron contained in these solutions may easily have been leached from the sedimentary rocks, most of which contain about 5 percent of FeO.

The same reddening of the country rock is visible along the ridge southwest of Sunshine Valley, where only a few small croppings of granitic rocks occur. It is believed that at this locality a larger body of granitic rocks lies at no great distance below the surface, so that the visible red border effects are those produced above the apex of an intrusive mass, rather than along its borders. If this interpretation is correct, this locality should be a favorable site for prospecting for deposits of metalliferous ores.

To judge from the character of the sedimentary rocks close to the granitic rocks, these intrusives have tended to follow argillaceous beds, rather than graywacke, in the process of their injection. Such argillaceous rocks are likewise more prone to be altered by thermal metamorphism than the more siliceous and feldspathic massive rocks. Hence, in the vicinity of most of these intrusives altered phases of the argillaceous rocks are rather common, but altered graywacke is also found. Some of the argillaceous rocks along the south side of Akuluktok Mountain close to the granite show only incipient recrystallization to biotite, but others are more thoroughly recrystallized to biotite and quartz, with sporadic crystals of green hornblende, and intersected by fine seams of quartz. Another phase of the recrystallization at this same locality is the development, along with fine-grained biotite and quartz, of phenocrysts of fresh, unaltered labradorite. One of the most complete examples of recrystallization and replacement was observed in the contact rock at the north end of the intrusive mass at Akuluktok Mountain, where the country rock is altered to a panidiomorphic groundmass of fine quartz, in which are set larger crystals of biotite and some garnets. Rocks of the graywacke type, which show the effects of thermal and contact metamorphism, were also observed in places along the south margin of the intrusive. In such rocks the groundmass is similarly recrystallized to fine-grained biotite and quartz, but the original detrital grains of plagioclase are either sericitized or are replaced by quartz and albite. Along the border of the intrusive of the Muklung Hills, a contact rock of unique type was seen at one locality. This was found under the microscope to consist mainly of greenish pyroxene and quartz, with some apatite and a little interstitial alkali feldspar, either orthoclase or albite.

It should be emphasized that the contact-metamorphic effects above outlined were observed in the vicinity of the granite intrusives and were not seen to the same extent around the periphery of the quartz monzonite on the ridge between Lakes Kulik and Beverly. These facts suggest that the granites were injected at a considerable depth below the surface that existed at the time of the intrusion. Such facts likewise suggest, though they do not definitely prove, that the quartz monzonite may have come closer to the surface that existed at the time of its injection. But as the granite of Akuluktok Mountain, and the quartz monzonite on the ridge between Lakes Kulik and Beverly occur in masses of the same general order of magnitude; and, further, as both types occur together in the ridge southwest of Sunshine Valley, it would appear probable that the quartz monzonite represents a later intrusion, which took place after a considerable part of the original cover above the granites had been denuded. These facts also suggest that this difference in age does not represent merely an intrusive body shattered after or during its cooling stage and invaded by a magmatic residue, such as forms late aplitic or pegmatitic dikes. On the contrary, there is suggested a second and distinctly later epoch of intrusion when the quartz monzonite was injected.

AGE AND CORRELATION

As no determinable fossils have been found in the sequence of sedimentary rocks that extend from Lake Nuyakuk southward to the flats about Nushagak Bay, the age of the granitic rocks that have invaded them cannot be determined from paleontologic evidence. From stratigraphic and lithologic evidence, however, which has been given on pages 59 and 60–61, it is inferred that this series of sedimentary rocks is largely of Cretaceous age and that the more southerly part of the sequence may be as young as Upper Cretaceous. The granitic rocks are found both in the older and in the younger groups of the undifferentiated Cretaceous rocks, but it cannot be inferred that the latest Cretaceous sediments have been intruded, first because the amount of these sediments that has been removed by erosion is unknown, and second because the stratigraphic sequence of the uneroded rocks is not sufficiently well known to recognize with assurance the youngest part of the sequence. The direct stratigraphic evidence, therefore, indicates merely that the granitic intrusion occurred after some of the later undifferentiated Cretaceous sediments had been deposited.

It is rather unlikely, however, that the Cretaceous sediments were intruded while they were still flat-lying, little-indurated beds. In fact, the stratigraphy gives some indication on this point, for granitic rocks of the same composition and texture are found in the vicinity of Tikchik Lake, in the basal part of the Cretaceous system, and at the Muklung Hills, in what appears to be the upper part of the system. It is therefore believed that the Cretaceous rocks were folded before the granitic rocks were injected, and it is not unlikely that they were also elevated above the sea and exposed to erosion before the invasion of the granitic rocks. Yet even without a stratigraphic basis, this assumption of general contemporaneity between tectonic movements and volcanism is not illogical. Such considerations suggest strongly, though they do not necessarily prove, that the granitic rocks of this area are of Tertiary age; and they are thus shown on the explanation that accompanies the geologic map.

Petrographic comparisons are generally regarded as unsafe criteria for correlating granitic rocks from different regions, yet such similarities or differences in granitic rocks from different parts of Alaska may have more significance than is now realized. It should therefore be observed that the petrographic and chemical characters of the granite of the Nushagak district are essentially similar to those found in some of the smaller bodies of granite in the Yukon Valley, as at Ruby and at Circle.

The granites at both Ruby and Circle, in the absence of stratigraphic data in those regions, have more or less conventionally been regarded as of Mesozoic age, but it is entirely possible that many of the so-called Mesozoic granitic rocks of interior Alaska may subsequently be found to be of Tertiary age. The monzonitic rocks from the ridge between Lakes Kulik and Beverly, however, resemble very much the quartz monzonite from the Nixon Fork district, and they also resemble some of the monzonitic rocks of the Rampart district. The monzonitic intrusives in the Nixon Fork and Rampart districts have been considered to be of Tertiary and possibly of mid-Tertiary age.

The facts now known with regard to the age of the post-Paleozoic granitic rocks of Alaska are these: The earliest of such granitic intrusions took place sometime, and perhaps intermittently, in the interval between late Middle Jurassic and early Lower Cretaceous time. This, the greatest of all granitic injections in Alaska, gave rise to the Coast Range batholith. For stratigraphic, lithologic, and petrographic reasons already presented the granitic rocks now known in the Nushagak district are not believed to have originated at this time.

The second period of post-Paleozoic granitic injection occurred in late Upper Cretaceous or early Tertiary time. The evidence for this conclusion is described in the various geologic reports on parts of the Alaska Range, but it is not within the scope of this report to review that evidence. The granites of the Nushagak district certainly belong to this same epoch of intrusion, and the conclusion favored by the writer is that this injection occurred in early Tertiary time. This statement, while it correlates the granites of the Nushagak district with similar granitic rocks in the Alaska Range, does not necessarily correlate them with all the granites of the Yukon Valley, though the petrographic characters make a correlation with some of those granites appear possible. It is known that granitic rocks of two distinct ages are present in the Yukon-Tanana region, and it is probable that three epochs of intrusion are represented. Hence it may not be inappropriate to correlate the granites of the Nushagak district with some of the similar granites of the Yukon-Tanana region, with the proviso that both older and younger granitic rocks are probably also present in that region.

The correlation of the quartz monzonite from the ridge between Lakes Kulik and Beverly with similar monzonitic rocks elsewhere in Alaska must necessarily be based largely upon comparative petrographic studies and is therefore correspondingly inconclusive. The mineralogic and chemical similarity of this monzonitic intrusive, however, to numerous other rocks of the same general character, from the Rampart district southwestward in southwestern Alaska, is highly suggestive though not conclusive evidence of their consanguinity. All these monzonitic rocks are believed to be of Tertiary age, and at some localities stratigraphic and other evidence suggests that they may all represent a third, distinct epoch of granitic intrusion that occurred in mid-Tertiary time.

For the reasons already given, as well as from analogy with conditions of granitic injection in other parts of Alaska, the monzonitic rocks are regarded as probably injected as the latest phase of granitic activity in the Nushagak district, though no absolute proof of this interpretation can be cited. Under such a hypothesis, the granites of the Nushagak district may be regarded as early Tertiary, whereas the quartz monzonite may possibly be of mid-Tertiary age.

MINERALIZATION AND PROSPECTING

In the preceding pages the sedimentary and igneous bedrock geology has been described, and the physical geography of the present surface has been in some measure analyzed. From these facts certain conclusions may be drawn as to whether the Nushagak district is a favorable area in which to prospect for mineral deposits.

Mineral deposits include many kinds of raw materials found in nature, but all inorganic and some organic products, if they occur in air, water, or ground, are classified into two general types of deposits—metalliferous and nonmetalliferous. Many nonmetalliferous deposits occur in Alaska, but on account of high costs of production, high freight rates to markets, and other causes, few such deposits now have significant economic value, except for local use. In the Nushagak district there is, for example, an abundant supply of gravel that is suitable for road-building and has been excavated and used in building the Snag Point-Kanakanak road. In a similar way the Nushagak district might yield many other nonmetallic mineral products, such as building stone, clay, lime, and cement materials, but all such products are practically valueless at the present time, as there seems to be little local demand for them. On the other hand, coal deposits, which might possibly be of local economic value, have not been found in the Nushagak district.

The same economic considerations that apply to the nonmetalliferous minerals apply likewise to most of the metalliferous deposits. Large supplies of ores of iron, copper, lead, zinc, and other common metals are available in the United States, so that even if such ores in workable quantities could be located in the less accessible parts of Alaska, they would not have any immediate commercial value. Ores of certain metals, such as tin and nickel, in which the United States is deficient, would be valuable if found in workable deposits, but no evidence of the presence of such metals has yet been found in the Nushagak district.

There remain the precious and semiprecious metals, such as gold, silver, and platinum, as possible metalliferous resources. These metals may occur either as lodes or as placer deposits, but as mineralized rock must exist as a source for placer deposits, the possible occurrence of lodes of the precious and semiprecious metals is of prime consideration. It is now a well-known fact that gold and silver ores are genetically related, either directly or indirectly, to granitic rocks. Experience in Alaska has also shown that such lodes are more likely to be found in or near small bodies of granitic rocks than in the vicinity of the larger masses. This is believed to result from the facts that hot mineral-bearing solutions tend to move upward along the flanks of cooling masses of granitic rocks and to be precipitated at or near the apices of such bodies, and that many small areas of granitic rocks represent merely apophyses projecting upward from larger masses of the same rocks that lie below the surface. Hence, any or all such small areas of granitic rocks in the Nushagak district are potential sites of gold and silver ores. On the other hand, it is equally well recognized that only a small percentage of such areas will prove to contain commercial ores, and in the present state of knowledge regarding such matters the best way of locating productive areas is to prospect for them. The mapping of the granitic areas, however, is an important preliminary step, as it saves much prospecting in areas where the chances of finding ores of gold and silver are almost nil.

On the accompanying geologic map several areas of granitic rocks are shown. These, however, are not the only areas where such rocks occur, as the exigencies of reconnaissance mapping do not permit the careful examination of all the country. This is not only true for the unmapped parts of the Nushagak district but is hardly less true for the mapped area, as it is easily possible in reconnaissance mapping to overlook small granitic areas, and these smaller areas may have as much significance as sites of ore bodies as the larger areas. In places, also, the granitic rocks are not exposed at the present surface but lie at so short a distance below the surface that they may easily have caused important mineralization. Usually, however, at such places small apophyses, dikes, or quartz veins will show at the surface and give a clue to the subsurface proximity of intrusive rocks. This condition is well exemplified along the ridge southwest of Sunshine Valley, at the head of Lake Aleknagik, and it should be added that a diffuse type of mineralization has been recognized along this ridge and a little placer gold has been found by prospectors in one or more of the streams leading northward from it.

Reference has already been made to the analyses of three of the granitic rocks of the Nushagak district. These rocks were also examined spectroscopically by George Steiger, of the Geological Survey, for traces of the rarer metals. As a result of this work the granites near Tikchik Lake and at Akuluktok Mountain both showed two persistent lines characteristic of silver, and the granite of Akuluktok Mountain also showed a single beryllium line. These tests were made by placing the powdered granitic rock directly in the arc and therefore obviate any possible contamination from other laboratory chemicals, as might occur if the material had just been fused with a flux. Such tests are capable of detecting quantities as small as 0.01 or 0.02 percent but will not show 0.001 percent. No spectroscopic tests were made for gold. The presence of silver in quantities as great as this in granitic rocks that were not visibly mineralized is an encouraging feature, as it indicates that silver and possibly gold were associated with these particular granitic intrusives, but it does not necessarily indicate the presence of commercial lodes. The prospector for lodes of gold and silver is therefore advised to concentrate his efforts around the mapped and unmapped areas of granite, in order to save much useless effort in other areas where there can be little or no probability of finding ore deposits.

The platinum metals are commonly associated with intrusive rocks of ultrabasic character, such as peridotite or pyroxenite. Within the areas of the Tikchik and Wood River Lakes, where the rocks were mapped by the writer, no such ultrabasic rocks were observed. It should be noted, however, that such rocks and important placer deposits of platinum metals have been found in recent years in the Goodnews Bay district, about 100 miles west of Lake Aleknagik. Inasmuch as all of the Nushagak district has not been mapped, it would be well for prospectors to have in mind the possible occurrence of such deposits.

To the prospector with small capital, who is interested in obtaining quick returns for his work, placer deposits are of more importance than lodes. Placer deposits may be found at any locality where there are lodes that can act as a source of metals, but in general they are best developed in areas where prolonged and undisturbed stream erosion and concentration have taken place. These conditions exist in the highest degree in unglaciated regions of low relief. Interior Alaska, for example, has not been regionally glaciated, and there, in areas lying from 600 to 1,000 feet above sea level, most of the highly productive placer camps of Alaska are located. Placer deposits occur in some glaciated regions, however, as, for example, in the Cache Creek and Valdez Creek districts, but generally the odds are against finding commercial placers in glaciated areas, as the heavy metals are likely to be greatly disseminated in glacial or glaciofluviatile deposits. The formation of placer deposits from such disseminated metals requires that the postglacial or present streams must have accomplished a great deal of concentration of these elements in a relatively short time; and the conditions necessary for such concentration are not commonly present in recently glaciated regions.

On applying these facts to the Nushagak district, it will appear at once that the region of the Tikchik and Wood River Lakes is not a favorable site in which to search for high-grade placer deposits. This is due in part to the fact that any preglacial placers would probably have been scoured out and dissipated by glacial action, but also to the fact that most of the streams have high gradients and therefore have not been thoroughly effective in the concentration of heavy metals. Moreover, even if their gradients were lower, they have scarcely had time since the retreat of the ice to develop continuous and high-grade placer deposits.

These considerations, however, do not apply to the Nushagak Hills or to the country north and east of the Nushagak district. Practically the entire Nushagak Valley, within the area shown on plates 1 and 2, with the exception of the headwaters of its western tributaries, is unglaciated. To the east of the mapped area, the lower half if not two-thirds of the Mulchatna Valley is likewise unglaciated. The Aniak and Holitna Rivers and their tributaries drain the region north of the Nushagak district, and both these streams occupy unglaciated valleys. Moreover, the Nushagak Hills and most of the region contiguous to the Nushagak district on the north and east are areas of relatively low hills, drained by streams of moderate gradient so that the physiographic conditions required for concentration of gold into workable placers are excellent.

Such favorable physiographic conditions, however, have no significance unless the geologic conditions are such that mineralization has occurred in the country rock. The presence of granitic rocks is the most important desideratum, if gold lodes or placers are to be found. Kemuk Mountain, east of the glaciated area, and Tikchik Mountain and the Muklung Hills, at the eastern edge of the glaciated area, are the sites of granitic intrusives and are therefore better sites for placer prospecting than the Tikchik Mountains proper. If bodies of granitic rocks are present in the Nushagak Hills, that area should be an even better site for prospecting; but not enough work has yet been done by the Geological Survey to determine definitely whether granitic rocks are there present. The same lack of definite information also applies to the Aniak, Holitna, Hoholitna, and Mulchatna Rivers, but no reasons are known why granitic rocks should not be expected to occur in the Nushagak Hills and in the contiguous areas north and east of the Nushagak district.

The prospecting that has already been done indicates that gold is widely distributed in the eastern part of the Nushagak district and in contiguous areas to the north and east. Some of these occurrences of gold were summarized for the Geological Survey by Mr. F. H. Waskey and are outlined below.

It is stated that flour gold may be panned on Keeler's Bar, on the Nushagak River about a mile downstream from the inlet to Scandinavian Slough. Some coarse gold has been found along the northeast slopes of the Muklung Hills, in a tributary of the Kokwok River; and fine gold has been found along both the north and west slopes of Tikchik Mountain. In the vicinity of Sleitat Mountain, south of the Nushagak Hills, a small body of granitic rocks was located years ago, and along their periphery were found some small gash veins, from which lode gold to the value of $200 was recovered; and a few coarse colors of gold were found on a nearby creek. Colors of gold have also been found on a headwater tributary of the Nushagak River, known by the natives as the Pulchatnachakcharak River, which flows northward into the Nushagak River in the northeastern part of the Nushagak district. Another headwater tributary of the Nushagak River, known locally as Caribou Creek, which is beyond the mapped area, is said to have been the site of some small-scale gold placer mining in the early days succeeding the stampedes of 1900. Some coarse gold was also found in the upper valley of the King Salmon River in 1907. The headwater region of the Holitna River has not yet been visited or mapped by the Geological Survey, but some prospecting for gold placers was being done in 1933 about 12 miles east of Nishlik Lake, so that there appears to be evidence of mineralization in the country drained by the West Fork of the Holitna and the King Salmon Rivers.

East and northeast of the Nushagak Hills gold has been found at a number of localities in the Mulchatna Valley. In fact, gold was discovered on the Mulchatna River as early as 1890, and since that time this valley has been a site for prospecting and even for gold placer mining on a small scale, though no commercial placers of importance have yet been located; but prospecting and development work may be expected to be slow in areas as inaccessible as the Mulchatna Valley.

In the absence of geologic information showing the presence or absence of granitic rocks in the areas above mentioned, the presence of gold, whether in workable deposits or otherwise, is of much significance. The wide distribution of the reported occurrences of gold indicates that the country rock has been intruded and presumably mineralized at numerous sites. These facts are certainly favorable indications and taken together suggest strongly that gold placers may possibly be found in the northeastern part of the Nushagak district and in contiguous areas to the north and east. Such areas, at least, must be rated as favorable for prospecting.

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