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THE LAKE CLARK-CENTRAL KUSKOKWIM REGION ALASKA

BY

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ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

The lower part of the Kuskokwim Valley has long been known, for it was explored by the Russians in the first half of the eighteenth century. During the Russian occupation of Alaska a trading post was maintained at Kolmakof, on Kuskokwim River near the one hundred and fifty-eighth meridian. This post was reached from Bering Sea, and when the Russians charted Kuskokwim Bay they mapped the river as far up as Kolmakof. Little was known of upper Kuskokwim River, however, until 1898, when it was explored by J. E. Spurr and W. S. Post, of the Geological Survey. This expedition practically completed the exploration of the Kuskokwim, though the exigencies of travel permitted no detours into adjacent areas. The Iliamna region had been in part explored before 1909, but most of it was relatively little known until that year, when G. C. Martin and D. C. Witherspoon covered it by an extensive geologic and topographic reconnaissance survey. The discovery of placer gold in the Innoko and Iditarod districts has led to surveys of the region west of the Kuskokwim.

The exploration of the Lake Clark-Central Kuskokwim region, the results of which are here set forth, was planned to tie together the surveys of the Iliamna region on the east and those of the Kuskokwim on the west. It traversed a field that was almost unknown except through the reports of a few prospectors and fur hunters, and therefore its results replace a nearly complete blank in our knowledge of the geography and geology of Alaska. For this reason, rather than because the region gave any special promise of yielding mineral wealth, its exploration was undertaken. In spite of the difficulties of traversing by pack train the great swampy lowland east of the Kuskokwim the surveys were carried out as planned. Topographic reconnaissance surveys of an area of 4,800 square miles and geologic reconnaissance surveys of an area of 3,500 square miles were completed in one field season.

The geologic work was much hampered by the absence of bedrock exposures over wide areas. Nevertheless, the results show that the stratigraphic sequence in this region and that in the Alaska Range, 100 miles to the north, have certain features in common. The two regions are, however, separated by an unexplored area, which must be surveyed before definite geologic correlations can be made. This unexplored area, which lies between Lake Clark and the upper basin of the South Fork of the Kuskokwim, merits the early attention of the geologist.

Southwest of the region here described is another extensive area about which little is known. This area is drained by southern tributaries of the Kuskokwim and by rivers that flow into Bristol Bay. The results of a survey of this area will form an important link between the geography and geology of the region here described and those of the Tuluksak-Aniak placer district, which has already been surveyed. The two unexplored areas above referred to, including some 40,000 square miles, must be surveyed in order to determine many of the geographic and geologic features of the Kuskokwim basin.

THE LAKE CLARK-CENTRAL KUSKOKWIM REGION, ALASKA.

By Philip S. Smith.

INTRODUCTION.

SCOPE OF REPORT.

The Lake Clark-Central Kuskokwim region lies between Lake Clark on the southeast and the settlement of Georgetown, on the Kuskokwim, on the northwest. Figure 1 shows the relation of this

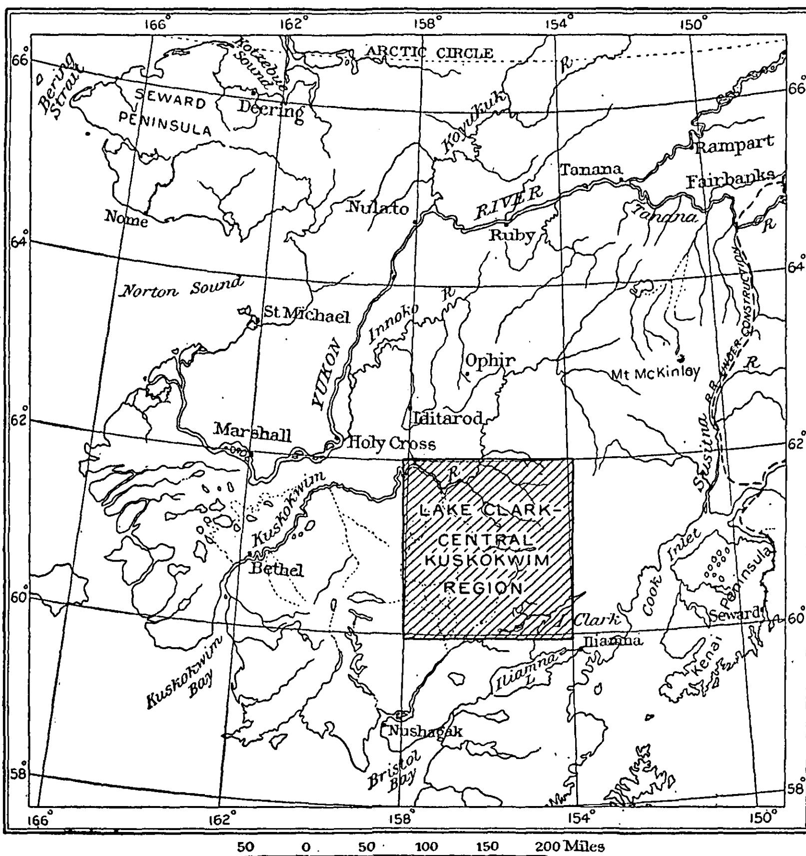


Figure 1.—Map showing location of the Lake Clark-Central Kuskokwim region.

area to the southwestern part of Alaska, and Plates I and V (in pocket) show its geology and topography. Different parts of this area have been examined with very different degrees of thoroughness; certain parts that were examined in detail are described fully in this report; other parts, which were examined cursorily or concerning which the only information is derived from prospectors, are described less completely and probably less accurately. In spite of this inequality of description, however, it seems desirable to assemble in one publication all that is now known of this remote region.

In a part of the country so little known as the Lake Clark-Central Kuskokwim region the geographic facts of relief, drainage, climate, settlements, population, animals, and vegetation are of prime importance. These facts will therefore be stated more fully than would similar facts about a better-known region. The geologic data will also be presented in full, for the determination of the geologic character and history of the area was the principal object of the investigation.

In addition to or coincident with the strictly geologic studies, Survey parties have examined the mineral resources of the Lake Clark-Central Kuskokwim region; and although these resources are not so abundant nor so valuable as those of certain other parts of Alaska, complete data concerning the known deposits are given.

This report, therefore, aims to present all the known facts concerning the geography, geology, and mineral resources of this area and to show the general relations of these features to those of contiguous parts of Alaska.

SOURCES OF INFORMATION.

EARLY EXPLORATIONS.

Information concerning the region has been obtained by field work done in 1914 by a party from the United States Geological Survey, of which the writer was a member, and from the published reports of earlier investigators. Numerous prospectors and trappers have doubtless traversed parts of the region, but few of them have left permanent records of their trips. Nearly every one of the few maps that have been prepared by prospectors are so out of scale and orientation and their representations of the features are so generalized that before the maps can be used it is necessary to visit the field and verify them.

The early marine explorations of Alaska, from those of Bering in 1741 to those of Kolmakof in 1829, although they blocked out the coast of southwestern Alaska, yielded little information regarding the interior region described in this report. The history of the early Russian explorations has recently been thoroughly investigated by Alfred H. Brooks, from whose unpublished manuscript the following statements have been taken:

So far as can be ascertained one of the first inland explorations of part of the Lake Clark-Central Kuskokwim region was made in 1818 by Korasakorsky, who went from Cook Inlet to Iliamna Lake and thence to Bristol Bay and along the coast to the mouth of Nushagak River, where was established a post, Alexandrovsk.

In 1829 Vasilief, "lieutenant of pilot corps," of the Russian-American Co., accompanied by a Creole, Lukeen, as interpreter, starting from Alexandrovsk, ascended Nushagak River, explored Tikchik Lake, and later portaged across to the Holitna. This river he followed to the Kuskokwim, which he descended to its mouth, and thence traveled along the coast back to Nushagak River. He was, therefore, the first man who has left a record of a trip to the Kuskokwim.

The importance of Vasilief's discovery of the Kuskokwim was at once recognized, and in 1832 the governor, Wrangell, sent Kolmakof to make a further exploration of the region. Kolmakof, accompanied by Lukeen, followed Vasilief's route from Nushagak River to the mouth of the Holitna, on the Kuskokwim. A hundred miles below this point Kolmakof left Lukeen to establish a post, which was locally known as Lukeen's Fort, and here Lukeen remained for several years. During this trip Kolmakof apparently ascended the Kuskokwim above the Holitna as far as the Takotna. For several years Lukeen's Fort was the principal interior trading post of the Russians, but in 1841 there was an uprising of the natives at this place, during which a part of the town was destroyed by fire. This settlement was replaced by a new one, built a few miles farther down the river, and named Kolmakof's Redoubt. Kolmakof is still a village on the Kuskokwim, and ruins of the old Russian block houses still stand near it.

In 1834 Andree Glazanof, the discoverer of the Yukon, went to the Kuskokwim and visited Lukeen's Fort. He went upstream from Lukeen's Fort in February to a river then called Tchalochuk, now known as Stony River. At the mouth of this stream the native guides deserted him, but he and his Russians continued for about 50 miles in an air line to a point near the highlands known as the Lime Hills. His party's return from this point to the Kuskokwim was made with great suffering, and his lack of compass prevented him from making close determination of the course he had traveled.

One other Russian exploration, that of Lieut. Zagoskin, in 1842–1844, deserves special mention. He visited much of the central part of Alaska, but the expedition in his charge which traversed the part of the region that is the subject of this report went from the Yukon into the basin of Innoko River and thence across the divide into the Kuskokwim basin. The route from the Kuskokwim into the Innoko had probably been already traversed in 1839 by Kolmakof's son, who is reported to have traveled from the mouth of the Takotna to the Innoko basin en route for Nulato. He was deterred, however, from continuing his trip by the news of the massacre at Nulato, and turned back after he had reached only the headwaters of the Innoko. In the summer of 1844 Zagoskin made a trip from Lukeen's Fort up the Kuskokwim as far as the Takotna. The map accompanying his report shows with considerable accuracy the course of the Kuskokwim from the Takotna as far as the Yukon portage; the Holitna drainage is clearly indicated, and the lower parts of most of the tributaries of the Kuskokwim are rather definitely shown and their headward continuations broadly conventionalized; some of the hills along the main stream are represented by generalized hachures. Few of the names given on Zagoskin's map, however, are in present use. This map seems to have been the main source of accurate information concerning the central part of the Kuskokwim basin until practically the end of the nineteenth century.

During their occupation the Russians were active in the fur trade, and apparently their only interest in the territory was due to this trade. They consequently made but few excursions to the inland parts of the territory and left little information about the country remote from the forts. As a result, practically the only information about the country back from the rivers or coast consists of vague, crude, and inaccurate accounts, derived mainly from the natives.

The acquisition of Russian America by the United States gave an impetus to the exploration of other parts of Alaska but had practically no effect on this part, and little additional information about it was recorded until after 1890.

A contribution to the knowledge of the geography of the southern part of the area here considered was made in 1891 by the explorations of A. B. Schanz, of Frank Leslie's Magazine, who was accompanied by J. W. Clark, the Alaska Commercial Co.'s agent at Nushagak. These men entered the region by Nushagak River and ascended its large eastern branch, the Mulchatna. They traversed some of the region east of that river and first definitely indicated the existence of Lake Clark. The presence of a large lake in the general position of Lake Clark had been vaguely known for a long time and, according to Martin and Katz,[1] had been indicated on some of the early Russian charts and about 1881 the lake had been visited by C. L. McKay, of the United States Signal Service.

The most important of the early expeditions, however, was one from the United States Geological Survey, in charge of J. E. Spurr, with W. S. Post as topographer. This party, consisting of six men,

[1] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, p. 24, 1912.

provided with three canoes and supplies for the entire trip, reached Tyonek, near the head of Cook Inlet, April 26, 1898. From that place the party went up the Susitna and its tributary, the Skwentna, to the headwaters, thence across the range into the basin of the Kuskokwim, down that stream to its mouth, thence by devious courses along the shore and by river to Nushagak and thence across the Alaska Peninsula to Katmai, where they made connection with the lines of regular passenger steamships. In this remarkable journey a vast, hitherto unknown area was explored and a multitude of geographic and geologic facts were acquired. The data were carefully collected and studied, and when published[1] they furnished authoritative information about the region traversed. In that part of the Kuskokwim basin which lies between the mouth of Stony River and Georgetown the survey in charge of Spurr was more or less coextensive with the survey made by the expedition in 1914. In this report the exploratory mapping of the area between the mouth of Stony River and Georgetown has therefore been revised to conform with the more detailed work done by later expeditions, but both upstream and downstream from these places the maps made by the earlier survey have been used with advantage in preparing the accompanying maps.

In 1902, under instructions from the Biological Survey of the United States Department of Agriculture, W. H. Osgood, with A. G. Maddren as assistant and one camp hand, traveling chiefly by canoe, explored and roughly mapped the route from Lake Clark by way of Chulitna, Mulchatna, and Nushagak rivers to Nushagak and thence by Spurr's route to Katmai. A general account of the region traversed on this journey, with detailed notes on the animals found, was published.[2]

In 1902 and 1903 William R. Buckman, a prospector, visited parts of the Holitna basin in his search for valuable minerals. He prepared a map based on compass and paced surveys and transmitted it to the Geological Survey. This map has been the principal source of information about this part of the region and has been used as the base for the part of the main Holitna shown on the maps accompanying this volume. Although obviously his map is only approximately accurate, Buckman deserves much credit for preserving for others a record of his journeys, and his example should be more generally followed by other prospectors.

An exploration for a railroad line from Iliamna Bay to Anvik, on the Yukon, was begun in 1901 and continued more or less actively

[1] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898; U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 43–264, 1900.

[2] Osgood, W. H., A biological reconnaissance of the base of the Alaskan Peninsula: U. S. Dept. Agr. Biol. Survey North American Fauna No. 24, 86 pp., 1904.

for several years. A route was finally selected, and a plat of the proposed line was accepted and filed in the General Land Office in 1912, but no work of construction other than the laying of a few ties near the coast terminus was undertaken. So far as can be judged from this plat, a crude exploratory survey was carried nearly to Mulchatna River, but the map of the region beyond that point is so inaccurate that it can not be used.

The next important exploration in the region here described was made in 1909 by Geological Survey parties in charge of D. C. Witherspoon and G. C. Martin, with 10 other men. These parties surveyed topographically and geologically much of the region adjacent to Iliamna Lake and Lake Clark. A report on the investigations made by these parties has been published,[1] and it affords the most complete information available concerning the geography, geology, and mineral resources of the region contiguous to the Lake Clark-Central Kuskokwim region on the south and east. Many of the observations and interpretations made by the geologists and other members of the expedition of 1909 have been of material service in interpreting the observations made in the adjacent area treated in this report and will be referred to more specifically in the later pages. The topographic map prepared by that expedition has been used in the present volume practically without change for the larger part of the region adjacent to the eastern part of the Lake Clark basin.

The northern part of the Lake Clark-Central Kuskokwim region was the scene of a stampede of gold hunters in 1908, and since that time much of that part of the area has been traversed by prospectors. The Geological Survey, in accordance with its policy of keeping in touch with new mining developments in Alaska, sent a small party in charge of A. G. Maddren into the Innoko region in 1908 and a larger topographic and geologic party in charge of the same geologist into the Innoko-Iditarod region in 1910. The expedition of 1910 traveled through part of the area adjacent on the north to the area described in the present report. A statement of the general results of this trip was made,[2] but no final report was published.

In 1912 H. M. Eakin, of the United States Geological Survey, with one camp hand, started at Ruby, on the Yukon, and made a traverse to Iditarod, covering in general the same route that had been followed by Maddren. Eakin's report[3] contains a topographic

[1] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, 138 pp., 1912.

[2] Maddren, A. G., Gold placer mining developments in the Innoko-Iditarod region: U. S. Geol. Survey Bull. 480, pp. 236–270, 1911.

[3] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, 45 pp., 1914.

map prepared by C. G. Anderson, the topographer attached to the expedition of 1910 in charge of Maddren, and a geologic map that includes not only Eakin's observations but those of Maddren and the other geologists who had visited the region. His report is therefore the most complete published record of the geography, geology, and mineral resources of the region contiguous to the Lake Clark-Central Kuskokwim region on the north.

In 1914 Maddren again visited Iditarod and hurriedly traversed the region between that place and Georgetown on the Kuskokwim. From Georgetown he descended the Kuskokwim to its mouth, stopping on the way at many of the small mining camps. A report of his observations west of Georgetown is being prepared by him for a separate bulletin, but his data on the region that falls within the area of the Lake Clark-Central Kuskokwim region have been kindly turned over to the writer and have been incorporated in this report.

Delay in the preparation of this report allowed a field season to intervene between the field work and the completion of the manuscript. In that season (1915) R. H. Sargent, topographer, in charge of a Geological Survey party, with J. B. Mertie, geologist, started at Ruby and traveled southward to Takotna, near the abrupt bend of the Kuskokwim. Their route thence lay westward to Iditarod. A report[1] on this expedition will be issued later, but the writer of the present report has had the advantage of learning the results of this work and, so far as possible, of considering their bearings on the problems arising in the region that he had studied.

In 1915 H. A. Cotton was detailed by the Coast and Geodetic Survey to map the Kuskokwim. He ascended the river on a steamboat and carried a continuous survey, checked by numerous observations of latitude and longitude, from the mouth of the river up to McGrath. The results of this work, adjusted to correspond with the data from all other sources, have been used to define the position of the Kuskokwim as shown on the accompanying maps.

THE LAKE CLARK-IDITAROD EXPEDITION OF 1914.

NARRATIVE OF THE EXPEDITION.

The expedition of 1914 was in charge of R. H. Sargent, topographer, with the writer as geologist. The party consisted of seven men, and its supplies and equipment were carried by a pack train of 20 horses. The party assembled at Seattle and left there May 25 on one of the coastwise steamers that visit the larger settlements

[1] Mertie, J. B. jr., and Harrington, G. L., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. — (in preparation). A preliminary report on the mineral resources of this region was published in Bull. 642.

in southeastern Alaska and the Prince William Sound-Cook Inlet region, and was put ashore June 4 at Iliamna Bay. From the coast the party followed the trail leading inland to Iliamna village. At that settlement the party divided, the writer, with most of the supplies, going by boat down Iliamna River and along Iliamna Lake to the Newhalen portage, and thence up the valley of Newhalen River to the outlet of Sixmile Lake, and Mr. Sargent and the rest of the outfit going overland around the eastern slopes of Roadhouse Mountain to the lower end of Sixmile Lake.

The observations necessary for beginning the survey having been completed, the expedition started northward from Sixmile Lake on June 20. Because of the large quantity of supplies to be transported the pack train made double trips over the route to the camp of August 2, an air-line distance from the starting point on Sixmile Lake of about 90 miles. Throughout this part of the journey the route lay mostly in broken country, which afforded good traveling except where the lowland flats adjacent to the larger rivers, such as those of the Mulchatna and the Hoholitna, were crossed.

Beyond the camp of August 5 the route lay through the lowland of Kuskokwim and Stony rivers. In this area the difficulties of travel increased so much that in the 50 miles from that camp to the Kuskokwim more than 50 fills and bridges had to be built and horses repeatedly had to be pulled bodily out of impassable morasses. The water in all the streams and sloughs was abnormally high and the party was therefore compelled to take a circuitous course.

The Kuskokwim was safely reached on August 21 at a point where a feasible crossing with rafts could be made. With the help of six or seven natives from the adjacent country the party felled trees and moved them to the river preparatory to building rafts, but when one raft had been completed a small river boat bound for the gold diggings on Takotna River appeared. Arrangements were made by which this boat carried the party and outfit across to the north side of the Kuskokwim, where the expedition arrived on August 23, ready for the last stage of the journey to Iditarod.

At this place the writer left the main camp and went downstream in a small boat to the Parks mercury prospect, some 15 miles above Georgetown. The writer examined this property and the neighboring region until August 29, when he returned to the main camp, which in the meantime had moved slowly westward, and the united party continued westward on the George-Kuskokwim divide, which afforded fine traveling, until September 2, when it crossed George River about 2 miles above Georgetown. On ascending the steep slopes on the west side of this stream the party found the well-marked Iditarod-Georgetown trail on the divide and followed it continuously to Iditarod. On September 10 the main outfit reached Iditarod, where field work for the season stopped and where the horses and other material unsuitable for future expeditions were sold. While waiting for connection with the regular passenger boats the writer visited the near-by mining camps on Flat and Otter creeks and sought information from prospectors about the recent developments in the more distant camps. The party then returned by the regular route up the Yukon to Dawson and Whitehorse, thence across the railroad to Skagway, and thence by steamer along the "inside passage" to Seattle.

As a result of this trip 5,000 square miles of previously unsurveyed country was mapped, the positions of certain previously known features were determined with more precision, data were obtained concerning the geologic and physiographic character and history of the region, and some notes were made about the flora, fauna, climate, and population of the area explored.

METHODS OF WORK.

TOPOGRAPHIC SURVEY.

By R. H. Sargent.

The topographic survey of the region was begun at the lower end of Sixmile Lake from points located in 1909 by D. C. Witherspoon and C. E. Giffin, and was extended to the head of Flat Creek, in the Iditarod district, to connect with the survey made in 1910 by C. G. Anderson. The distance from Sixmile Lake to Iditarod along the course taken by the party is about 280 miles.

The results of the survey were as follows:

Days in field	99
Days of travel	43
Days of actual survey work	53
Days lost on account of rain	3
Base lines measured	4
Stations occupied with the transit	16
Stations occupied with the plane table	94
Latitude observations made	3
Azimuth observations made	4
Points located and elevations determined	3,200
Square miles of country mapped	4,800

The field scale of the survey was 1:180,000 and the contour interval was 200 feet. In general the methods used were those customarily employed in reconnaissance surveys in Alaska. The positions of the starting points were based on the survey made by Witherspoon and Giffin, expanded from the triangulation of the Coast and

Geodetic Survey. The datum for the vertical control was the elevation of Sixmile Lake, 215 feet, as determined by Witherspoon and Giffin.

On the longest straight stretch of beach on the east side of Sixmile Lake, near the outlet, a base line 1,834 feet long was measured twice with great care. An intermediate station on the base line was also occupied, thus making virtually two bases from which to check the main triangle. In order further to insure accuracy, the first stations sighted from the base line were placed on the opposite shore of the lake, in positions to give most effective arrangement for further triangulation and test of the measurements already made. From these stations a further expansion was made to points about 5 miles apart on the adjacent mountains to obtain a suitable base line for plane-table control. Eleven stations were occupied with the theodolite in expanding from this base, the angles between the stations were measured by theodolite, and the triangles were computed mathematically. At the north end of this base a solar azimuth was observed. From the points located by the theodolite the work was carried by the plane table as far as station 59, on the west bank of Stony River.

Near the camp of August 3 (station 51) a check base 1,600 feet long was carefully measured, and six points, from 2 to 8 miles distant, were located by triangulation with the theodolite. A comparison of the computed distances with those determined by the plane table showed that the lines of the plane-table survey were short approximately 1 in 100, a fact shown also by an observation of latitude that was made on the base line. A solar azimuth was also observed on this base line.

The extensive flats in the lower part of Stony River basin and along the Kuskokwim prevented a continuous survey beyond station 59, but special care was taken to observe the most advantageous points for connecting the surveys across the flats. It was possible to make three-point locations at several places along the route.

At station 60, on the west side of the Kuskokwim, where the land is high, a three-point location was made from points already located. Twelve or more angles were read and computed in order to ascertain the elevation of this station. The distances to the points sighted ranged from 30 to 60 miles, but as the elevations thus computed coincided closely their mean is probably within 25 feet of the true elevation.

About 7 miles west of station 60 a new base line, 2,000 feet long, was measured, and from this line triangulation was expanded graphically to five points from which the survey could be readily and accurately expanded by the plane table. The graphic expansion from the base line to these five points was made by plotting the base on a scale of 1,000 feet to the inch—a scale so much larger than that used for the regular mapping that any errors would be far less than those that might have resulted from plotting on the regular scale. At the south end of the base line a solar azimuth was observed.

Near station 91, on Table Mountain, north of the areas shown on the maps accompanying this report, a check base 2,400 feet long was measured, and from this base the positions of three well-defined points, from 1 mile to 4 miles distant, were determined by the graphic method just described. The results disclosed no appreciable error in the work.

At station 84, on Lookout Mountain, and at a point near the Regina Hotel, in Iditarod, latitude was determined by solar observations.

In combining the surveys for publication the datum at the southeast end is the elevation of Sixmile Lake as found by Witherspoon and Giffin and afterward modified by the latest corrections furnished by the Coast and Geodetic Survey. The plane-table surveys have been adjusted by means of the check bases and the observations of latitude and azimuth. The geodetic position determined by the survey made by Anderson near Iditarod in 1910 did not agree with the position determined by the survey made in 1914. As the results of the observations of latitude made near Iditarod checked closely with the results obtained by the plane-table survey, and as the longitude of the datum for Anderson's work was only approximate, the geodetic position determined by the survey of 1914 was considered more nearly correct and adjustments were made accordingly.

GEOLOGIC SURVEY.

Observations on the geology were made mainly by the geologist, but the topographer and the other members of the expedition, whenever they visited places that were not near the route traversed by the geologist, collected specimens of the country rock and observed facts of geologic interest, which they brought to the attention of the geologist. The geologist worked in such close connection with the topographer that most of his foot traverses were tied at frequent intervals to the topographic stations, so that the horizontal control was excellent. Elevations for geologic mapping were determined by aneroid readings, which were checked in the field by readings on topographic stations that had been instrumentally determined, as described on the preceding pages. The geologic records are the field notebooks, the rock specimens, and the photographs, all of which are on file at the Geological Survey.

About 175 specimens of the rocks, minerals, and ores that were noted in the field were collected and were studied in the office. Many specimens of the mineralized rocks were subjected to blowpipe or chemical tests, and nearly 100 were examined in thin section under the microscope. In addition to the specimens collected by the writer many of those collected by Spurr in 1898 were compared with those in the later collections and all the microscopic sections of the rocks collected by the Iliamna-Lake Clark expedition of 1909 were reexamined.

More than 300 photographs, some of which are reproduced in this volume, were taken. These form a permanent record of many of the topographic and geologic observations and have been of service in clearing up points not fully explained in the field notebooks.

MISCELLANEOUS OBSERVATIONS.

In addition to the regular work done, as complete a collection of the flowering plants and grasses as time allowed was made by the topographer and the geologist. This collection has been deposited in the United States National Museum and, although incomplete, furnishes a partial record of the flora of this section of Alaska.

In a personal diary of the expedition a record was kept of many of the details and incidental features of the trip, such as the kind of game seen, general impressions concerning the region traversed, and the various happenings that were not suitable for incorporation in the official record. This diary has helped to recall certain phases of the work and has supplemented the more formal record of the observations. For instance, the depth of a certain stream is indelibly fixed by the terse comment: "In crossing river went in to the waist." Or the abundance of mosquitoes is suggested by the number crushed between the pages of the notebook used on a certain day, or by the note, "Wore head net all day."

In spite of the best intentions, however, many of the things seen were not noted in any form but were recorded only as mental impressions. In recalling these vague impressions for use in this report an attempt has been made to corroborate them by obtaining from the topographer an independent statement as to his recollections of points in question. The writer hopes that by thus checking things that were not definitely recorded he has avoided errors that are likely to arise if observations are not recorded while the object to which they refer is visible.

ACKNOWLEDGMENTS.

To the members of the Survey who have worked with the writer in the field and in the office hearty acknowledgments are rendered. Special thanks are due to R. H. Sargent, in charge of the field expedition, for his unfailing assistance in furthering the writer's investigations. Obligation is acknowledged to the temporary field mem-

bers of the expedition, namely, E. C. Carlberg, C. A. Anderson, J. D. Nelson, Olaf Holt, and Earl Kelso. In the microscopic examination of the rock specimens collected by this expedition the writer was aided by J. B. Mertie and R. M. Overbeck. The paleontologic determinations were made by T. W. Stanton and Edwin Kirk.

The few white people living in the region courteously assisted the expedition with all the help and information they possessed, especially the late Commissioner Hanmore, W. S. Foss, and A. Ruel, at Iliamna village; Hans Sieversen and Frank Brown, at Newhalen and Sixmile Lake; Fred Bishop and E. W. Parks, near Sleitmut, on the Kuskokwim; Capt. Jung and crew of the boat used in crossing the Kuskokwim; the officers of the Northern Commercial Co., and residents of Iditarod and prospectors on Flat and Otter creeks.

The natives employed at Iliamna Lake, at Sixmile Lake, and on the Kuskokwim worked faithfully and efficiently to promote the objects of the expedition and deserve appreciative thanks. The services rendered by Sakaren, chief of the Nondalton natives, and of Wasca, a native living near the mouth of the Holitna, are acknowledged with special gratitude.

GEOGRAPHY.

MAJOR FEATURES.

The northeast-southwest trending highland of the Pacific mountain system is one of the most prominent features of southwestern Alaska. In the Lake Clark-Central Kuskokwim region the main axis of the Alaska Range does not extend beyond the north end of Lake Clark and the axis of the Chigmit Mountains lies east of both Lake Clark and Iliamna Lake. The region here described, therefore, lies west of this great physiographic province and is part of the central plateau region. In few places is the mountain province sharply separated from the plateau province, but the two usually merge through a foothill belt into the mountains on the one hand and the plateau on the other. Although not a high mountain mass, this province is characterized by much-deformed rocks, which range in age from Paleozoic to Tertiary.

Many of the large streams head in the highland area and flow across the trend of the general structural axes until, at a greater or less distance from the high mountains, they collect to form the major rivers, whose courses are more or less parallel with these axes. Other streams originate in the plateau province and swell the master streams of the region, but most of these streams are relatively short and small.

By far the most important stream in the region is the Kuskokwim, which receives several tributaries from the east that rise in the high mountains, as well as many other streams that head within the plateau province. The two other major basins, indicated in order from south to north, are the basin drained by Lake Clark, Iliamna Lake, and Kvichak River into Bristol Bay, and the basin of Mulchatna and Nushagak rivers which also discharges into Bristol Bay.

These three main basins form definite areas, that may be easily delimited for convenience of description and that will be so delimited in this report. They do not, however, form geomorphologic units, for each basin lies in several physiographic provinces and subprovinces, and several of the subprovinces extend uninterruptedly from one basin to another. Thus, in each of the basins are highlands and lowlands, the boundaries of which are not everywhere coincident with the boundaries of the drainage basins.

Taken as a whole, the Lake Clark-Central Kuskokwim region is an area of moderate relief containing scattered, irregularly distributed, rather small highland areas that are separated by lowlands, some of which are large. The relative proportion of highland to lowland is approximately 2 to 1. In the area east of the route traversed this ratio is probably greater, but in the area west of the route it is smaller; yet at some places in each area this proportion is reversed. At some places the main streams lie near the surface of the broad, widely open lowlands; at other places they are hemmed in by steep slopes that rise to the rolling uplands through which they flow.

Trees and bushes are common in the valley bottoms, but on the hill slopes they decrease in size and number until at altitudes of 500 to 1,000 feet above the streams they are absent and their places are taken by grasses and mosses or by bare rocky ledges. Game is rather scarce throughout the region, though hard-beaten trails indicate that many of the larger animals were once abundant. Probably not more than a hundred people live in the region shown on the maps. The bare, undistinctive hills, the low brown flats, with lakes and marshes, and the scarcity of people and animals make the region as a whole appear desolate and uninviting.

DRAINAGE AND RELIEF.

KVICHAK BASIN.

As has already been pointed out, the Lake Clark-Central Kuskokwim region is drained by three main streams whose basins serve well to subdivide the region into separate parts for description. Each of these will be described successively in the following pages.

The Kvichak basin is a long, proportionally narrow basin trending northeast-southwest, containing Lake Clark and Iliamna Lake. Its southern and eastern divide is formed by the Chigmit Mountains and the northern part of the Aleutian Range. Its western divide in its northern part is probably formed by the Alaska Range but in its central part by the plateau that separates the Kvichak from the Mulchatna-Nushagak basin, and in its southern part probably by the coastal lowland that surrounds the northern shore of Bristol Bay.

A noteworthy feature of the eastern divide is that at several places, especially at Iliamna Bay, it is near the coast of Cook Inlet. At that bay it is only 3 miles from salt water and a low pass offers an easy route across it into the interior.

The western divide, which is not more than 2,000 to 3,000 feet high at any place except near its northern limit, lies close to Iliamna Lake but is 20 or more miles west of Lake Clark. The widening of the basin in its northern part is due to the greater extension of the streams there, notably Chulitna and Kijik rivers.

Chulitna River was seen in some detail and will be described separately. It enters Lake Clark about 15 miles north of the lower end of the lake. The main stream trends a little north of east, but its course is very crooked and its current is sluggish. It was crossed at camp June 24 on a riffle in water less than 3 feet deep, but at most places and at most stages it is much deeper. In the upper part of its basin the stream expands into several lakes, the largest of which is called Nikabuna. Many other lakes are scattered irregularly through the lowland adjacent to the river. The higher land consists of isolated knobs, some of which rise more than 1,400 feet above sea level, but most of them are considerably lower. A low pass, said by Osgood[1] to be only 50 feet above the river, leads across the divide at the head of the Chulitna into a series of lakes that form the headwaters of Swan River, which joins the Koktulee and eventually is tributary to Nushagak River.

No long streams enter the Chulitna from the south, but from the north Koksetna River joins the main stream about 12 miles from its mouth. The Koksetna has an extremely irregular course. In its upper part it flows almost due west, then it abruptly turns to the south, and after joining Black Creek it flows eastward for 10 miles and again swings to the south and joins the Chulitna. Its course has been determined in large measure by past glaciation and its valley consequently shows many glacial features.

Its headwaters are mainly in the highlands of the plateau and foothills provinces, but its central and middle parts are in a broad, open lowland in which no pronounced divide separates its basin from that of the Mulchatna, to the west. Along its course are morainic ridges and marshy, lake-covered flats, which are inter-

[1] Osgood, W. H., A biological reconnaissance of the base of the Alaskan peninsula: U. S. Dept. Agr. Biol. Survey North American Fauna No. 24, pp. 16–17, 1904.

rupted by narrow gorges at places where the stream flows transverse to the bedrock ridges. A low pass leads from Black Creek, a western branch of the Koksetna, to Tutna Lake and thence into the upper part of the Mulchatna basin.

Three miles southwest of the mouth of Koksetna River a stream that drains Long Lake and the contiguous country joins the Chulitna. Its drainage is derived from an isolated group of hills south of the Koksetna. It is especially worthy of note because of the marked changes that have taken place in the arrangement and course of some of its tributaries. These changes are undoubtedly due to the former invasion of the region by glaciers and the consequent obstruction and obliteration of the earlier drainage lines. Plate II, *B*, shows a view of the narrow transverse gap which is occupied by lakes east of the camp of June 29. The terraces and small benches on the hillsides indicate earlier levels of erosion and deposition.

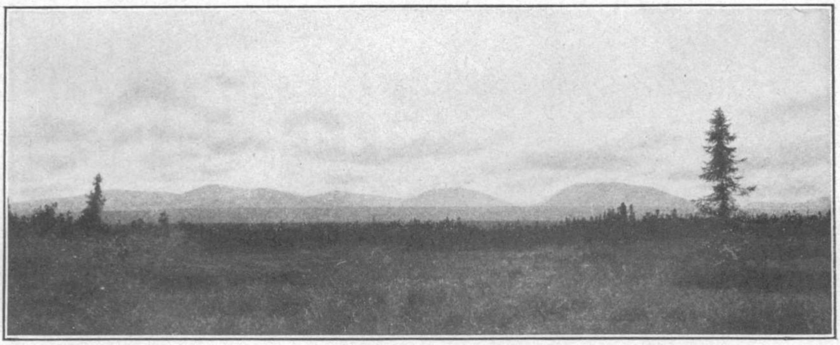
Long Lake, which is nearly 5 miles long and 1 mile wide, lies between low rocky ridges that have been overrun by ice. At its lower end is a peculiar delta-like deposit which apparently has been built into the lake. This abnormal feature may be due to the growth of vegetation, but it appears more likely to have been built by outwash from the ancient glaciers of Lake Clark when, probably, some of the discharge went westward into Mulchatna River by way of the Chulitna Valley.

MULCHATNA BASIN.

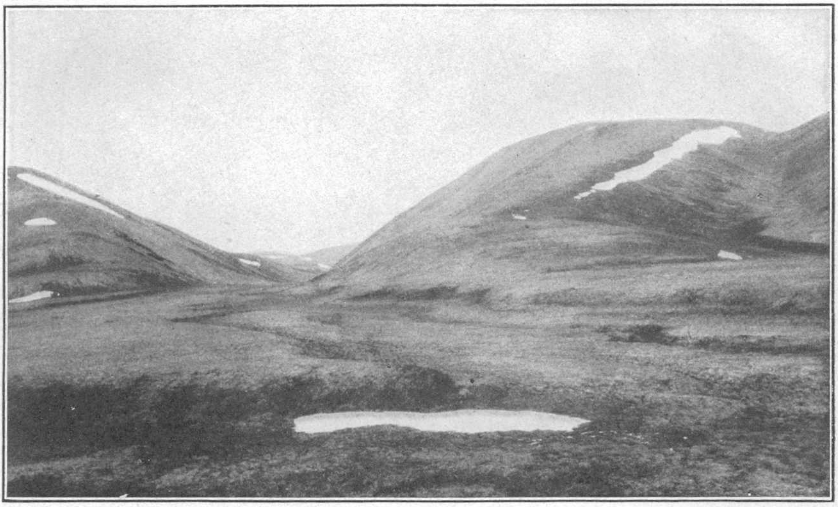
The Mulchatna is the large eastern tributary of Nushagak River that joins that stream about 60 miles in an air line from the sea. Its basin trends nearly northeast-southwest, is about 120 miles long, and in places is 40 miles wide. The southern and eastern divide is the northern and western divide of the Kvichak basin, already described. The extreme eastern headwaters rise in the rugged mountains which form the foothills of the Alaska Range. The Mulchatna at its head is probably so nearly surrounded by Stony River that it does not rise in the high mountains. Its water contains no glacial rock flour, so that little, if any, of it comes from the glaciers of these mountains.

The eastern part of the northwestern divide of the Mulchatna basin is formed by more or less connected uplands which rise to elevations of 2,500 to 3,500 feet and across which are many low gaps. Farther west this upland is much less continuous and is mainly a region of broad flats, from which rise a few low hills and ridges. Much of this region would be traversable by horses only with great difficulty.

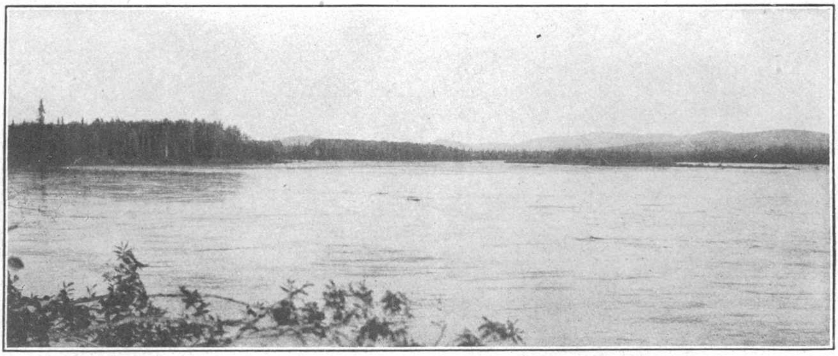
The Survey party of 1914 crossed Mulchatna and Chilikandresten rivers a mile or so above their junction in water less than



A. VIEW SOUTHWARD ACROSS THE MULCHATNA VALLEY, SHOWING TERRACES AND DISTANT HILLS.



B. TRANSVERSE GAP THROUGH HILLS AT HEAD OF PORTAGE LAKE DRAINAGE BASIN.



C. VIEW WESTWARD DOWN THE KUSKOKWIM FROM THE VICINITY OF CAMP OF AUGUST 17.

waist deep. Although the current at the places of crossing is swift, poling boats can ascend either fork of the Mulchatna for several miles above their junction. Broad deposits of outwash material are prominent features of this part of the valley. Plate II, *A*, shows a view southward across the Mulchatna Valley from the hill 2 miles north of the camp of July 12. The hills, the terraces, and the broadly open valley shown in this view are typical of a large part of the Mulchatna basin.

The streams in the central part of the Mulchatna basin are incised in the outwash deposits. The larger streams have already formed broad flats in this material, and the successive stages in the process are shown by minor terraces. The smaller streams, however, have not carried erosion so far; they flow in narrow gorges incised in the outwash deposits. The valley of Dummy Creek, in which the camp of July 11 was located, is a good example of a recent valley carved by one of the smaller streams. This valley, which is scarcely recognizable at a distance, is cut across the terrace in a trench whose sides are so steep that they can be descended only by zigzagging back and forth. In thus cutting down its bed the stream has here and there in its course uncovered knobs of bedrock which now form rocky ledges in the walls of the canyon.

Lakes are numerous in the lowland areas. The largest one seen was Tutna Lake, which, as already noted, occupies the flat that forms part of the Mulchatna-Chulitna divide at the head of Black Creek. This lake is about 2 miles wide and 3 miles long, and owes its position, in part at least, to the obstruction of drainage by deposits laid down by former glaciers. Countless smaller lakes are distributed over the flats in the neighborhood of Tutna Lake, but the intervening ridges are well-drained gravel deposits, so that the region is not difficult to traverse.

Although the Mulchatna occupies a drainage line that has been in existence for a long time the surficial features in its valley show that it has only recently taken on its present form. The valley consequently shows features that represent different degrees of adjustment to the streams that traverse it and is in a distinctly youthful stage.

KUSKOKWIM BASIN.

MAIN STREAM.

The Kuskokwim is the second largest river in Alaska. Its eastern headwater streams rise in the high mountains of the Alaska Range and flow westward to the border of the highlands and thence northward for many miles across a broad lowland to a point near the sixty-third parallel. Here it turns nearly due west and follows this course for an air-line distance of about 30 miles. Beyond this stretch it turns abruptly to the west of south and flows on this general course, but with many angular large-scale bends, for an air-line distance of over 120 miles to the mouth of the Holitna. From the Holitna it flows in a somewhat irregular course, with many large bends, in general westward, until it nearly reaches the Yukon. It then turns and flows more than a hundred miles southwestward to the head of Kuskokwim Bay. The parts of the river's course that fall within the Lake Clark-Central Kuskokwim region are the stretch in which it flows west of south to a point between Swift and Stony rivers and the stretch in which it flows westward from that point beyond Georgetown.

In these parts of its course the river is somewhat more than half a mile wide, is deep enough for navigation by river steamboats, and has a current of 2 to 3½ miles an hour. The average width of this part of the Kuskokwim basin is about 100 miles.

West of the Holitna the river flows through a highland in a rather narrow gorge. The highlands rise 1,000 to 1,500 feet above the river. Some benches and terraces on the flanks of the hills mark successive stages in the development of the valley, but on the whole few gravel deposits occur at a considerable elevation above the river. At the extreme west end of the highlands, outside the area mapped, the highlands disappear or give place to isolated knobs and ridges that rise only a few hundred feet above the river. Several large tributaries enter the main stream in this part of the valley, the largest of which is the Holitna. The passes reached by way of the southern tributaries lead to streams draining into Bristol Bay and those reached by way of the northern tributaries lead into the Yukon or one of its tributaries, notably the Innoko or the Iditarod.

At the north end of the part of its course where the Kuskokwim flows west of south to a point below Swift River the country near the river is low, but rolling hills stand 10 to 20 miles distant on the east. In the center of this part of its course, however, the hills are nearer the river and are higher, so that the topography here is somewhat similar to that of the region immediately west of the Holitna. Toward the south the hills again recede from the Kuskokwim, and though not so far distant on the west side of the stream are more than 50 miles away on the east side. The river in this part is somewhat meandering, and it splits into numerous sloughs. The lowland adjacent to the river is swampy and contains many lakes and partly drained depressions, in which even caribou are said to become mired and lose their lives. In this section the Kuskokwim receives one large tributary from the west, Takotna River, and at least one large tributary from the east, Stony River. Several small streams, which, however, are navigable by shallow poling boats, also enter the river in this part of its course, especially from the east.

Plate II, *C*, shows a characteristic view of the Kuskokwim, looking downstream from the camp of August 17 toward the distant hills, which lie west of the mouth of the Holitna. The river was at a very high summer stage when the photograph was taken, but scars and drift on the trees showed that it had been 8 to 10 feet higher in the spring, so that most of the low ground shown in the view must then have been inundated.

HOLITNA RIVER BASIN.

The Holitna is one of the largest branches of the Kuskokwim. As already noted, it was one of the first of the inland streams known by the Russians, and it early furnished a route from the southern coast of Alaska into the interior. It drains a roughly fan-shaped area lying north of the Nushagak and north of part of the Mulchatna divide and measuring about 100 miles from east to west by 60 miles from north to south. About 15 miles above its mouth the stream splits into two branches, the western named the Holitna and the eastern the Hoholitna. Concerning the western branch little is accurately known, though several prospectors and others have traversed parts of its valley. The most definite information concerning this basin is afforded by a sketch map made by W. R. Buckman during 1902 and 1903. This map has furnished much of the data for mapping the drainage system of the Holitna basin, shown on Plates I and V, accompanying this report. Unfortunately the distances and directions given by Buckman were obtained by crude traverse methods, so that they are not entirely reliable. From Buckman's account the extreme headwater region is a lowland characterized by many lakes and low, isolated hills in which the small headwaters of many of the streams rise. Farther north the river traverses ridges that trend northeast-southwest across the general trend of the river. Still farther north the Holitna flows along the eastern flanks of highlands that are probably the continuation of those already noted in the description of the main Kuskokwim Valley west of the Holitna.

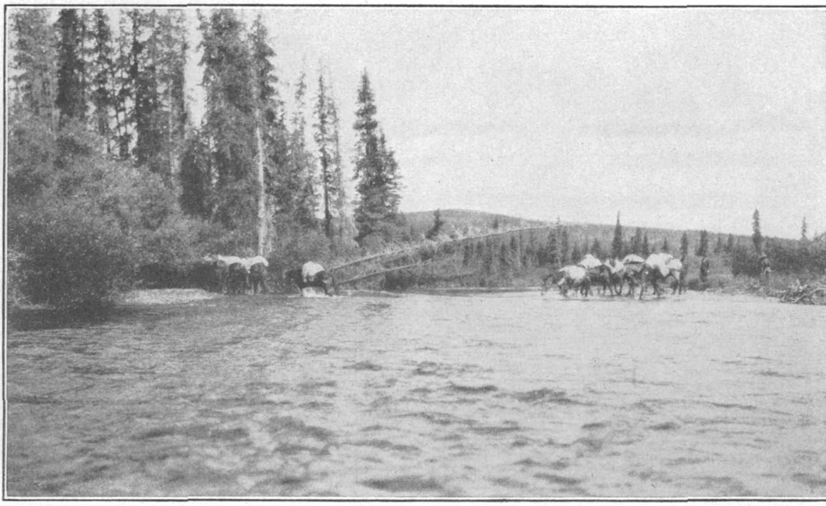
The eastern branch, called the Hoholitna, was seen only in its headwater parts; but the information that it really connects with the Holitna was obtained from natives familiar with the region. The part of the Hoholitna basin seen by the expedition of 1914 was the headwater area west of Whitefish Lake. Its northern divide separates it from Stony River. The convergence and final junction of the divides of Mulchatna and Stony rivers appears to cut out the valley of the Hoholitna east of Whitefish Lake. This lake is more than 8 miles long and from 1 to 2 miles wide. It is in a rather broadly open lowland in which are discontinuous ridges and knobs.

The drainage lines in the parts of the basin that were seen are extremely irregular and have undoubtedly undergone considerable modification in the recent past. Many of the tributaries flow in circuitous directions opposite to the general course of the main stream. Other streams have abandoned their apparently normal courses and, turning abruptly, have cut canyons across ridges. Hook Creek, for example, in the region south of the camp of July 20, has abandoned its obvious course northward toward Stony River basin and has taken a southerly course across the hills. As a whole, the Hoholitna basin appears to have gained drainage area at the expense of the Stony River basin on the north. Few of the streams, however, are of a size commensurate with the size of their valleys, a feature probably due to the great volume of water that the streams were compelled to carry when the ice of the maximum stage of glaciation was waning and yielding an enormous outflow of water.

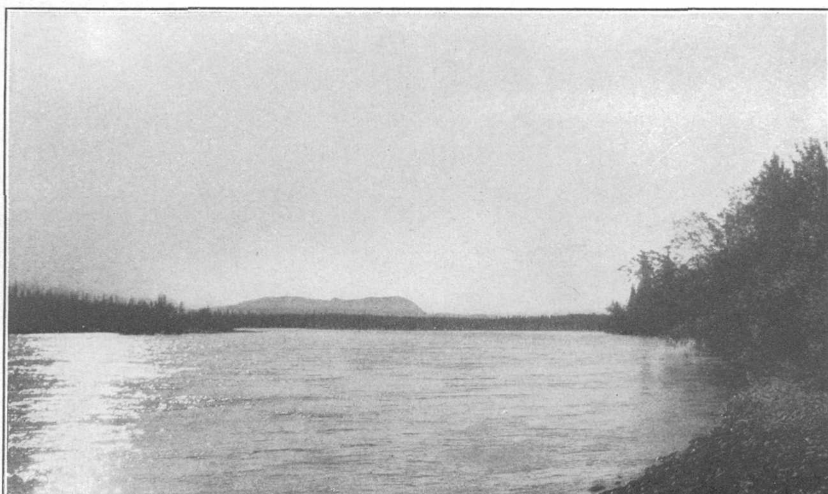
Owing to the intricate patterns of the stream courses the crests of the uplands do not fall into a single nearly straight line on the main divides between contiguous major drainage basins, but instead are irregularly located, some being even on minor divides—for example, Cairn Mountain and other peaks near the camp of July 25, which are as high as or higher than most of the peaks on the main divides. The correct determination of the extent of the different basins from a distance is therefore exceedingly difficult.

At the place where the Hoholitna was crossed, on a riffle near the camp of July 23, the stream was only about knee-deep. Here the current, though strong, was not strong enough to prevent the ascent of the stream in a poling boat. Plate III, *A*, shows the general features of the Hoholitna at the camp of July 23 and gives a good idea of the size of the stream and of the characteristic vegetation of the valley floor. The tributaries that were crossed northwest of this place were nearly as large as the stream flowing out of Whitefish Lake, which has been considered the main stream. Consequently, in the country not far west of the area explored the Hoholitna is doubtless a large stream and probably can not be crossed by fording. In this western area, however, the country appears to be low, and, except for short stretches, the current of the river is probably not swift.

The western part of the divide between Hoholitna and Stony rivers is a low, nearly featureless plain, whose actual watershed is not recognizable at a distance. This area was not seen at close range, but it probably contains some lakes. Its surface is here and there broken by knobs that rise to elevations of a few hundred feet. It doubtless could not be traversed by horses except with great difficulty.



A. THE HOHOLITNA NEAR CAMP OF JULY 23.



B. STONY RIVER AND DISTANT LIMESTONE HILLS.

View taken near camp of August 7.

STONY RIVER BASIN.

Stony River is one of the largest eastern tributaries of the Kuskokwim. Its headwaters are reported to come from the glaciers on the western flanks of the Mount Spurr group of hills, which are high and perpetually covered with snow. This report is probably correct, for the size of the river at the camp of August 6 shows that it has a large drainage area to the east, and the milky color of the water, caused by the large amount of glacial rock flour it is carrying, shows that the stream heads in glaciers. At the camp of August 6 Stony River is over 100 yards wide, has a very strong current, and is unfordable. Its general features at that place are shown in Plate III, *B*. Large boulders derived from the glacial deposits through which the stream flows make rapids and white water at several places, but the stream is reported to be rather easily ascended in poling boats.

As already noted, the southern divide of Stony River basin forms the northern divide of the Hoholitna basin. Some involved and rearranged drainage lines like those in the Hoholitna basin were also seen in the basin of Stony River. The basin contains many subordinate ridges, which are more or less parallel to the main divide but separated from it by poorly drained lowlands. One such lowland is the lake-dotted flat between the Lime Hills, north of the camp of August 3, and the conglomerate hills of Cairn Mountain and vicinity, south of that camp. A view (Pl. IV, *A*) taken from the hills north of the camp of August 3 looking south shows this lowland with its numerous irregular lakes and swampy interlake areas, which make travel with a pack train from one ridge to the other exceedingly laborious.

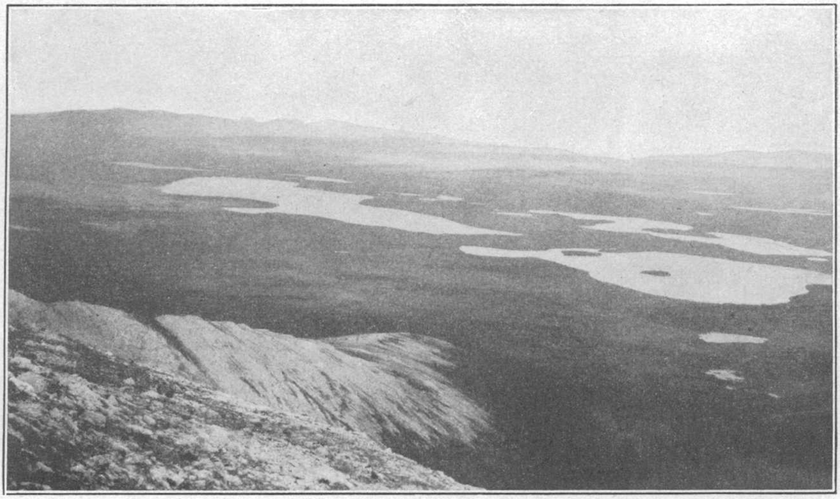
The eastern divide is presumably the high mountains of the Alaska Range. A low, narrow gap occupied by a long lake is said to lead across the range from Little Beluga River, in the latitude of Tyonek, on Cook Inlet, to the head of Stony River. This pass, however, is not much used and apparently is known to few persons except natives. The northern divide in its eastern part separates Stony River from Big River, also a tributary of the Kuskokwim. Farther west, however, the northern divide separates the basin of the Chagavenapuk (or Swift River) from that of Stony River. Only the western part of this divide was seen, and from a considerable distance, but it appeared to be mainly low rolling hills and large intervening flat areas. Although the drainage divide trends nearly east and west the ridges and higher points seem to trend nearly northeast-southwest. This direction, as will be shown later, corresponds closely with that of the axes of the folds of the bedrock.

Although the larger features of the basin of Stony River are very old most of its surface features indicate that its present drainage system has not long been effective. In fact, a large part of the area seen in detail is not adequately drained, and the driest parts are those that lie near the streams. This fact was noted particularly in passing from the camp of August 5 to the camp of August 13. This part of the journey lay first through an undrained tundra, in which the miring of a horse was an almost hourly occurrence. Half a mile or so from the camp of August 6 the footing improved; the low ridges were well drained, and the trees increased in size and number. Country of this sort was found along Stony River as far as Stink River, beyond which the higher land bore off more to the southwest, away from the desired route. On leaving this slightly higher ground the party passed through an undrained plain that was almost untraversable, until it reached a small stream, Muskeg Creek, whose banks were sufficiently well drained to afford fair footing. The course lay down this stream to Stony River, which was again reached at the camp of August 13, and here again the surface of the plain near the main stream afforded the best and driest highway in the region.

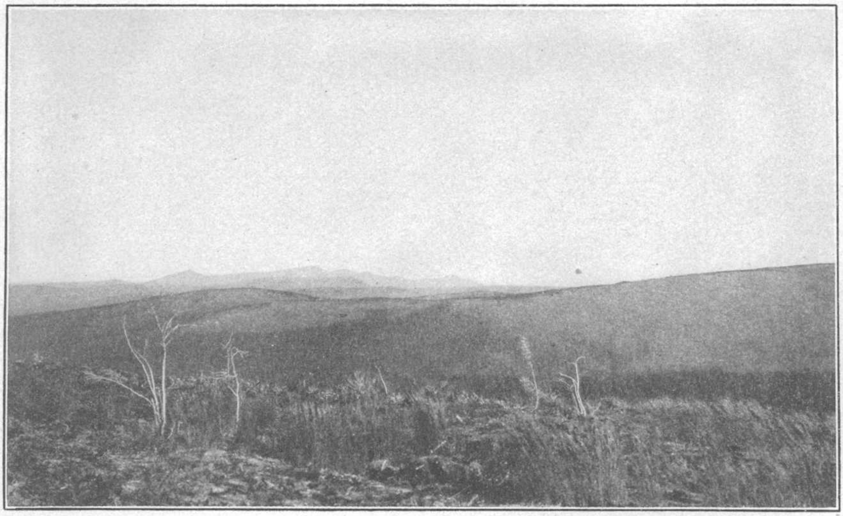
GEORGE RIVER BASIN.

George River, so named for the trader George Fredericks, who had a trading post near its mouth, is one of the northern tributaries of the Kuskokwim. This stream is also known by its native name, Yukwonilnuk. It joins the Kuskokwim about 22 miles, in an air line, below the Holitna and drains an irregular area measuring approximately 50 miles from northeast to southwest by 35 miles from east to west. Most of its basin is in a dissected plateau, and owing to the lack of any dominant structural control the streams have formed a decidedly irregular drainage pattern. From a distance, therefore, the determination of the actual watershed of the basin is extremely difficult, as many of the hills of the main divides are no higher or more massive than those in the rest of the upland.

The southern divide of George River is at most places nearly parallel to the Kuskokwim and about 4 miles away from it. The peaks along the divide stand 1,000 to 2,000 feet above sea level and have a relief above the Kuskokwim of 800 to 1,700 feet. The eastern divide, in its southern part, which separates the basin of George River from the basins of small tributaries of the Kuskokwim, is rather irregular. The part of the eastern divide farther north, however, forms the divide between the southern tributaries of the Takotna and George River and Black River, a tributary of the Kuskokwim. Most of the eastern boundary of the George River basin has been seen only from a considerable distance, and consequently little is known about its details.



A. FLANKS OF LIME HILLS AND LOWLAND WITH LAKES NEAR CAMP OF AUGUST 3.



B. VIEW NORTHWARD ON THE DIVIDE OF GEORGE AND IDITAROD RIVERS.

The northern divide of the basin of George River separates it from the Iditarod River. At a few places it is marked by peaks having an elevation of 2,500 feet, but at most places it is not more than 2,000 feet high. The divide trends in general east-west, but in detail it is minutely irregular; at some places it swings abruptly toward the north or the south. Most of the slopes from the crest to the creeks are steep, but undrained areas in the saddles are nevertheless common, and at some places on the divide, and even on the hill slopes, the ground is soft enough to mire horses. The crest of the divide, however, nearly everywhere affords good footing and is almost invariably followed by the traveler.

The northern part of the western divide of the basin of George River is also a part of the divide of Iditarod River, but the southern part separates George River basin from the basins of other tributaries of the Kuskokwim. The largest of these tributaries in the area west of the basin of George River is Crooked Creek. George River is somewhat unsymmetrically placed in its basin; it is much nearer to the western than to the eastern divide, so that the western tributaries are much shorter and smaller than the eastern. Plate IV, *B*, a view northward toward the high hills near Iditarod, shows a part of this divide. This view was taken from a point somewhat north of the area shown on the maps, but it indicates the character of much of the country in the basin of George River.

George River was crossed by the Survey party about 2 miles above its mouth, at the camp of September 2. Though it was at a high summer stage and was backed up by the Kuskokwim, it was crossed on a riffle in water about 4 feet deep. In this part of its course the stream is rather closely confined by steeply sloping walls, so that changes in rainfall rapidly affect its volume. Within a day after the Survey party crossed George River heavy rains caused it to rise more than 2 feet, and people living at Georgetown stated that within a few days after the rainstorm ceased it would probably not be more than knee-deep at the same place. When the river is in flood its current is strong, but, according to report, under ordinary conditions it may easily be ascended in poling boats for an air-line distance of probably 25 to 30 miles.

CLIMATE.

TEMPERATURE.

The Lake Clark-Central Kuskokwim region, situated as it is in the interior plateau province of Alaska, has a climate characteristic of a region in that position. In other words, it has a subarctic climate—a short, warm, fairly wet summer and a long, cold, relatively dry winter. Few instrumental observations of the various climatic elements have been made so that our knowledge of the temperature and precipitation is based mainly on indefinite records. Martin,[1] however, quotes instrumental observations made on the north shore of Iliamna Lake from December, 1907, to May, 1908, both inclusive, which show an average mean temperature for these six winter months of 16° to 18° F. The temperature is probably somewhat mollified by the influence of the near-by bodies of water and may be higher than that of regions in Alaska that lie farther inland. Furthermore, these observations were made at a place considerably south of most of the Lake Clark-Central Kuskokwim region.

The summer of 1914 seems to have been exceptionally cold; few days were genial enough to permit members of the party to work comfortably in the open without jackets. On July 6, even at an elevation of not more than 1,000 feet above the sea, the temperature was so low that the precipitation was in the form of snow, and on August 5 ice formed on water buckets and shallow puddles in the basin of Stony River, at an elevation of about 1,000 feet. Even in the lowlands, therefore, killing frosts may occur in almost any month in the year. The cold, however, is seldom intense enough to interfere with mining until the middle of September, and most of the streams are free of ice before the end of May. The regular passenger boats usually reach Iditarod by the middle of June, and the last one to leave Iditarod in 1914 started on September 25. Near the coast the temperature is somewhat higher and the streams are not closed so long. Martin and Katz[1] give records of observations made in the region as follows:

> December 31, 1905, ice began to form on Iliamna Lake; January 12, 1906, ice 16 to 18 inches thick on Iliamna Lake; February 12, 1906, ice in Iliamna Bay; March 16, 1906, ground began to become bare; January 17, 1908, Iliamna Lake froze; May 28, 1908, Iliamna Lake opened; June 2, 1909, ice out of upper end of Iliamna Lake; June 20, 1909, ice all gone from Iliamna Lake.

Many of the prospectors reported that the temperature in winter is lower in the valley bottoms than on the adjacent higher land. This condition has been reported also from other parts of central Alaska, and is apparently due to the fact that the heavy cold air settles into the lowlands. This condition was observed late in August near Sleitmut, where small vegetable gardens in the flats near the creeks had been badly frostbitten, whereas the plants on terraces only a few score feet higher had not been affected.

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[1] Martin, G. C., and Katz, F. J., op. cit., p. 16.

PRECIPITATION.

The prevailing winds in summer appear to come from the west and south and are usually attended by considerable precipitation. The northerly winds generally bring cold, dry weather. In 1914 the streams were at a high stage, and Kuskokwim River was said to be more than 10 feet above its normal summer level. The observations made in 1914 by the Survey party, which record rainfall on 60 out of 99 days in the summer of that year, therefore leave an impression of heavier precipitation than is perhaps justified, and do not necessarily indicate the average summer rainfall. Eakin,[1] however, states that when he visited the Innoko-Iditarod region in 1912 the rainfall was also exceptionally heavy, and that between July 17 and September 3, a period of 47 days, only 5 days were without rain in some part of the region. Spurr, in his report on his trip to the region in 1898, states that "the whole Kuskokwim River * * * was, during the time that we were on it—that is, about five weeks, from the middle of July till the latter part of August—a very rainy country, showers falling nearly every day and continuous rains being frequent."[2] According to local reports the precipitation in summer is two to three times as great as in winter, so that, although summer travelers report a large number of rainy days, the annual precipitation is low—probably only about 20 inches a year.

From May to September most of the precipitation is in the form of rain, but even during that period, as has already been noted, snow sometimes falls at low altitudes, and snow, sleet, or hail is not at all uncommon on the high hills. Thunderstorms occur frequently in summer in the Mulchatna basin, which has an unenviable reputation on that account. These storms seem to originate near the higher hills and move along the main valleys, and two or three storms may be in sight at the same time. Several thunderstorms occurred in 1914 while the party was working in the valleys of Stony and Kuskokwim rivers.

POPULATION AND SETTLEMENTS.

The region between Lake Clark and Georgetown is so sparsely settled that after leaving Lake Clark the members of the Survey party of 1914 saw no other persons until they reached Stony River, at the camp of August 6. They saw no one in the area west of this camp all the way to the camp of August 21, on the Kuskokwim. Along the divide followed by the party from the crossing of the

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[1] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, p. 16, 1914.

[2] Spurr, J. E., op. cit., p. 67.

Kuskokwim to Georgetown no persons were seen, yet this region does not impress the traveler as uninhabited, for in the distance at many places along the Kuskokwim the party saw cabins and noted at several places indications of the former presence of travelers. Between Georgetown and Iditarod a well-beaten trail and numerous old camp sites and pieces of discarded camp equipment showed that the region was by no means unfrequented.

The settlements of the region may be roughly arranged into two main groups, one including the villages on Kuskokwim River and the other those in the Kvichak basin. Between these two main groups there are practically no settlements.

The largest town on the Kuskokwim, Bethel, is described by Maddren[1] as follows:

> The native settlement of Bethel, on the tidal portion of Kuskokwim River, about 100 miles above its entrance into Bering Sea, is the most important supply station for this region, and probably it will always be of commercial importance because of its natural location as a port of entry for ocean-borne traffic to the extensive region drained by Kuskokwim River. Bethel was established in 1886 as the local headquarters of a Moravian missionary society, and since that time has served more or less as a trading center for the native population and a place of supply for prospectors within reach of it. Shallow-draft seagoing power vessels can reach Bethel during the season of open navigation—from June to October—and for the last five or six years a somewhat irregular trade has been carried on between Bethel and Seattle, Wash. Kuskokwim River is navigable for stern-wheel steamboats for fully 500 miles above Bethel. Consequently this place is a logical point for the discharge of ocean traffic and its transshipment up the river. Without doubt the greater part of all supplies for the Kuskokwim region will be brought to it by this water route, no matter where future developments in the valley may take place.
>
> Several river steamboats have been operated on Kuskokwim River each summer since about 1907, when the miners came from Nome to the Innoko district by way of this river. The trade of these boats increased until 1911, when several additional boats were placed upon the river, but since then it has fallen off, and in 1914 only one large river boat was required to carry all the freight offered. At its maximum the freight carried on the river each summer amounted to about 2,500 tons, but in 1914 it had dwindled to about 500 tons.

The main post on upper Kuskokwim River is Takotna, which is near the former settlement called McGrath. This place was practically the only one on the Kuskokwim above Bethel where any supplies could be bought in 1914. It was established as a distributing center for the placer region of Takotna River and is not more than 35 miles in an air line from the placer camp of Ophir, on Innoko River. The winter trail used by the mail carriers and by foot travelers from Iditarod to Cook Inlet passes through this settlement. During the summer Takotna is reached by a moderate-sized river

[1] Maddren, A. G., Gold placers of the lower Kuskokwim, with a note on copper in the Russian Mountains: U. S. Geol. Survey Bull. 622, pp. 302–303, 1915.

steamboat that brings freight upstream from tidewater for about $30 a ton, but the service is very irregular and uncertain.

Both Bethel and Takotna, however, lie outside the region visited. The only two settlements on the Kuskokwim seen by the writer were Georgetown and Sleitmut. Georgetown, on the Kuskokwim, west of George River, and its continuation, Lousetown, east of that stream, form a small village consisting of not more than a score of cabins, one store, and a now deserted roadhouse. It has a population of 4 or 5 white persons. As already stated, this place was for many years a trading post, conducted by George Fredericks, from whose name Georgetown is derived. In 1910, on the discovery of placer gold on some of the streams in the neighborhood, a stampede took place and a boom town sprang up. Not so much gold was found as had been expected, however, so the prospectors struck out for more promising fields and the place dwindled to its present size.

Sleitmut consists of several native shacks and a store run by the only white man in the village. It is on the north bank of the Kuskokwim, a short distance below the mouth of the Holitna. It is said that "sleit" means whetstone and "mut" means people. The whetstones, for which this place was named, apparently came from the contact-metamorphosed sandstone that outcrops near the mouth of the Holitna.

Here and there along the Kuskokwim are cabins, many of which are occupied by prospectors and trappers, and several native families have permanent homes along the river. The natives are employed mainly in hunting and fishing, but all of them do more or less work for the white people and so earn money to buy tea, flour, and sugar, which they crave. Many of the natives have a considerable admixture of Russian blood, and the leaders are usually half-breeds.

Several native villages have been reported by prospectors on the Holitna, mainly in the headwater part of the basin, but little information about them could be obtained from the Kuskokwim natives. A trading post, called Kongollon, patronized mainly by natives, is said to be situated on Stony River, nearly north of Whitefish Lake, which is at the head of the Hoholitna. This post is in charge of a half-breed, who gets most of his supplies from the white trader at Sleitmut. Kongollon is visited by natives from Lake Clark and goods are there exchanged. In 1914, however, supplies at Kongollon were almost entirely exhausted and probably could not be replenished until very late in the season, so that some of the natives planned to migrate from Kongollon to Lake Clark. Several deserted cabins were passed on the lower part of Stony River, near the mouth of Stink River. From these cabins Kongollon was said to be about two days' journey upstream.

On Big Bonanza Creek, a tributary of the Mulchatna, supposed to enter its northern branch about 3 miles above the camp of July 12, some placer mining has been done, and four to six persons are said to be living on the creek. The settlement was not visited but is reported to consist of only a few cabins. Some old caches below it on the Mulchatna indicate that supplies are brought up the river by poling boat, but most prospectors that come to this place from Lake Clark go across the country by a route not far from that traversed by the Survey expedition of 1914. So few people have used this route, however, that the trail is not marked on the ground.

Nondalton is the main settlement in the vicinity of Lake Clark. It is on the northwest shore of Sixmile Lake. A store, in charge of a white trader, and a score of cabins of natives are the only buildings. The population consists almost entirely of natives. At the time Nondalton was visited in 1914 the town was deserted and all the people were living in tents and in rough shelters at a fishing village at the outlet of Sixmile Lake. Most of the supplies for Nondalton are brought in boats up Kvichak River and along Iliamna Lake and are back-packed across the Newhalen Portage and thence taken up Newhalen River and Sixmile Lake in boats.

About 40 miles in an air line southeast of Sixmile Lake is Iliamna, the chief trading point for the southern part of the district. It is on Iliamna River, about 12 miles from Iliamna Bay, the port on Cook Inlet. Steamers from Seattle call at Iliamna Bay about once a month during the summer and leave mail and supplies at a deserted cabin at a place locally known as AC Point. North of AC Point the head of Iliamna Bay is very shallow and at low tide is a mud flat impossible to traverse in a skiff. Another group of cabins has been built at the head of the bay, but none of them is permanently occupied. A well-beaten trail leads from these upper cabins through a pass about 900 feet high, 3 miles distant from salt water, and thence follows Chinkelyes Creek down to Iliamna, at the junction of that creek with Iliamna River. At Iliamna are a store and more than a score of cabins, as well as a Government school and a United States commissioner. The population in 1909, as estimated by Martin,[1] consisted of about 15 whites and 40 natives.

ANIMALS.

For an area so sparsely inhabited and so seldom traversed the Lake Clark-Central Kuskokwim region has a surprisingly small amount of game. The only report on the animals of the region made by a trained biologist is that given by Osgood,[2] who describes

[1] Martin, G. C., and Katz, F. J., op. cit., p. 20.
[2] Osgood, W. H., op. cit.

the animals in the southern part of the area. The following notes aim only to set forth incidental observations on the character and distribution of the animals. Caribou and bear were the only large animals seen at close range. The greatest number of caribou were found in the morainic country in the basin of Koksetna River north of the camp of June 29. Others were seen near the camps of July 21, 26, and 31. According to the accounts of natives caribou at one time were much more numerous in the Lake Clark-Central Kuskokwim region. On almost all the more continuous ridges are hard-beaten game trails, some of them worn 2 feet below the general surface. None of these trails shows much recent use, and parts of them are almost entirely obliterated by the growth of bushes. Trails of this sort were especially strongly marked on the morainic ridges south of the camp of July 3, near the low hills of the camp of August 5, and on the Kuskokwim-George river divide.

Bears are reported to be numerous in the Mulchatna Valley, but only one was seen in this basin, and few trails or other signs of these animals were noted except in the vicinity of Halfway Mountain, near the Mulchatna-Hoholitna divide, north of the camp of July 18. Both brown and black bears are found, but none of the very large brown bears similar to those on Kodiak Island are reported. A small black bear was seen near the camp of July 5, and one was killed on Stony River near the camp of August 6, and a large black bear was seen at close range near the camp of August 16. Bear meat was obtained from the natives at Sixmile Lake and is said to form an important part of their food supply, but it is becoming increasingly difficult to obtain.

Signs of moose were particularly noticeable in the vicinity of the lakes in the valley of the stream tributary to Gnat Creek in which the camp of July 17 was situated, and in the lowland of the Kuskokwim near the camp of August 14. The natives near Sixmile Lake had moose meat which they said was killed in the basin of the Chulitna. No signs of sheep or goats were observed in any of the region visited by the expedition of 1914, but in the high, rugged hills north of the east end of Lake Clark sheep are reported to be fairly numerous.

The smaller animals—foxes, beavers, squirrels, porcupines, and rabbits—were seen at several places. The only foxes seen were the tawny and black cross-fox. Several holes made by foxes were noticed in the gravel ridges near the lowland with lakes south of the camp of August 3, and a trapper evidently had made this place his headquarters during the preceding winter. A pair of beavers were seen in the small lake near the camp of July 24. They had made several runways on the shore for getting out sticks for their house, which they had partly completed. Many beaver dams were noticed in the lowlands of the Kuskokwim, especially along Muskeg Creek, the stream that enters Stony River near the camp of August 13. Small, reddish tree squirrels were seen at a few places. The so-called ground squirrels, so common in the unforested parts of northern Alaska, were nowhere numerous, and even their characteristic gopher-like holes were seldom observed, though in some of the coarse talus piles near the tops of the more rocky knobs, such as on Groundhog Mountain, near Lake Clark, their scolding chatter was often heard. Porcupines were found in almost all parts of the area. Apparently they live in the timbered areas, but most of those seen were traveling over the bare, brushless uplands. According to prospectors, rabbits are very numerous in many parts of the area traversed by the expedition of 1914. A large number of bushes had been nibbled by rabbits, but surprisingly few rabbits were seen. They were seen most commonly in the willow thickets along Stony River, especially at the mouth of Stink River, near the camp of August 7.

Several kinds of birds were seen in the region, and those especially sought for their flesh or eggs are gulls, ptarmigan, spruce hens, cranes, ducks, and geese. Gulls are numerous around Iliamna Lake, and their eggs, which are gathered from the rocky islands in that lake, form an important part of the food supply of both the natives and the whites living in that region. On June 12 the Survey party met four or five egg hunters and sampled some of the several hundred eggs they had gathered. A few fish gulls were also seen on the Kuskokwim, but, so far as known, these birds are seldom hunted as meat or for their eggs. Ptarmigan in small flocks, rarely consisting of more than a score of birds, were seen often in the unforested areas, seldom on the gravel bars in the valleys. Those seen near Iliamna Bay on June 6 were nearly pure white, and those seen on the divide of George and Iditarod rivers in the early part of September had a considerable growth of white feathers on their feet and were already beginning to get their winter plumage. Most of the spruce hens seen early in the season were in the well-forested areas, but those seen a little later were much nearer the edge of the timber. Early in September they were especially numerous in the thickets near the Kuskokwim and the larger side streams. The raucous cries of cranes were heard in the lowlands near Stony and Kuskokwim rivers, and a crane was shot near the camp of August 16. A few geese and ducks were seen near the lakes in the lowlands of the Kuskokwim and of the Mulchatna, and several were shot near the camp of July 23 on the Holitna.

Fish are probably abundant in most of the streams of the region, but the sites selected for the camps of the expedition of 1914 allowed few opportunities to obtain first-hand information about their distribution. The most common food fishes are salmon, grayling, whitefish, and trout. Salmon were beginning to run in Newhalen River before June 13, and were still running in good numbers on the Kuskokwim as late as August 29. The salmon taken at both places were in good condition, and had none of the spots that are usually seen on fish that have traveled far from salt water. Along all the larger streams that were crossed by the expedition of 1914 surprisingly few dead salmon and almost no fishing trails made by bears were seen. The absence of these two features, so common on good salmon streams, suggests that possibly salmon are not numerous. Whitefish are said to be especially abundant in the large streams after the salmon have left. They are caught throughout the winter in the Kuskokwim below the Holitna and probably elsewhere throughout the region. Whitefish Lake, at the head of the Hoholitna, is said to owe its name to the abundance of whitefish in it. Grayling were caught in several of the larger clear-water streams, and were seen even in the smaller brooks. Many of the grayling caught were 18 inches or more long. The only trout caught by the members of the expedition of 1914 were taken in the stream on which the camp of June 29 was situated, but probably they may be found also in many other similar streams in the region.

VEGETATION.

The general distribution of forests in the Lake Clark-Central Kuskokwim region is shown in figure 2 (p. 42). As this map shows, the proportion of timbered to untimbered areas in the region traversed is about 1 to 2. No part of the region traversed is densely forested. The areas indicated as timbered are in the main covered with a scanty stand of large trees and a much denser growth of willow and alder, which grow near the watercourses. The timbered area is mostly low ground, at few places reaching an elevation of more than 2,000 feet. In the narrow lowlands trees form only a fringe along the better-drained areas near the streams. In the broader lowlands, however, large trees, some about 2 feet in diameter, grow in the flats near the well-drained banks of the larger streams, and smaller trees, averaging 1 foot or less in diameter, grow in less well-drained but not marshy areas. Spruce is the most common and widespread of the larger trees, but tamarack—the largest trees nearly a foot in diameter—was seen at many places in the lowland of the Kuskokwim, and birch is common toward the upper limit of timber. Along the streams, in places that are periodically overflowed at very high water, willow and cottonwood form dense thickets, which are impenetrable except by chopping trail.

At the upper limit of the timbered areas the spruce forest gradually gives place to tangles of alder, which in turn are succeeded by open country. The spruce and birch at their upper limit are not exceedingly stunted, as they usually are where their growth is controlled by climatic conditions, but the transition from the forested

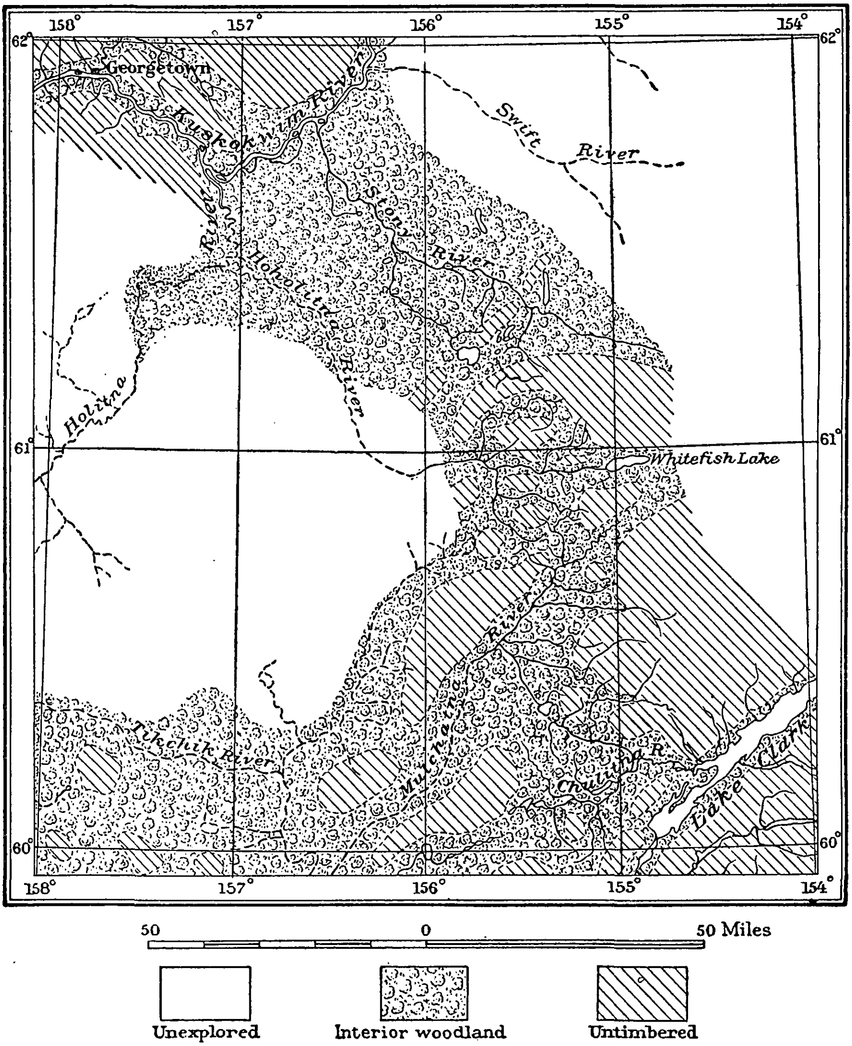


FIGURE 2.—Map showing distribution of forests in the Lake Clark-Central Kuskokwim region.

to the unforested areas is notably abrupt, as if the trees had not yet reached the limit imposed on them by their environment. This conclusion is suggested also by the lack of old dead trees near the margins of the forests.

The untimbered areas are divisible into lowland swamps and tundras and bare uplands. Above the upper limit of trees the surface of the country is covered with small scattered bushes or grass, and still higher with moss, lichens, and bare rocks. Grass is especially luxuriant at the upper margin of timber but becomes scanty on the more exposed areas higher up the slopes. The lowlands are apparently unforested because they are poorly drained or swampy. Even ridges that rise only a few feet above the general level of the surrounding swamp have a light covering of trees, whereas the adjacent lowland is overgrown with marsh grasses and small water-loving plants. Several features other than dampness, however, doubtless control the distribution of the trees. A more complete discussion of the character and distribution of the life zones of part of the region is given by Osgood.[1]

The numerous illustrations accompanying this report will perhaps give a more vivid idea of the general forested and unforested condition of different parts of the area than can be gained from any description. The pictures show different landscapes, affording views of the bare, unforested slopes of the rocky hills and swampy tundras (Pls. II, *A*, *B*; IV, *A*, *B*; VI, *A*. *B*; VIII, *B*; IX, *A*, *B*; X, *A*, *B*; XI, *A*, *B*) as well as of the more densely forested parts of the Kuskokwim basin (Pls. II, *C*; III, *A*, *B*; XII, *A*).

Berries suitable for food are found in many parts of the Lake Clark-Central Iditarod region. Of these, the most common are blueberries, salmonberries, cranberries, spruce berries, and currants. A few raspberries were found, but they were not at all abundant. Blueberries were particularly numerous in the open, dry tundras near Stony and Kuskokwim rivers. Many blueberry plants were seen in the Mulchatna and Chulitna valleys, but the exceptionally late season had held them back so much that very little fruit had formed. Both low-bush and high-bush blueberries were found. The fruit from the high bushes showed considerable variation in shape, some of the berries being long and subcylindrical.

Salmonberries were found more commonly in somewhat wetter lowland areas than blueberries. Here and there they were plentiful, but they were not so universally widespread as the blueberries. Cranberries were particularly abundant on the drier, unforested uplands, such as parts of the Kuskokwim-Iditarod divide. Spruce berries—a small black spherical berry that grows on a low trailing vine having needle-shaped leaves like those of the spruce and that has a rather insipid, characterless taste—are much sought by the natives. This berry is usually found on the drier upland slopes and was particularly noticed in the hills north of the Kuskokwim east of Georgetown. Currants were very abundant in the denser forests near the large streams. They were gathered in great quantities in the

[1] Osgood, W. H., op. cit., pp. 21–25.

lowland of the Kuskokwim, especially between the camps of August 14 and 21.

In connection with the investigations that formed the more direct objects of the expedition Mr. Sargent and the writer made a collection of the more noticeable flowering plants of the region. This collection was submitted to botanists at the National Museum for identification and preservation, and although it contains no new forms the following list of the names furnished by William R. Maxon, of the National Museum, may be of interest as indicating the diversity of the flowering plants. The collection is by no means complete, as it includes only the more conspicuous flowers and practically no trees and shrubs.

Lycopodiaceae.

Lycopodium alpinum Linné.

Poaceae.

Calamogrostis scabra Presl.
Colpodium fulvum (Trinius) Grisebach.
Festuca altiaca Trinius.

Cyperaceae.

Carex.
Eriophorum.

Juncaceae.

Juncus.

Liliaceae.

Fritillaria camschatcensis (Linné) Gawler.

Convallariaceae.

Streptopus amplexifolius (Linné) De Candolle.

Iridaceae.

Iris setosa Pallas.

Salicaceae.

Salix.

Polygonaceae.

Polygonum plumosum Small.
Rumex treleasei Wight.

Silenaceae.

Arenaria arctica Steven.
Cerastium alpinum Linné.

Ranunculaceae.

Anemone narcissiflora Linné.
Ranunculus bongardi Greene.

Papaveraceae.

Papaver nudicaule Linné.

Brassicaceae.

Arabis lyrata intermedia (De Candolle) Wight.
Barbarea.
Cardamine pratensis Linné.
Cardamine purpurea Schlechtendal and Chamisso.
Parrya nudicaulis (Linné) Regel.
Radicula barbaraefolia (De Candolle) Wight.

Saxifragaceae.

Saxifraga flagellaris Willdenow.

Parnassiaceae.

Parnassia kotzebuei Chamisso.

Rosaceae.

Dryas drummondii Hooker.
Potentilla emarginata Pursh.
Rubus chamaemorus Linné.
Rubus stellatus J. E. Smith.
Sieversia rossii Robert Brown.
Spiraea steveni (Schleiden) Rydberg.

Fabaceae.

Astragalus.
Hedysarum americanum (Michaux) Britton.
Lupinus arcticus S. Watson.
Oxytropis gracilis (A. Nelson).
Oxytropis nigrescens (Pallas) Fischer.

Geraniaceae.

Geranium erianthum De Candolle.

Violaceae.

Viola adunca J. E. Smith.

Onagraceae.

Chamaenerion latifolium (Linné) Scopoli.
Epilobium.

Apiaceae.

Bupleurum americanum Coulter and Rose.

Cornaceae.

Cornus suecica Linné.

Pyrolaceae.

Pyrola grandiflora Radius.

Ericaceae.

Ledum decumbens (Aiton) Loddiges.
Loiseleuria procumbens (Linné) Desvaux.

Vacciniaceae.

Vaccinium uliginosum Linné.
Vaccinium vitis-idaea Linné.

Diapensiaceae.

Diapensia lapponica Linné.

Primulaceae.

Dodecatheon frigidum Chamisso and Schlechtendal.
Primula cuneifolia Ledebour.
Primula pumila (Ledebour) Pax.

Gentianaceae.

Gentiana frigida Haenke.
Gentiana glauca Pallas.

Polemoniaceae.

Polemonium acutiflorum Willdenow.

Scrophulariaceae.

Lagotis glauca Gaertner.
Pedicularis arctica Robert Brown.
Pedicularis labradorica Panzer.
Pedicularis langsdorfii Fischer.
Pedicularis sudetica Willdenow.
Pedicularis verticillata Linné.
Veronica wormskjoldii Roemer and Schultes.

Rubiaceae.

Galium boreale Linné.

Valerianaceae.

Valeriana capitana Pallas.

Asteraceae.

Achillea borealis Bongard.
Arnica lessingii (Torrey and Gray) Greene.
Artemisia globularia Chamisso.
Artemisia tilesii Ledebour.
Aster sibiricus Linné.
Saussurea monticola Richardson.
Solidago multiradiata Aiton.

GEOLOGY.

MAJOR GEOLOGIC FEATURES.

In the area between the west coast of Cook Inlet and Lake Clark the rocks are of different ages and complex structure and have been intruded by a batholithic mass of granitic rocks of Mesozoic age. In the area northwest of Lake Clark the hard rocks are dominantly Mesozoic sediments, which are considerably deformed and have been intruded at different times by igneous rocks of different composition. Paleozoic rocks also are exposed in the region examined, but they occupy only small areas. Although these hard rocks are exposed here and there in the region, the widespread unconsolidated water-laid deposits that mantle the lowlands and, as it were, submerge the lower hill slopes make up the dominant geologic formation.

The main stratigraphic units are shown in a general way on the accompanying geologic map (Pl. V), the scale of which, however, is too small to permit the delineation of details of distribution. For instance, the representation of the unconsolidated deposits has been so much generalized that the map does not show that practically every part of the region that was visited south of the Kuskokwim is more or less covered with these deposits—even the tops of some of the hills that rise 3,000 feet above sea level have pebbles and water-worn gravels on them.

The Paleozoic rocks that were recognized by the expedition of 1914 consist entirely of limestones, which are exposed in the Lime Hills south of Kuskokwim River and form a series of bare white hills that make prominent landmarks. Similar beds of limestone are reported on the Holitna, and beds of somewhat similar limestone and other Paleozoic rocks—mostly slate, chert, schist, and greenstone—have been reported and mapped by Martin and Katz[1] south and east of Lake Clark.

The Mesozoic rocks are dominantly shale and sandstone, but in places, especially near the base of the section represented in this area, there is a great thickness of conglomerate. Fossils that are definitely of Cretaceous age have been found in some of these rocks, and others of Jurassic age have been found in adjacent areas in rocks correlated with certain rocks of the Lake Clark-Central Kuskokwim region. All the rocks have been folded, faulted, and considerably eroded.

Igneous rocks, both intrusive and effusive, are associated with or cut the Mesozoic sediments. The intrusive rocks are mainly granitic and are probably the products of more than one age of intrusion. Thus, the granitic batholith east of Lake Clark is regarded as of pre-Cretaceous age, whereas acidic intrusives definitely cut the Cretaceous rocks at many places in the Kuskokwim basin. The intrusive rocks seen do not occupy any great area in the Lake Clark-Central Kuskokwim region but occur usually as rather small stocks or even more commonly as dikes.

The largest area of effusive igneous rocks is in the vicinity of Lake Clark. These rocks are porphyritic, are in general andesitic, and are probably of Lower Jurassic age, and in places they are overlain by other lavas of Tertiary or Recent age, which still retain a glassy aspect and surface-flow structures. Tuffs and agglomerates are associated with lavas of both these types. These range in color from dark brown (nearly black) to cream-white. Some of them are

[1] Martin, G. C., and Katz, F. J., op. cit., pl. 2.

interlaminated with the Mesozoic sediments, and probably parts of these sedimentary rocks are composed of volcanic tuff which has been but slightly worked over by water.

The unconsolidated deposits of nonresidual material are composed mainly of stream, glacial, and glaciofluviatile sand, gravel, and silt. The glaciofluviatile material mantles the whole region so deeply that it obscures in large measure the record of the early Quaternary history. A definite limit between the glacial and the glaciofluviatile deposits can not usually be drawn, for all phases of intergradation between the two types are shown. Distinct moraines are recognizable at a number of places, but usually they are obliterated by outwash deposits produced at a later stand in the retreat of the vanished glaciers. The glaciofluviatile deposits merge, on the other hand, into typical stream deposits. The modern streams in the main are reworking the older deposits and are eroding the hard rock of their valleys at relatively few places. The deposits therefore contain a large amount of material that is foreign to the drainage basins of the streams in which they occur.

The axes of the geologic structure of the region trend in general northeast-southwest, but this general trend is complicated by minor structures and is obscured by the unconsolidated deposits. The general structure between Lake Clark and the Paleozoic limestones of Stony River basin appears to be that of a somewhat faulted and deformed synclinorium, the limestones appearing to be on the southern flank of the accompanying anticlinorium. Whether another syncline succeeds the limestones on the northwest has not been determined. The abrupt change in the topography in the area between the Lime Hills and the flats of the Kuskokwim suggests that a great fault may occur in this area. Whether or not this is the correct explanation of the structure the fact remains that the country north of the limestones is so deeply covered with recent deposits that no structural observations on the hard rocks have been made within a distance of about 50 miles northwest of the limestones. North of this point as far as Iditarod the rocks are in rather open folds whose axes trend nearly northeast-southwest. Beyond Iditarod Paleozoic rocks are again exposed as though on the southern flank of another structure possibly similar to that near the Paleozoic limestones.

The deformation that formed the Pacific mountain system seems to have formed also most of the structural features of the Lake Clark-Central Kuskokwim region. The deformation caused by these movements seems to be greatest in the Alaska Range and the Chigmit Mountains. In places remote from this main axis the deformation is less, so that the major structures seem to become more regular toward the west and northwest. At no place in this region, however, are the structural features of the pre-Tertiary rocks simple, and the dip of the rocks is at few places less than 30°.

PALEOZOIC SEDIMENTARY ROCKS.

SUBDIVISIONS.

Rocks of Paleozoic age outcrop within the area described and mapped in this report only in the Lime Hills—the last highlands of hard rock south of the Kuskokwim—and in three areas south and east of Lake Clark. Paleozoic rocks probably also occur in other parts of the Lake Clark basin and perhaps in areas near the high mountains in the unsurveyed regions east of the route traversed by the expedition of 1914.

The rocks formed in this area are separable into two main divisions—(1) the limestones and (2) the gneisses, quartzitic schists, and slates. Each of these divisions will be described, and the facts and inferences concerning its distribution, lithologic character, structure, age, and interrelations will be presented.

GNEISS, QUARTZITIC SCHIST, AND SLATE.

DISTRIBUTION.

The oldest rocks reported within the area mapped occur east of Lake Clark in the vicinity of Kontrashibuna Lake. At this place gneisses and quartzitic schists are exposed along the northern shore of the lake for about 8 miles and form the country rock farther north, being well exposed for about 5 miles on the shore of Lake Clark west of the mouth of Currant Creek. The mapping and the description of these rocks are taken directly from the report of Martin and Katz.

Slates are exposed at two places within the area studied by Martin and Katz which fall within the area covered by the map accompanying this volume. These localities are as follows: (1) An elliptical area 2 miles long and 1 mile wide, south of Kontrashibuna Lake and about 2 miles east of its outlet; (2) a circular area a mile in diameter, about 2 miles northeast of the northernmost of the Pickerel Lakes, which are east of the southern end of Lake Clark.

LITHOLOGIC CHARACTER.

The gneisses and schists in the area near Kontrashibuna Lake are described by Martin and Katz[1] as follows:

> These rocks include distinctly sheared quartzites and argillaceous quartzites composed largely of quartz with varying amounts of biotite and accessory magnetite and carbonaceous material. * * * The rocks exposed on the east shore of Lake Clark west of Currant Creek and on the opposite shore

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 31–32.

eastward from Portage Creek are quartzites, quartzitic schists, and mica schists, of undoubted sedimentary origin, in alternate succession of moderately thin beds. These are minutely plicated, the axial planes of the folds and the schistosity being vertical and striking about N. 40° E. (magnetic). Some basic dikes invading this formation have been folded with it. Later undeformed granitic intrusives into this formation were seen also on the northernmost of the two islands opposite the mouth of Currant Creek.

The following is a description of the slates:[1]

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

AGE AND INTERRELATION.

According to Martin and Katz:[2]

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

The rocks of other Alaskan regions with which these may be compared include the schists of Willow Creek,[3] on the edge of the lower Matanuska Valley, and the "Klutina series"[4] farther east. Both of these lie in the same general belt with the rocks here described, and neither is of determined age. Other areas of rocks of the same general lithology occur in many parts of Alaska.[5]

Martin and Katz[6] make the following statements regarding the age of the slates:

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

[1] Martin, G. C., and Katz, F. J., op. cit., p. 37.
[2] Idem, p. 32, pl. 2.
[3] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 10–11, 1907.
[4] Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 410, 1900.
[5] Brooks, A. M., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 208–218, 1906.
[6] Op. cit., pp. 37–38.

upon general lithologic similarity, the rocks of each area differing from the others in considerable detail.

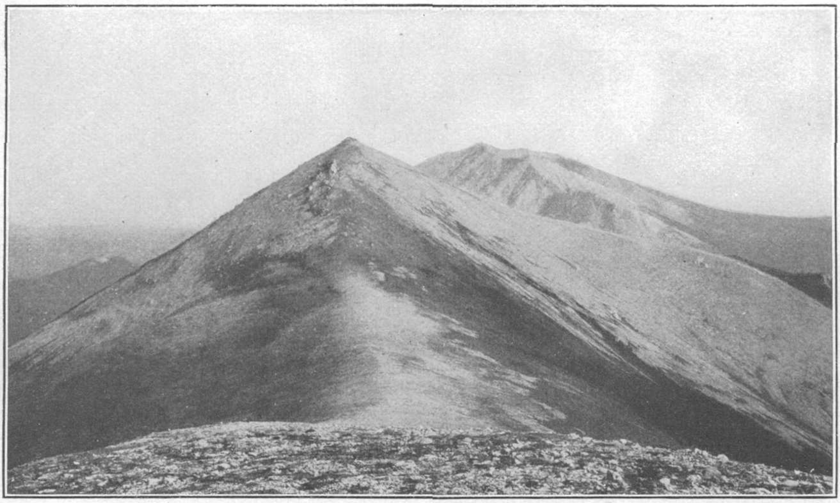
The slates and chert of the district between Kontrashibuna and Iliamna lakes are more metamorphosed and distinctly older than the volcanic rocks with which they are areally associated. The latter are believed to be of early Jurassic age, although the evidence is not positive.

On the legend of the map accompanying the report of Martin and Katz these slaty rocks are called "Late Paleozoic?" and are separated from the gneisses and quartzitic schists. In the map accompanying the present report, however, the two kinds of rocks have been grouped together and are shown by the same pattern. By thus grouping them as Paleozoic, the writer does not intend to dispute the conclusions of Martin and Katz that a part of the rocks may be older or that a part may be younger than Paleozoic. The grouping here adopted only indicates that, as a whole, the rocks are of that age.

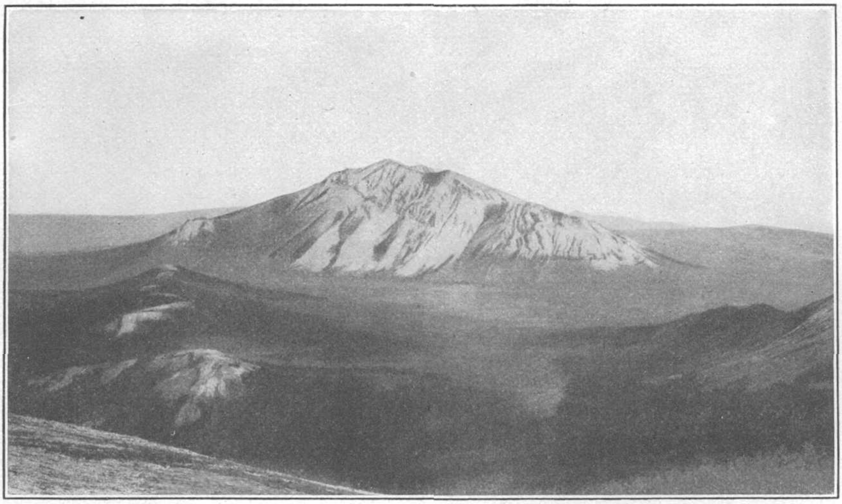
LIMESTONE.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION.

The Paleozoic rocks exposed in the Lime Hills south of the Kuskokwim, near the camp of August 3, consist entirely of limestone. These hills form striking landmarks, because usually they are devoid of vegetation and consequently the white color of the limestone is conspicuous. Plate VI, *A*, shows a near view of some of the hills in the central part of this range, taken from the top of one of the peaks north of the camp of August 3. It illustrates the bare white slopes, the narrow pinnacled crest line, and the characteristic disintegrated rock-covered surface. Plate VI, *B*, a view taken near the same place, shows a more distant hill, the one just west of Stony River. This view exhibits many of the features shown in the other, and in addition shows the separation of the limestone belt into knobs, which are characteristic of the belt as a whole. These knobs rise abruptly from the lowlands like islands above the sea. Their lower slopes appear to be submerged in the great deposit of recent alluvium, and owing to this submergcnce the relations of the different knobs to each other and to the other hard rocks of the region is so masked that they can not be determined with certainty. Plate IV, *A* (p. 32), shows the character of the lowland surrounding these knobs and illustrates the difficulty of tracing the extent and boundaries of the hard rocks in the lowlands. In spite of this difficulty, however, the color of the limestones is so characteristic that the hills they form can be recognized for long distances. For this reason the discrimination of the general area occupied by the limestones is not particularly difficult. From the top of the ridge near the camp of August 3 limestone knobs



A. NEAR VIEW OF LIME HILLS, STONY RIVER BASIN.



B. STRUCTURE IN LIMESTONES, STONY RIVER BASIN.

stretching for 20 miles to the southwest and for more than that distance to the northeast could be distinctly recognized.

The width of the belt of limestone thus recognized is a little more than 2 miles, but because much of the lowland in which no rocks are exposed may be underlain by similar or associated rocks the actual width of the area occupied by the Paleozoic rocks can not be even approximately estimated at present and probably can not be determined accurately at any time except by boring or by some other expensive and laborious investigation.

Prospectors report a similar belt of limestone on the Holitna, about 120 miles by river upstream from its mouth. This part of the region has not been surveyed, but prospectors' sketches indicate that the limestone exposures are probably more than 50 miles due west of the camp of August 3 and are apparently far north of the place where the trend of the limestone hills near Stony River, if projected, would intersect the Holitna. If the strikes remain constant and if the two limestones are the same, the eastern continuation of the limestone on the Holitna is probably buried under the alluvial deposits of the lowland of the Kuskokwim north of the limestone hills that were examined.

The limestones east of Lake Clark are described by Martin and Katz[1] as forming "a continuous belt * * * from a point near the mouth of Currant Creek, on the shore of Lake Clark, southward to a point near the head of Kasna Creek, about 2½ miles south of Kontrashibuna Lake, beyond which they were not followed." Calcareous schist was also reported on an island in Lake Clark, west of the mouth of Currant Creek, and is regarded as probably the continuation of the belt noted above.

So far as could be learned the limestones near Lake Clark are not distinguishable at a distance from most of the other rocks, either by differences in topographic expression or by strongly marked differences in color. They are exposed in hills that rise to elevations of 5,000 feet, but they are also exposed in the valleys below, so that they are not distinctly either ridge makers or valley makers. Most of the high hills in which these limestones occur have bare, freshly exposed rock surfaces, so that the usual light color of the limestones is not striking. Their lack of distinctive features is probably due to the narrowness of the exposures, which makes them a subordinate instead of the dominant factor of the topography.

LITHOLOGIC CHARACTER.

The Paleozoic limestones of the Lime Hills are dominantly gray-white and semicrystalline. At a distance bedding or a laminated

[1] Martin, G. C., and Katz, F. J., op. cit., p. 32.

structure, such as that shown in Plate VI, *B* (p. 50), is frequently distinctly recognizable. On nearer view, however, these structural partings are so much less evident that they are recognizable only in a few outcrops. The obliteration of the original bedding is due in large measure to the recrystallization which the rock has undergone as a result of the dynamic metamorphism of the region. At some places the limestone has also been silicified, and on many of its exposed surfaces the more siliceous parts, which weather less rapidly than the calcareous parts, stand out with considerable prominence. The silicification has not followed any one layer of the original rock but occurs usually as irregular small stringers and masses, which roughly simulate the structure seen in some corals but do not show the same orderly arrangement.

Although this stratigraphic unit is dominantly calcareous, some dolomitic beds were recognized in it and possibly more detailed examination might prove that these are of stratigraphic significance. The greater number of dolomitic rocks were observed in the higher hills just north of the camp of August 3, whereas all the rocks of the lower parallel ridge that is separated from the high ridge by the narrow alluvium-covered lowland are nondolomitic.

In some of the dolomitic phases of this limestone there are irregularly shaped open cavities, which appear to have been formed by the leaching out of its more soluble constituents. Few of these cavities are more than an inch long or more than an eighth of an inch wide. On the walls of these cavities small, perfectly formed crystals of dolomite are common.

Although the rocks have the chemical difference noted, they show surprisingly few lithologic differences. In the part of the Lime Hills that was examined with care no rocks in place other than limestones were seen. This absence of other rocks is particularly notable because, owing to the lack of vegetation, large areas are so well exposed that even thin partings of shale or other rocks would be easily seen. Float of rocks other than limestone was found up to elevations of more than 1,800 feet, but all of it had certainly been brought from a distance and marked a remnant of Quaternary deposits that had been laid down on the limestones.

The Paleozoic limestones east of Lake Clark are described by Martin as follows:[1]

> The limestone and calcareous schist on Lake Clark apparently overlie the mica schists and quartzites already described. * * * They are predominantly calcareous throughout, and pure limestone beds contribute a large proportion of the thickness. * * *
>
> On the east side of Lake Clark the western and presumably lower part of the calcareous rocks is made up of thin interlaminated bands of schistose

[1] Martin, G. C., and Katz, F. J., op. cit., p. 33.

material and of fine-grained crystalline limestone. Immediately east of this a presumably higher horizon consists of fine-grained, light-colored limestone, in places coarsely crystalline. The exposures of this limestone are cut off on the north by the alluvial lowlands of Currant Creek. On the headland just north of Currant Creek the cliffs are of calcareous schist composed largely of sericitic and serpentinous material and calcite with chlorite and quartz and containing veinlets of quartz and epidote. A secondary parallelism of the materials is well developed. The rock is without much question a sheared calcareous argillite. * * * These rocks at all localities observed on Lake Clark are thoroughly recrystallized as the result of regional metamorphism. The degree of metamorphism is, moreover, the same in each of the recognized horizons.

STRUCTURE.

The dominant trend of the Paleozoic limestones of the Lime Hills in the area traversed, as has already been pointed out, is about N. 30° E. The strikes of the rocks in the different exposures, however, diverge considerably from this direction; at one or two places they actually strike northwest. These variations apparently are due to the deformation of the rocks and are distinctly local in their significance.

The dip is generally toward the southeast, but it differs considerably in amount in different parts of the region. The change in the angle is by no means systematic, but in a broad way the dip is steeper in the low ridge north of the higher hills than it is in the area farther south, though even in that area vertical dips are not at all uncommon. At one place about 1½ miles west of the camp of August 3 a dip toward the north was observed, but this was unique, did not persist far, and was probably the oversteepened dip of nearly vertical beds rather than the normal dip of beds on the northern limb of a fold.

Faults parallel to the general trend of the limestone were observed at several places in the Lime Hills. One of these faults may be recognized in Plate VI, *B*, a little south (to the right) of the central part of the bare exposure. Some of these faults apparently mark considerable displacements, but as the fault planes and the dip of the rocks are so nearly parallel no strikingly different beds are brought into contact. Small faults are numerous throughout the limestones. Jointing is also common and has caused the rock to break up under the influence of weathering into rather flaggy pieces.

The absence of well-marked bedding planes or recognizable key horizons and the rather complex structures produced by deformation prevented the accurate determination of the thickness of the limestone. The limestone is exposed throughout an area at least 2 miles wide, and nowhere do the beds dip less than 30°. If these measurements represent the average width and dip, the limestone must be more than 5,000 feet thick. Some reduplication by faulting is probable, and possibly the bed of limestone on the isolated northern low ridge may not be the bed exposed in the main ridge, so that this estimate of thickness may be too great. On the other hand, however, the dip probably averages more than 30°, and the limestone may underlie some of the moss-covered region where its presence was not determined. For these reasons, therefore, more refined measurements and observations probably would show a greater rather than a less thickness.

The limestones east of Lake Clark are mapped by Martin and Katz as occupying a belt about half a mile wide, and according to the text,[1] "they have a thickness of many hundred feet, but the complexity of folding is such that the actual thickness can not be determined." They have been so much metamorphosed that their original structure is nearly obliterated, and without considerable detailed work their general structure can not be determined. These beds strike much more nearly north and south than the limestones of the Lime Hills, but a short distance east of the area shown on the maps accompanying this volume, within the area mapped by Martin and Katz, the strike is more nearly northeast-southwest—that is, almost parallel with the strike of the rocks in the Lime Hills.

AGE AND INTERRELATION.

No fossils were found in the limestone of the Lime Hills. A few indistinct markings suggested organic remains, and one circular area resembled a cross section of a crinoid stem. None of these, however, was definitely organic or of value in fixing the age or stratigraphic position of the rocks in which they were found. In the absence of specific paleontologic data the assumption that the rocks are of Paleozoic age rests on indirect evidence of various kinds.

Great thicknesses of limestone were formed in Alaska at several times in the Paleozoic era, but except in the Triassic system they are not common in the rocks of the Mesozoic and Cenozoic eras. The Triassic limestones are exposed in the vicinity of Lake Clark and Iliamna Lake, about 100 miles south of the limestones here considered, and are widely distributed throughout south-central Alaska. The reasons for believing that the limestone of the Lime Hills is not the same as the Triassic limestone are as follows: The Triassic limestone on Iliamna Lake, as described by Martin,[2] is a fine-grained blue rock containing considerable carbonaceous matter, which is revealed by a strong odor when the rock is broken; it has been greatly crushed and shattered but otherwise is not much altered; it is about 2,000 feet thick; and at most places it contains fossils. None of these features is characteristic of the limestones in the Lime Hills.

[1] Martin, G. C., and Katz, F. J., op. cit., p. 33.
[2] Idem, p. 42.

Possibly some of these differences, such as those in color, the quantity of bituminous matter, the degree of recrystallization, and the quantity of fossils may be due to the greater metamorphism in that part of the Kuskokwim basin where the limestones crop out than that where the known Triassic limestones crop out. Certainly the two limestones show a marked difference in the amount of metamorphism they have undergone, but the writer believes that the metamorphism took place at two different times and that the metamorphism which affected the limestone of the Lime Hills was earlier than that which affected the known Triassic limestone. This belief is not supported by incontrovertible evidence but rests on the apparent degree of metamorphism of the other associated rocks in the two regions and on the relative position of the two regions to the main mountain axes and loci of intrusion during the mid-Mesozoic deformation. If this belief is correct the deformation by the post-Triassic metamorphism must have been much more intense in the Iliamna-Lake Clark region than in the area where the limestones were seen in the Kuskokwim basin.

If, then, this limestone is not Triassic and if no other thick deposits of limestone are known in the Mesozoic or younger section in Alaska, it is probably Paleozoic. Its assignment to the Paleozoic era, however, leaves its correlation with other Alaska formations unsettled, for thick limestones occur in the Cambrian, the Ordovician, the Silurian, the Devonian, and the Carboniferous systems. With the meager information now available little or nothing can be done to determine even the system to which these rocks belong. Their Devonian age, however, seems to be strongly indicated. This correlation is probable because in the Mount McKinley region not more than 125 miles to the northwest along the strike, rocks that are clearly of Devonian age have been reported by Brooks.[1] These rocks are in general similar lithologically to the limestones of the Lake Clark-Central Kuskokwim region.

Some further evidence afforded by the following statement from Edwin Kirk, who examined some questionably organic remains found in the limestone from the Lime Hills, tends to confirm this interpretation:

> Locality 14 AS 108. Station D, northwest of camp, August 3, 1914, Stony River basin. The small silicified subspherical bodies shown in the collection are probably organic in origin. They probably represent calcareous algae that subsequently have been silicified. Similar bodies, though usually calcareous in composition, are found throughout the Paleozoic and have no stratigraphic significance.

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[1] Brooks, A. H., The Mount McKinley region, Alaska, with descriptions of the igneous rocks and of the Bonnifield and Kantishna districts, by L. M. Prindle: U. S. Geol. Survey Prof. Paper 70, 1911.

Judging by the lithologic character of the matrix, I should say that the age of the limestone could safely be put as not earlier than Devonian, though it might well be later.

A slight piece of evidence indicating the late Paleozoic age of this limestone is afforded by fossils found in a pebble from the first exposed formation overlying the limestone. Concerning this collection Edwin Kirk states:

No. 14 AS 104. Pebble of calcareous sandstone from conglomerate probably of Mesozoic age. Divide between Stony and Hoholitna rivers, southwestern Alaska. *Orthothetes* sp., *Productella* sp. The material is too poor to warrant definite correlation with Devonian material from other portions of Alaska. It is, however, of Middle or Upper Devonian age and may well correlate with the Salmon Trout limestone.

Another small bit of paleontologic evidence is afforded by a collection of Middle Devonian fossils, obtained by Spurr and determined by Schuchert, found in the so-called "Tachatna series," on the Kuskokwim, about 100 miles north of the place where the route of the expedition of 1914 crossed the limestone.

These fossils only prove that Devonian rocks lie areally close to the limestone. The real bases for postulating a late rather than an early Paleozoic age for the limestone are its slighter degree of metamorphism and dislocation as compared with the early Paleozoic limestones in other parts of Alaska and its areal relations to Devonian limestones of the Mount McKinley region. Further search must be made for fossils or the relation of this formation to rocks of known age must be traced before their age can be definitely determined. Although fossils may be found at any place where the rock is little metamorphosed the areas in which the relation of these to other Paleozoic rocks may best be disclosed are probably north or east rather than south or west of the Lime Hills.

No evidence as to the age of the limestones reported to outcrop on the Holitna is available. Inasmuch as these rocks are reported to show the same general features as the rocks examined, they are probably of the same age, but their assignment to a more definite period than the Paleozoic era is believed to be unwarranted.

Concerning the age of the limestones east of Lake Clark, Martin and Katz [1] state:

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

The rocks in contact with the limestone of Lake Clark are (1) the granitic rocks, (2) the porphyries and tuffs, (3) the mica schists and quartzites. The granite, which is presumably early Jurassic, is intrusive into the limestone,

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 34–35.

which was metamorphosed and folded prior to the intrusion. The porphyries and tuffs, which are probably Lower Jurassic, rest unconformably upon the limestone. The mica schists and quartzites, which belong to an indeterminate horizon in the Paleozoic, underlie the limestone without known unconformity. Their degree of metamorphism is approximately the same as that of the limestone. The local evidence thus merely shows that the calcareous rocks are certainly pre-Jurassic. * * *

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

MESOZOIC SEDIMENTARY ROCKS.

SUBDIVISIONS.

The greater part of the consolidated bedrock of the Lake Clark-Central Kuskokwim region consists of Mesozoic sediments. These rocks differ lithologically in different parts of the region, but, broadly speaking, they are dominantly a monotonous succession of sandstones and shales. Although the subdivision of this great series of rocks has been left largely to later investigators, who will examine the geology in greater detail than the expedition of 1914, four main subdivisions of the Mesozoic rocks of this part of Alaska have been made. These are, from oldest to youngest, the conglomerate of Cairn Mountain, the Mesozoic shales south of the Kuskokwim (in part of Jurassic age), the Mesozoic sandstones south of the Kusko-

[1] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 218–221, 1906.

kwim, and the Mesozoic sedimentary rocks north and west of the Holitna, in part of Upper Cretaceous age. The separation of the conglomerate from the other rocks is based not only upon lithology but also upon its probable stratigraphic position near the base of the exposed Mesozoic section. The separation of the shales south of the Kuskokwim from the sandstones in the same region is believed to express differences not only in lithology but also in age, as part of them are of Jurassic age. The separation of the Mesozoic rocks on the basis of their position north or south of the lowland of the Kuskokwim, although of stratigraphic significance, as part of the rocks are of Upper Cretaceous age, was made principally to avoid making correlations without a sufficient groundwork of fact. Each of the four subdivisions of the Mesozoic rocks enumerated above will be described separately in the following pages, and the facts and inferences concerning the distribution, lithologic character, structure, age, and correlation of each will be given.

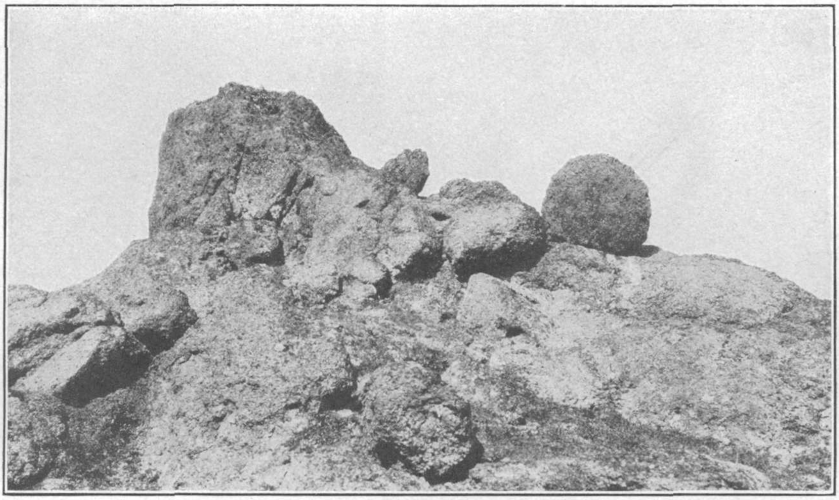
CONGLOMERATE OF CAIRN MOUNTAIN AND VICINITY.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION.

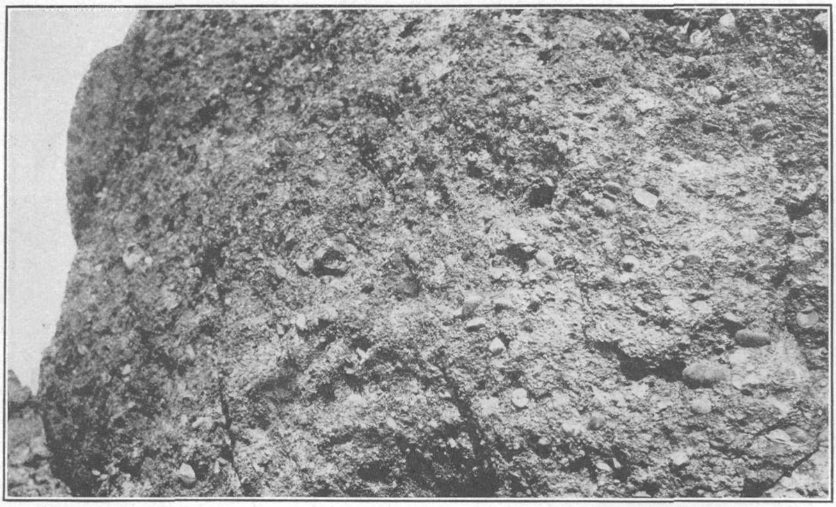
The conglomerate of Cairn Mountain and vicinity forms the country rock of the high hills in the basin of Stony River south of the Paleozoic limestones as well as some of the highest hills in the entire region. Cairn Mountain (the 3,898-foot hill north of the camp of July 29), the highest hill in the entire region traversed by the expedition of 1914, is formed of rocks of this group.

The conglomerate forms notable pinnacles on the tops of the ridges, which are distinctly recognizable for considerable distances. Plate VII, *A*, is a characteristic view of part of the crest of the ridge between the camps of July 29 and August 1. It shows a very common type of the conglomerate exposures—pinnacles rising 20 or more feet above the general level of the crest of the ridge, with frost-disintegrated fragments scattered irregularly around their bases. The nearly spherical mass of rock to the right of the central part of the picture is an untransported block of the conglomerate and is not a waterworn boulder, as its form in the picture suggests.

The conglomerate occupies an area about 5 miles wide and at least 20 miles long. Undoubtedly it is longer, but its limits could not be distinguished with certainty in the hills farther from the route traversed. Spurr reports conglomerate at the base of the Mesozoic section on the Kuskokwim about 90 miles north of the conglomerate area noted in the Stony River basin, and possibly rock of this type is continuous between the two places, though the strike



A. CONGLOMERATE PINNACLES ON RIDGE NORTH OF CAMP OF JULY 29.



B. DETAIL VIEW OF CONGLOMERATE NORTH OF CAMP OF JULY 29.

of the rocks, as known, does not indicate this connection. Brooks[1] also noted a conglomerate at the base of the Mesozoic section in the Mount McKinley region. Too little is known about the region north and east of the route traversed in 1914 to warrant any definite statement, but conglomerate is probably the country rock in a considerable part of the area.

A small amount of conglomerate float was found along the shores of Long Lake—the lake on which the camp of June 26 was situated—but no exposures of that rock in situ in this vicinity were seen. The float in this lowland consists of a mixture of rocks of all kinds, which have been brought by ice and other agencies from foreign drainage basins, and the fragments of conglomerate also may have been brought from places remote from those at which they are now found. Their occurrence shows that conglomerate rocks similar to those of Cairn Mountain probably outcrop in the Lake Clark basin northeast of the place at which the float was found.

LITHOLOGIC CHARACTER.

The conglomerate at Cairn Mountain and vicinity is a dark-gray rock. It differs in the size of its component fragments, at some places being made up of bands of coarse conglomerate and at others of fine conglomerate or coarse sandstone. It includes few or no beds of shale. In some of the coarse phases cobbles a foot or more in smallest dimensions are by no means uncommon, but most of the pebbles are less than 3 inches in diameter. Plate VII, *A*, already described, shows a characteristic outcrop of the conglomerate and illustrates the general lithologic texture. A nearer view of exposures of conglomerate on this same ridge (Pl. VII, *B*), however, shows the details much more distinctly. The largest pebbles shown in this view are about 6 inches in diameter and, as will be seen, they are considerably less numerous than the smaller pebbles. The view was taken so nearly parallel to the bedding that that structure is not so distinct in the picture as it is in the outcrop.

The pebbles are composed of a great many different kinds of rocks. Most of the small pebbles are usually formed of dark, nearly black slate; most of the larger pebbles are of igneous rocks. Granite, greenstone, and andesitic rocks were recognized as components of the conglomerate. In addition to slate the sedimentary rocks forming the pebbles are limestone, chert, and quartzite. Two distinct types of limestone were recognized—one a bluish-gray limestone similar to the Paleozoic limestone of the hills to the north, and the other a brown-weathering sandy limestone, which is considerably less crys-

[1] Brooks, A. H., op. cit., p. 88.

talline. It was in a pebble formed of the brown-weathering limestone that the fossil noted on page 56 was found. No distinctly schistose rocks were recognized among the pebbles. A few of the smaller pebbles and grains of the conglomerate are formed of vein quartz.

The matrix of the conglomerate appears to consist mainly of comminuted fragments of the various rocks that form the pebbles. Although the matrix seems to have the same composition as the pebbles, it contains much more lime. In fact, although only a few pebbles of limestone were recognized, wherever the matrix was tested with acid, lime was detected in considerable abundance. The high lime content of the matrix is probably due to the slight resistance of limestone to attrition, whereby the large fragments soon wore away and only the fine particles remained.

In the conglomerate exposed near the camp of August 1 holes were numerous. Some of these holes were 5 inches across and at least a foot long. Their origin was not determined, but they appeared to be cavities from which the original filling had been removed. Possibly they were formed by the leaching out of pebbles of easily soluble rock, such as limestone, after the conglomerate had been formed. They looked like some cavities in Carboniferous conglomerate at Pondville, Mass., which were produced by the decomposition of logs that had been built into the conglomerate when it was deposited. No indications of organic remains, however, were detected in the vicinity of the holes in the conglomerate near the camp of August 1.

The lithology of the conglomerate on the Kuskokwim north of the area covered in this report is described by Spurr[1] as follows:

> As before mentioned, the basal bed of the Holiknuk series consists of conglomerates and arkoses which are quite different from the shaly limestones of the Tachatna series farther up the river, having a comparatively fresh appearance. The pebbles in the conglomerate are sometimes 5 or 6 inches in diameter and are mostly of black or dark-gray siliceous limestone or limy shale evidently derived from the Tachatna series.

STRUCTURE.

Wherever the conglomerate was seen its structure, though relatively simple, was deformed. The conglomerate passes upward into beds of sandstone and shale and so into the overlying formation, without recognizable stratigraphic break. North of the plane which has been rather arbitrarily selected as the top of the conglomerate the beds dip dominantly southward. The dip at many places is so steep as to be nearly vertical. The only considerable area in which northerly dips were observed was in the hills immediately south of the camp of August 1, where steep northerly dips predominated. Al-

[1] Spurr, J. E., op. cit., p. 159.

though the evidence was not so clear as to be incontrovertible, the change of dip appeared to mark overfolding rather than anticlinal structure. If this interpretation of the structure is correct the strata have not been reduplicated but have been inclined slightly beyond the vertical by the intensity of the folding. Reverse dips of this sort are by no means uncommon in beds that stand so nearly vertical as these.

The relation of the conglomerate in the Stony River basin to the underlying formation to the north has not been actually seen, but many items of geologic evidence indicate that it lies unconformably on the underlying formation. The facts leading to this conclusion are (1) the diversity of the kinds of rock that form the pebbles of the conglomerate, (2) the considerably less amount of metamorphism the conglomerate has undergone, (3) the apparently different trends of the conglomerate and the underlying limestones, (4) the presence of fragments of the underlying formation in the pebbles of the conglomerate, and (5) the marked difference in the lithology of the two formations.

Some faults of small throw were recognized and some of larger throw probably occur. In general, however, the dips of the fault planes are so nearly parallel to the dips of the bedding planes that no strikingly different rocks are brought into contact by the faulting, and therefore the amount of the displacement is uncertain. Jointing also is common in the conglomerate. The mode of weathering of the conglomerate into pinnacles is characteristic and is undoubtedly due to atmospheric attack along the joint planes and to consequent more rapid disintegration along the joint planes than in the intervening areas.

AGE AND INTERRELATION.

The only definite information as to the age of the conglomerate of Cairn Mountain and vicinity is derived from Devonian fossils contained in a pebble found in it between the camps of July 29 and August 1. A detailed report on this locality is given on page 56. This information shows that the conglomerate must have been formed after the consolidation of this Devonian rock. No one has described any conglomerate in southwestern Alaska except the Chisik conglomerate, found east of the Chigmit Mountains in the vicinity of Iniskin and Coal bays, on the west side of Cook Inlet, and small local conglomerates in the Naknek formation, farther south. The Chisik conglomerate at the type locality was described by Martin[1] as 290 feet thick and of Upper Jurassic age. The thinness of the Chisik conglomerate seems to preclude the probability that it and the conglomerate of Cairn Mountain and vicinity are the same.

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 68–69.

Further, in the Lake Clark-Central Kuskokwim region, as will be shown in a discussion of the other Mesozoic sedimentary rocks south of the Kuskokwim (pp. 63–77), the conglomerate appears to underlie rocks whose continuation in the adjacent region Martin considers of Lower or Middle Jurassic age. Accordingly, a correlation of this conglomerate with Upper Jurassic rocks seems to be precluded.

In the Matanuska region there is a conglomerate, described by Paige and Knopf, which in places is 1,100 feet thick and which they correlate with Upper Jurassic. This conglomerate was afterward correlated with the Chisik conglomerate by Martin and Chapin. The assignment of this conglomerate to the Upper Jurassic seems to be based on conclusive paleontologic evidence,[1] and the same reasons as given in the preceding paragraph prevent correlating the conglomerate of Cairn Mountain and vicinity with the conglomerate described by Paige and Knopf.

A conglomerate in the Yukon basin and in the area draining into the eastern part of Norton Sound has been described by Smith and Eakin.[2] This was called the Ungalik conglomerate and was regarded as Upper Cretaceous. The age of the Ungalik conglomerate was not determined by direct paleontologic evidence but by the apparently unbroken sequence from the conglomerate to fossiliferous sandstones that lie stratigraphically many thousand feet above the conglomerate, by the fact that a marked stratigraphic break occurs in other parts of Alaska between the Upper and Lower Cretaceous, and by the presence in the conglomerate of pebbles of granitic rocks that are assumed to be of Jurassic age. If the Ungalik conglomerate is Upper Cretaceous the thick conglomerate in the vicinity of Cairn Mountain, which is probably older than Upper Jurassic, can not be correlated with the conglomerate in the Norton Bay-Nulato region, or with the conglomerate near the mouth of the Melozitna River on the Yukon.

The presence of pebbles of granite in the conglomerate at first seems to indicate that the conglomerate was formed after the great intrusion of the Coast Range batholith, which in the Matanuska region occurred in Middle Jurassic time. This conclusion, however, is not justified, for granitic rocks of a composition similar to that of the Coast Range intrusives were injected into Cretaceous rocks in this part of Alaska, and there is reason to believe that similar rocks may have been injected before the main period of intrusion. In fact, in other parts of Alaska there is evidence to show that some of the granitic igneous rocks are even as old as Paleozoic.

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 21–23, 1907.

[2] Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, pp. 55–56, 1911.

If the conglomerate is of early Mesozoic age—if it really underlies the sandstones and shales of the Jurassic and if beds of these rocks extend upward into the Upper Cretaceous sandstones and shales—stratigraphic breaks representing the period of Coast Range intrusion and the break between the Lower and Upper Cretaceous should occur. No such breaks in the stratigraphic sequence have yet been recognized.

The early Mesozoic age of the conglomerate is also made improbable by the fact that nowhere along the Alaska Range where Paleozoic rocks are overlain by Mesozoic rocks has a conglomerate of comparable thickness been observed. This lack of evidence may, of course, be due to the fact that the upper part of the Paleozoic section and the entire lower part of the Mesozoic section have been seen at only a few places, and at these places the beds are so incompletely exposed that the conglomerate may not have been recognized or may have been cut out by faulting, obscured by overlap, or removed by erosion.

In spite of the facts cited, which suggest that the conglomerate may be of late Mesozoic age, several others indicate that it may be older, among them the fact that the conglomerate almost certainly lies below shales and sandstones that seem to be in part of Jurassic age. This relation is indicated not only by the dips that have been observed but by the absence of the conglomerate between the shales and sandstones and the overlying formations where it should occur if it were late Mesozoic.

In view of the uncertainties that are due to lack of adequate field observations and that lead to antithetical conclusions, it has seemed expedient to leave the stratigraphic correlation of the conglomerate in abeyance and to state instead only that, in the light of the information now available, a thick conglomerate seems to occupy a position near the base of a nearly uninterrupted succession of Mesozoic rocks. This conglomerate was probably deposited unconformably on the underlying formations, but it is conformable with the overlying rocks and though this conclusion can not be definitely proved the conglomerate is believed to be older than Middle Jurassic.

MESOZOIC SHALES SOUTH OF THE KUSKOKWIM.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION.

In the region extending southward from the conglomerate of Cairn Mountain and vicinity into the basins of the Hoholitna, Mulchatna, and streams tributary to Lake Clark, as far south as Chulitna River, the bedrock is a monotonous succession of sandstones and shales that include practically no distinct horizon markers. Not all the rocks exposed in this region, however, are sedimentary, for igneous rocks, either intrusive or effusive, are fairly abundant, especially in the southern part of the region.

The widespread covering of Quaternary gravels and sands, as already noted, mantles so much of the region that many of the hills are more or less elongate islands of sedimentary rock that rise above the alluvium. The underlying bedrock in the greater part of the region is probably sandstone and shale, with very subordinate amounts of igneous rock. As far as the eye could see on both sides of the route traversed by the expedition of 1914, except in the very distant snowy mountains at the head of the Kuskokwim, the bedrock is apparently composed mainly of these sedimentary rocks. Westward from the route traversed these rocks probably extend for many miles, but the hills in that direction are low and isolated, so that from a distance the kind of rock of which they are composed could not be determined. Furthermore, the region in which these hills stand is one of the least explored parts of Alaska. Farther northeast on the Yentna and other rivers of the Susitna basin and on the tributaries of the Nando, or south fork of the Kuskokwim, are similar rocks, which have been described by Spurr[1] and by Brooks.[2]

The shales south of the Kuskokwim do not form strongly marked topographic features. They generally produce subdued forms whose very lack of notable features is distinctive. The general shape of the hills that are composed of these rocks is indicated in Plates II, *A*, and III, *A*, which show some of the hills in the Mulchatna and Hoholitna basins, and Plate VIII, *B*, which shows the hills east of the camp of July 29.

In areas where the rocks are dominantly shales most of the hills have rather smooth conical, rocky peaks, which rise a few hundred feet above the grass-covered lower slopes of the main ridges, but in areas where igneous rocks are associated with the shales the topographic form depends in large measure upon the degree of control exercised by one or the other. The highlands south of the Chilikandresten show in different areas forms determined by both igneous and sedimentary rocks, whereas those north of the Mulchatna show at most places forms determined almost exclusively by sedimentary rocks.

LITHOLOGIC CHARACTER.

Although the assemblage of rocks mapped and described as "Mesozoic shales south of the Kuskokwim" is composed mainly of dark, nearly black shale, it includes in almost every large exposure some

[1] Spurr, J. E., op. cit., pp. 153–157.
[2] Brooks, A. H., op. cit., pp. 87–90.

beds of sandstone and at a few places in it the question may be raised whether shale or sandstone predominates.

The shales are generally so fine grained that their component constituents can not be recognized by the unaided eye. Examined microscopically they are seen to be composed of small particles, which have undoubtedly been derived from many of the different kinds of rock seen in the conglomerates. The typical shales differ in texture from place to place, ranging from rather thinly laminated rocks to more massive pelitic layers that are not so coarse grained as the sandstones.

Although throughout the area the shales show few important lithologic variations, they exhibit locally, especially near their contacts with large igneous masses, certain distinctive features. The most common of these features is the formation of new minerals of the contact-metamorphic group. The first noticeable effect of this contact metamorphism is the formation of small amounts of biotite. At some places where this process has gone far enough the rock has a brownish-red tinge, distinct from the usual gray or gray-brown color. Examined microscopically the biotite is seen to lie in the groundmass in irregular aggregates, which seem to be incipient crystals rather than the usual well-formed blades. Rocks showing this character were noted at several places especially on the isolated hill in the lowland of the Koksetna south of the camp of July 2, on the low hill southwest of the western end of Tutna Lake near the camp of July 7, on the small tributary of the Chilchitna, on the hill a short distance north of the camp of July 12, on the Chilikandresten, and in the float on the Lime Hills northwest of the camp of August 3.

Closer to the contact of the sedimentary and igneous rocks the biotite becomes somewhat more abundant and occurs in better-formed blades, and still closer other contact minerals begin to appear in the shales and pelites. The most striking of these minerals are cordierite and chiastolite. The cordierite was recognized microscopically, but the chiastolite occurred in crystals large enough to be readily seen by the naked eye. The chiastolite was especially abundant in the rocks near the contact north and east of the camp of July 7. Here this mineral occurs in well-formed crystals a quarter of an inch long, which on cross section show the characteristic rhomb of white material with a dark center. Under the microscope the peculiar cross formed of the dark dustlike inclusions is very distinct. So abundant is this mineral that it gives the rock a speckled appearance on cross fractures. On surfaces parallel to the lamination the small prisms of chiastolite are very characteristic. The width of the belt around the igneous mass containing chiastolite at most places is not more than a few hundred yards. The width of the belt containing cordierite was not determined, but it also is apparently not very great.

The slates are generally dark, but in one area, only a few hundred feet wide and not more than a few hundred yards long, on the hillside east of Chilchitna River, 1½ miles southeast of the camp of July 7, highly colored green and red slates were found. These green and red slates were apparently interbedded with the black slates and were part of the same stratigraphic series. At no other place in the region were similar rocks exposed, and even float of these rocks was not noticed elsewhere. Brooks,[1] however, reported similar slates in the Tonzona group in the Mount McKinley region.

These highly colored slates were more indurated and cleaved and looked older than the black shales. The region in which these slates occur, however, is one of considerable deformation and is adjacent to a large intrusive mass, so that the greater degree of metamorphism they show is not conclusive evidence that they are older than the black shales. They occupy a small area and their relations to other rocks are not clearly defined, so they have not been separated from the rest of the Mesozoic rocks in the mapping, though a closer study of the region may warrant their separation.

Organic remains are very uncommon in these rocks. Small fragments of plants were recognized in some of the beds, but they were by no means abundant, and no pieces that might be of service for paleobotanic determinations were seen. The dearth of traces of organisms in this great series of rocks was apparently a characteristic feature of the lithology. The small particles of plant remains were noted particularly in some of the finer sandstones. None were seen in the black shales.

The shales in many parts of the area contain quartz veins. None of these veins were very long, and all were composed of glassy quartz unaccompanied by other minerals. In some of these veins the quartz forms perfect crystals, which grew out from the walls of the cavity, but more commonly the quartz occurs in large glassy masses which are more or less lenticular in cross section. Quartz veins of this sort are especially numerous in the rocks near the camp of July 7, in the hills north of the Mulchatna north of the camp of July 12, and in the hills north of the small mapped area of intrusive rock between the main Hoholitna and its north fork, Hook Creek.

STRUCTURE.

Considerable diversity of structure was observed in the rocks south of the Kuskokwim. In the area of shales lying north of Hoholitna River the strike is almost uniformly a few degrees north of east, but

[1] Brooks, A. H., op. cit., p. 73.

the direction and angle of the dip are by no means constant. Near the conglomerate on the Stony-Hoholitna divide the dip is nearly everywhere southward at angles that generally become lower away from the conglomerate, but in the ridge between Hook Creek and the Hoholitna the dip changes in short distances from north to south and back again many times. Some of the main features of the structure in this region are indicated by the dip and strike symbols on the geologic map (Pl. V), but the less important are not shown because the scale of the map is too small.

In the area between the Hoholitna and the belt of conglomerate few igneous rocks are exposed at the surface. Probably the absence of intrusive masses is the cause of the absence of complex structures. In other words, the structural features in this area are due mainly to the large-scale folds which have not been complicated by later intrusion. On the other hand, these rocks may be younger than the rocks farther south and may not have been subjected to the same amount of deformation. Although this alternative explanation of the greater simplicity of the structure in this area than in the area to the south is worthy of consideration, the difference in structure is believed to be due to the greater distance of the northern area from the large intrusive masses.

South of the Chilikandresten fork of the Mulchatna the east-northeast trend of the rocks, although recognizable here and there, is by no means so dominant as it is farther north. An especially clear section of the rocks was seen in the canyon of the Chilchitna, or southern fork of the Mulchatna, south of the camp of July 7. At this place the strike is dominantly to the northwest and the dip is generally steep to the southwest. Still farther south, near the camp of July 5, the strike is north or a few degrees east of north and the dip is nearly west at angles of 50° to 70°. Still farther south, on the isolated hill in the lowland of the Koksetna basin about 4 miles south of Tutna Lake, the strike is nearly east and the dip is north. The dominant structure in this part of the area is therefore apparently a syncline, the western limb of which was not visited.

The rather isolated group of hills north of Long Lake is formed of rocks that have in general a synclinal structure. The strike of the rocks on the northern limb of this fold, near the camp of June 29, is nearly east and the dip is south at angles of 25° to 40°. On the 2,800-foot hill 3½ miles east of the camp of June 29 the strike is about N. 76° E. and the dip is northerly. This strike and dip appear to prevail as far as Long Lake, where, on the northern shore near the western end, good exposures showed a strike of N. 70° E. and a dip of nearly 90° to the north. In the few exposures between Long Lake and the Chulitna the rocks have been so shattered by frost and so dislocated by diastrophic movement or by the injection of igneous rocks that their larger structural features are not recognizable, though the folds here are nearly parallel to those on Long Lake. No sedimentary rocks of this series were observed between Chulitna River and Sixmile Lake, the southern limit of the area embraced in the Lake Clark-Central Kuskokwim region.

Some of the smaller structures, such as those due to metamorphism, have already been described in that part of this report which treats of the lithology of these rocks. Jointing is common in the shales throughout the region. Where the structures produced by faulting and those produced by the original lamination of the rocks intersect at suitable angles, the jointing forms "pencil slates."

A peculiar structure was noticed in the shales on the hills 6 or 7 miles south of the camp of July 29. For a considerable area the shales are marked by subcircular spots, half an inch to an inch in diameter, from which radiate faint markings that are similar in many respects to features usually interpreted as due to percussion. On weathered surfaces these spots are generally brownish gray, contrasting strongly in color with the rest of the shale, which is blackish gray. On many of the pieces examined the surface area is about equally divided between spotted and unspotted portions. Even on fresh fractures the spots could be recognized by their shape and by their lighter color. The spots are parallel to the cleavage planes of the rock, but in many specimens these planes stand at angles highly inclined to the bedding. In fact, the spots on probably the best specimens seen were on planes at right angles to the bedding. No adequate explanation of the origin or nature of these spots has been found, but they are probably due to some mechanical process and therefore have no stratigraphic significance. Somewhat similar markings were noted in the shales north of the Kuskokwim, near the Parks quicksilver prospect, but probably these markings also are not limited to any particular bed or series of beds, and are therefore also of no stratigraphic significance.

AGE AND INTERRELATION.

Throughout the area occupied by the Mesozoic shales south of the Kuskokwim practically no fossils sufficiently well preserved to indicate the age of the rocks have been found. The only collection obtained from these rocks in the Lake Clark-Central Kuskokwim region was made from the 2,000-foot hill 2½ miles south of the camp of July 17. Concerning this collection Mr. Stanton reports:

9219 No. 14 AS 82. Lake Clark-Iditarod region, Alaska. Hill south of camp July 17, north of the Mulchatna River. Mesozoic. Imprints of fragments of pelecypod shells—probably *Inoceramus*. If *Inoceramus*, the age is either Jurassic or Cretaceous.

The collection is so meager and so badly preserved that it serves but poorly to determine the place of these rocks in the stratigraphic column. The fossils came from shales that lie north of the line of contact with the supposed higher conglomerate and sandstones which are exposed on this hill. The rocks dip southward so that apparently the rocks from which the fossils were obtained underlie the conglomerate. There are strong reasons for believing (see p. 75) that these younger rocks may have been thrust by faulting on top of the shales to the north, so that the actual structure may be the reverse of the apparent structure.

As the age of these rocks is not definitely shown by paleontologic evidence, it must be inferred from the resemblances of the rocks to those of determined age in near-by regions, which may indicate probable correlations. These rocks are believed to lie conformably upon the thick conglomerate series that outcrops in the Hoholitna-Stony divide (see pp. 61–63), which is probably early rather than late Mesozoic.

Martin and Katz have shown that in the adjacent Iliamna-Lake Clark region the Mesozoic sedimentary rocks older than Middle Jurassic are limestones and cherts and are therefore not lithologically similar to the shales of the adjacent region. The Middle Jurassic rocks described by Martin and Katz[1] are predominantly sandstones, but they include considerable thicknesses of shale and a few thin beds of limestone and conglomerate. The sandstone in the Iliamna region has been called Tuxedni sandstone, the name having been derived from the name of the bay in which the formation is especially well exposed. Overlying the Tuxedni sandstone is the Chinitna shale, which is described as 1,300 to 2,400 feet thick. It is composed of shale with subordinate amounts of sandstone and limestone. It rests with apparent conformity on the Tuxedni sandstone, from which it is distinguished by its lithologic character and fossils. Both the Tuxedni sandstone and the Chinitna shale were formerly grouped together by Martin as the "Enochkin formation," and the subdivision was made only by means of rather refined stratigraphic studies. Martin states:

> The fauna of the Tuxedni sandstone is regarded by Stanton as showing that it certainly includes at least part of the Middle Jurassic, although he holds that further study of the faunas must be made before exact correlations with the European faunas can be made.[3]

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 58–68.
[2] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, pp. 401–402, 1905.
[3] Martin, G. C., and Katz, F. J., op. cit., p. 63.

In regard to the age and correlation of the Chinitna shale Martin[1] states:

The fauna of the Chinitna shale is regarded by Stanton[2] as indicating the boreal facies of the Callovian stage, which belongs at the top of the Middle Jurassic or at the base of the Upper Jurassic. * * * Its fauna shows close relationships with that of the Callovian of Russia, Franz Josef Land, and elsewhere in the northern as well as in other parts of Europe.

On the continuation of the trend of the Mesozoic rocks of the Lake Clark-Central Kuskokwim region and about 80 miles distant from the route traversed, Spurr in 1898 and Brooks in 1902 reported a series of similar rocks. These rocks, which were later called the Tordrillo formation, are described by Spurr[3] as follows:

The Tordrillo series consists of a considerable thickness of black shales which are often carbonaceous. Intercalated with these shales are numerous beds of sandstone, arkose, and impure limestone. In the upper part of the series the sandstone seems to become predominant. Throughout the rocks are imperfect plant remains. All the rocks have been highly folded or cut through by great masses of intrusive material.

Brooks,[4] who examined the region later than Spurr, states:

A few invertebrate fossils were found by Mr. Prindle in the slates of the Tordrillo formation near the camp of July 14. Although these fossils were rather fragmentary, they were sufficient to enable Dr. Stanton to refer the rocks in which they occur to the same horizon as the Enochkin. It does not follow, however, that the Tordrillo formation as here described is the exact equivalent of the Enochkin. The subjoined statement is quoted from Dr. Stanton's manuscript report:

"The following localities yielded Mesozoic fossils:

"No. 2. Kichatna River, opposite camp of July 9, Alaska Range: Imprint of a fragment of a large *Inoceramus*.

"No. 4. About 3 miles southeast of Simpson Pass, Alaska Range, near camp of July 10: *Inoceramus eximius* Eichwald, several specimens; *Inoceramus lucifer* Eichwald? two specimens; spine of an echinoid.

"No. 6. Near the pass, camp of July 14, Alaska Range: *Inoceramus eximius* Eichwald.

"No. 7. Near the pass, camp of July 14: *Inoceramus eximius* Eichwald? fragmentary imprint.

"The above are probably from a single horizon which is believed to be Upper Jurassic. When Eichwald described these species of *Inoceramus* with several others from 'Tukusitnu Bay,' Cook Inlet, he referred them to the Lower Cretaceous.

"Associated with the plants at locality 21 there are two imperfect specimens of invertebrates in the form of small annulated tubes. These are probably either marine worms or the tubes of burrowing mollusks."

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[1] Martin, G. C., and Katz, F. J., op. cit., p. 68.

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

[3] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 155, 1900.

[4] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, p. 90, 1911.

Under date of April 11, 1905, Stanton writes as follows:

"I have again examined the Mesozoic fossils collected by your party near the Alaska Range in 1902 and am now able to give a more definite opinion as to their age. They consist chiefly of *Inoceramus eximius* Eichwald, with possibly other species of the same genus. There can be little doubt that the horizon represented is the Enochkin formation, which we now refer to the Middle Jurassic. Since my original report was written we have visited the locality of Snug Harbor, where Eichwald obtained the species in question, and their stratigraphic position is now well established."

Other rocks with which the Mesozoic rocks south of the Kuskokwim might be correlated are the Chisik conglomerate and Nahnek formation, both of which are Upper Jurassic. These formations are well exposed in the vicinity of Iniskin Bay—the first bay northeast of Iliamna Bay. The Chisik conglomerate is about 300 feet thick and the Naknek formation which, according to Martin,[1] consists of shale, sandstone, arkose, andesitic tuff, and conglomerate, is about 5,000 feet thick. Martin [2] states:

The stratigraphic position of the Naknek formation has been established by Stanton [3] as being clearly in the Upper Jurassic and not below the Oxfordian of the European geologists, the closest relationship with the European faunas being with the boreal Russian Volga beds. * * * This formation covers a broad area around the upper ends of Naknek and Becharof lakes and southeastward to Katmai and Cold Bay. This area possibly extends in a continuous belt northeastward to the head of Kamishak Bay, and may extend southwestward as far as Chignik and Herendeen Bays, where Atwood [4] has found a similar fauna.

The same fauna was found by Paige and Knopf [5] in beds of similar lithologic character in the upper end of the Matanuska Valley.

The same type of *Aucella* has also been found in the Kennicott formation [6] of the Copper River region.

The beds outside of Alaska which are related to these, according to Stanton,[7] are the Mariposa slate and equivalent formations of California and Oregon; the marine Jurassic of the Black Hills and Rocky Mountains, which represents apparently only the lower part of the Naknek; and the widespread boreal Upper Jurassic of north Europe, occurring in Russia, Spitzbergen, Nova Zembla, and elsewhere.

In many features certain of the Mesozoic rocks south of the Kuskokwim resemble so closely the Upper Cretaceous rocks described

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[1] Martin, G. C., and Katz, F. J., op. cit., p. 69.

[2] Idem, pp. 73–74.

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

[4] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 35–36, 1911.

[5] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 20–23, 1907.

[6] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, p. 50, U. S. Geol. Survey Special Pub., 1901.

Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, p. 31, 1909.

[7] Stanton, T. W., op. cit., pp. 410–414.

elsewhere (pp. 77–84) that the two must be separated not by differences in lithology but by differences in structure. The long period of intrusion in this part of Alaska is generally supposed to have occurred in the later part of Lower Jurassic time. If this supposition applies to the entire Lake Clark-Central Kuskokwim region it may explain the almost complete absence of intrusives in the shales north of Holitna River and may serve as a basis for separating the metamorphosed and intruded shales south of the Mulchatna from the less metamorphosed and less intruded rocks north of it. This criterion, however, should be applied with considerable caution, for igneous granitic intrusives were injected at many times, from the Paleozoic era to the Upper Cretaceous epoch and probably even in the Eocene.

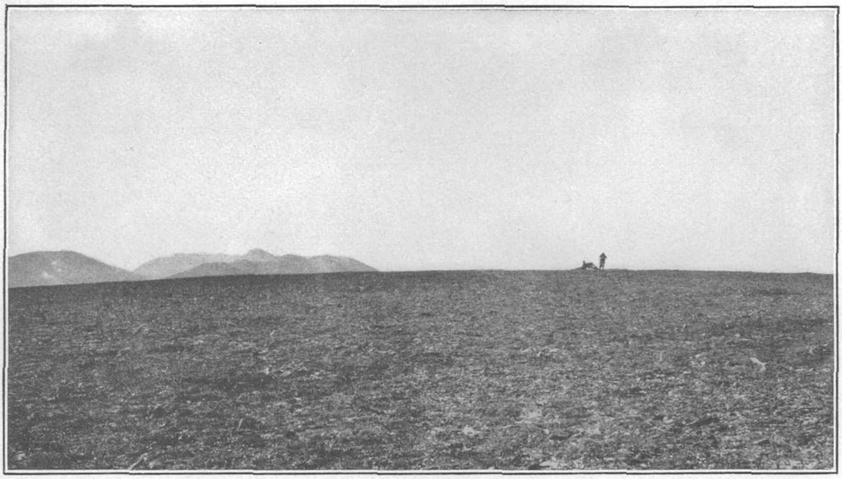
The Mesozoic shales south of the Kuskokwim must be correlated, in part at least, with the Tuxedni sandstone, Chinitna shale, and Tordrillo formation, but they may include rocks that belong to other formations. In view of the absence of specific determinations it has seemed best to abstain from close correlations and, while pointing out that some of these rocks are probably of Middle Jurassic age, to suggest also that the series may include also rocks of other ages. Some of the sandstones and shales, especially those near the conglomerate of Cairn Mountain, may have been formed during the early part of the Mesozoic era, but some of the higher beds may not have been deposited until near the close of that era. No marked stratigraphic breaks have been observed in this great series of sediments, but their apparent absence may perhaps be accounted for by the hurried manner in which some of the observations were necessarily made.

MESOZOIC SANDSTONES SOUTH OF THE KUSKOKWIM.

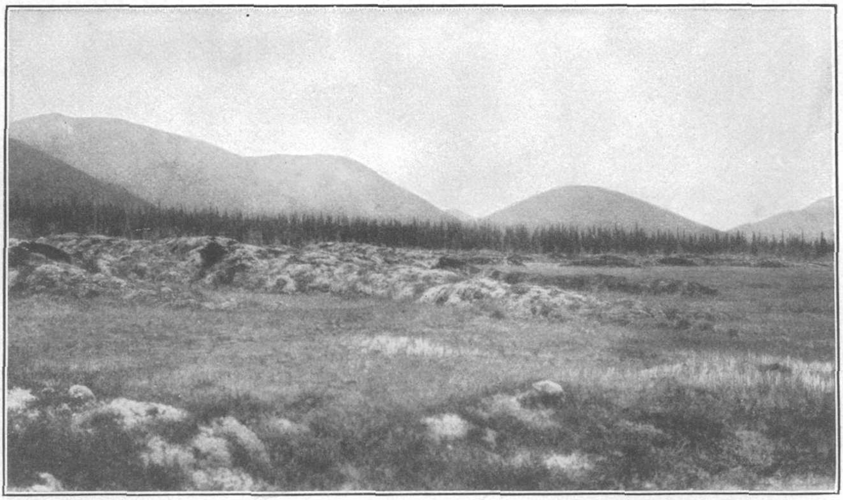
DISTRIBUTION AND TOPOGRAPHIC EXPRESSION.

South of the area occupied by the rocks already described as Mesozoic shales south of the Kuskokwim and extending nearly to the Mulchatna in the vicinity of the camp of July 15 is a great thickness of rocks which are dominantly sandstones. These rocks occupy an area about 15 miles wide and at least 20 miles long. Possibly some of these rocks are infolded with the shales in other parts of the region, but nowhere else were they so clearly recognized that they could be separated in mapping.

Where these sandstones predominate the summits of the hills are generally covered with a heavy mantle of disintegrated bedrock and are flat or tabular. Flat-topped sandstone hills formed of rather steeply inclined strata are common throughout the region occupied by these rocks but are particularly remarkable in the divide between



A. FLAT-TOPPED HILL SOUTH OF WHITEFISH LAKE, HOHOLITNA RIVER BASIN.



B. PEAT RIDGES SOUTHEAST OF CAMP OF JULY 29, HOHOLITNA RIVER BASIN.

the Mulchatna and Hoholitna rivers. Plate VIII, *A*, shows the summit of one of these flat-topped hills 9 miles west-southwest of the outlet of Whitefish Lake. This hill rises to an elevation of 2,400 feet, and the Hoholitna, 5 miles distant, flows at an elevation of 1,000 feet. The view is toward the southwest, and the hills in the background are those near the camp of July 20. The strata forming the hill are inclined at angles of more than 30°. No gravel was found on any of the strikingly flat uplands examined. The rocks of these uplands, though disintegrated, were but slightly decomposed. These peculiar topographic forms are therefore evidently not the result of the structure of the underlying rocks, of fluviatile or marine planation, or of long-continued weathering at low altitudes such as are believed to accompany peneplanation. In the absence of other adequate explanation the summits are believed to have been leveled by weathering processes which are especially effective in sub-Arctic regions. This feature is interpreted as leveling at a high level, not at base level.

The uplands formed of the sandstones are generally dry and the ridges, where they are continuous, afford the best footing for traveling. Unfortunately the ridges are not very long and are separated from one another by low marshy tracts, so that the good traveling on the ridges is interrupted by frequent steep descents into the lowlands and by consequent bad traveling over soft ground.

Most of the hills formed of sandstone bear no trees and are covered only with turf and moss. Unfortunately, however, the absence of good exposures of the rocks is nearly as noticeable as the absence of trees, and except near the very top, few rocky ledges break the smooth outline of the hills. The scarcity of rocky ledges in areas where the bedrock is sandstone is one of the things that have made the interpretation of many of the geologic details impossible.

LITHOLOGIC CHARACTER.

Although this assemblage of rocks is composed dominantly of sandstones it contains also some beds of conglomerate and shale. In fact, in any considerable exposure numerous small beds of shale are recognizable, and, as is noted in the discussion of the shales (pp. 64–66), the lithology alone may not indicate whether a certain area should be mapped as sandstone or as shale, but the subdivision made in this report is believed to separate the two not by difference in lithology alone but also by difference in age.

What is supposed to be the base of the section of the sandstone is exposed on the hill 2 miles north of the camp of July 22 and on the hill 4 miles north of the camp of July 15. At both these places the lowest member exposed is a fine conglomerate, the pebbles of which are in few places more than an inch in diameter. These pebbles consist of many different kinds of rock, including vein quartz, fine-grained dark igneous rocks, black slate, and some chert. No pebbles of limestone or of coarse, well-crystallized, deep-seated granitic rock were observed. The volume of the matrix is probably equal to or greater than that of the pebbles.

No metamorphic effects such as are recorded in the description of the shales (pp. 65–66) were seen in the sandstones. Their absence is perhaps due to the distance of the sandstones from intrusive igneous rocks, or the sandstones may be later than the igneous intrusion.

The rocks of this group appear to contain few traces of organic remains. Some indeterminate sticks or grasslike fragments of plants were recognized at several places, but they were of no value for determining the age of the rocks. The fragments of plants were small and were considerably broken, as if they had been rolled around with the sand and transported some distance before they were finally buried and consolidated with the rocks. No shells or other parts of animals that lived in the sea were recognized.

When examined microscopically the sandstones are seen to consist of rather angular fragments of different minerals and rocks, but principally of quartz. Most of the fragments are fairly well assorted by size and all are held together in a brownish matrix of indeterminate composition, which is probably fine material of the same general composition as the larger particles. The rock is but slightly decomposed, even some of the more easily weathered minerals, such as hornblende, having been but little altered. The angularity of grain and the variety of minerals give the rock in many places in the thin section the appearance of a somewhat worked-over tuff.

Quartz veins, which were fairly common in the shale, were also seen at a few places in the sandstone in which, however, they were not so abundant. The only place where they were numerous enough to attract attention was in the vicinity of Halfway Mountain, where the quartz occurred mainly in rather irregular lens-shaped masses of slight linear extent.

STRUCTURE.

The general structure of the sandstones is that of a syncline whose axis trends about N. 70° E. In the area north of this axis the beds dip southward, and in the area south of it they dip in general northward, the angle of the dip in both areas being about 30°. The relations at the extreme southern margin of the sandstone area are, however, somewhat complex, owing to faulting. The best exposures of the contact of the sandstones with the underlying shales were seen on the isolated group of hills 4 miles north of the camp of July 15. The relations observed at that place are shown in figure 3. The northern slope of the hills is formed of vertical-dipping shales that strike nearly north. Near the summit of the hill is a bed of conglomerate that strikes N. 60° E. and dips southward at an angle of about 40°. This conglomerate is composed of small pebbles, and is lithologically identical with the conglomerate on the hill north of the camp of July 23, which was regarded as the base of this group of sandstones. Conformably upon the conglomerate lie sandstones that include subordinate shale members and that are similar in all essential respects to the sandstones which overlie the conglomerate farther north. The main uncertainty in the interpretation of this section is that regarding the character of the contact between the shales and the conglomerate. This contact may be regarded either as a fault contact or as an unconformable contact between an old, eroded group and later deposits. The evidence obtained is by no means adequate

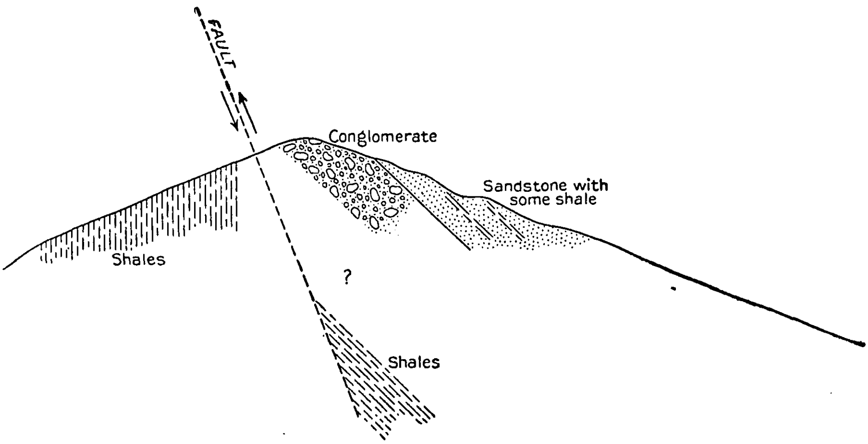


FIGURE 3.—Diagrammatic sketch of the relations of shales and sandstones on hill 4 miles north of the camp of July 15.

to decide between these two interpretations. The need of further investigation is evident, but the relations observed are probably due both to faulting and to depositional unconformity. According to this interpretation, the conglomerate and sandstone have probably been brought down from the position indicated by the dotted lines in figure 3. The rocks throughout much of the critical area are not exposed, so that it was not possible to determine how much of the apparent unconformity might be due to drag and deformation along the hypothetical fault plane. Undoubtedly some features of the structure are due to this cause and are distinctly local, for not very far to the south, on the hill 3 miles north of the camp of July 12, the shales strike parallel to the general trend of the major structures and dip northward.

Of the smaller structures the most common is jointing, which occurs everywhere in the region, though the sandstones are considerably less jointed than the shales. At some places, where thin beds of shale are interlaminated with the sandstone, "pencil slates" are developed, notably on Halfway Mountain, where "pencils" more than 8 inches long and not more than half an inch in cross section were numerous. The area in which the pencil slates occur is not more than a few hundred yards square and is apparently close to the arch of an anticline. At this place the cleavage does not coincide with the bedding and the two are cut by the joints.

The numerous "percussion figure" markings noted on the shales between Hook Creek and the main Hoholitna (see p. 68) were seen also on shales that are associated with sandstones on Halfway Mountain, where, however, they are not so numerous. They are generally less than half an inch in diameter, and on freshly fractured surfaces they have a distinct yellowish-brown color. They apparently extend for some distance into the freshly broken rock and may be of concretionary origin.

AGE AND INTERRELATION.

The age of the sandstones is indicated only by their relations to the Mesozoic shales and by the fact that they are not cut by intrusive rocks. The age of the shales themselves is not conclusively determined. (See pp. 68–72.) A suggestion that they may be Middle Jurassic was considered, but the final decision was that it was unsafe to assign them to a more definite stratigraphic position than the middle or upper part of the Mesozoic. It is therefore evident that the determination of the age of the sandstones, depending as it does on the determination of the age of the shales, is at best very uncertain.

The Tordrillo formation with which the sandstone might be correlated is apparently intruded by numerous dikes, but in the area examined no igneous rocks cut the sandstone. This difference may, of course, be of only minor significance, for obviously not all parts of any individual stratigraphic member have been equally intruded. It is therefore entirely reasonable to lay little stress on the absence of igneous rocks. Furthermore, the contact that was examined by the writer in the Lake Clark-Central Kuskokwim region was close to a fault, so that the features observed may have been abnormalities produced by local movements and may have little general significance.

Correlations based on lithologic features are notoriously dangerous. In spite of this danger, however, it may be of value to future workers of stratigraphic problems in this part of Alaska to record the fact that if the sandstones were correlated on their lithology alone the nearest equivalents would seem to be the Upper Cretaceous sandstones of the Nulato-Norton Bay region, the sandstones of the

Koyukuk-Kobuk region, and the sandstones north of the Kuskokwim that are described and mapped in this report. (See pp. 77–84.)

Although the sandstones here considered are in general lithologically similar to the Upper Cretaceous sandstones, they present some differences—such as the absence from them of coal-bearing strata—which make correlation even on lithologic grounds uncertain, and to carry the above suggestion any further at present would be unwarranted. The following is the most definite statement of the age of these rocks that can now be made: The thick series of sandstones that have a thin conglomerate at their base appear to overlie unconformably shales that are provisionally correlated with the Tordrillo formation, of Middle Jurassic age, and they therefore belong to the middle or upper part of the Mesozoic section and not to rocks lower than the Middle Jurassic.

MESOZOIC SEDIMENTARY ROCKS NORTH AND WEST OF THE HOLITNA.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION.

In the area south and east of the Kuskokwim for an air-line distance of 50 miles along the route traversed by the expedition of 1914 lies a broad lowland. In this lowland no exposures of bedrock were noted and probably none exist. In the area northwest of the Kuskokwim, extending as far as Iditarod and, according to the reports of others, still farther, the country rock consists of sandstones and shales which in lithologic features resemble some of the Mesozoic rocks in the region southeast of the Kuskokwim. Inasmuch, however, as the rocks from these two places are unlike in certain features, they are here separated in the mapping and the description. As more detailed facts are obtained a different subdivision of these rocks will probably be made and the present artificial separation will be replaced by a more exact correlation based on stratigraphic succession.

The conglomerates west of Iditarod and on the Kuskokwim near the old trading post of Vinasale are believed to underlie the Mesozoic sedimentary rocks north and west of the Holitna, here to be described. According to Spurr and Maddren, the sandstones, shales, and arkoses extend down the Kuskokwim from the vicinity of Vinasale to Ohagamute (Oknogamute). Similar rocks are reported to form the bedrock throughout the region southwest of the Kuskokwim, probably as far south as the Tikchik lakes. In the region farther north these rocks have been recognized by Maddren and Eakin, who traced them to a point within 55 miles of Ruby on the Yukon. In the area beyond this point the rocks may form a narrow belt stretching northeastward into the Rampart region, where rocks that are similar lithologically and that contain similar fossils have been described by Eakin.[1]

These Mesozoic rocks therefore occur in an irregular area that trends in general northwest-southeast, and that is apparently widest from a point near the mouth of the Holitna northwestward to Iditarod, where it is a little more than 80 miles wide. Its greatest length from northeast to southwest is not definitely known, as those parts of the region have not been explored, but it probably has a length of 500 miles, only a small part of which falls within the area covered by this report.

Not all the rocks within the area thus outlined are Mesozoic sediments, for younger igneous rocks have been observed at a number of places and others probably occur in parts that have not been explored. Possibly also local deformation has brought underlying rocks to the surface in this area. In this region taken as a whole, however, the bedrock probably consists mainly of these sediments, and the amount of other kinds of rocks is doubtless relatively insignificant.

Throughout the area they occupy these rocks show so few lithologic variations that the topography is remarkably uniform. The summits of few of the hills except those formed of intrusive rocks rise above 3,000 feet. In the part of the area between the Holitna and Iditarod that was seen in some detail few of the peaks stood higher than 2,000 feet. Their summits are smooth, rounded domes covered with frost-riven fragments of bedrock, and practically no outcropping ledges break their slopes. Plate IV, *B* (pp. 32–33), a view northward from the divide between Eldorado and Bonanza creeks, shows a part of this region beyond the area mapped. It represents fairly well the type of topography produced by this group of rocks and shows the general monotonous appearance of the dissected upland. The larger streams have incised their beds from 1,000 to 1,500 feet below the general level of the upland. The slopes from the divides to the streams are in many places so steep that pack animals can descend them only by taking a winding course. Their lower parts up to elevations of 1,000 or 1,500 feet, are generally covered with a light growth of trees, but their higher parts are bare. Smooth slopes and massive forms are perhaps the most characteristic topographic features produced by the rocks of this group. Strongly marked structural trends to the topography are not conspicuous, because the differences in lithology are not marked and the structural features are not persistent over large areas. The drainage is therefore not strongly controlled, and at a distance even its direction is in places difficult to recognize.

[1] Eakin, H. M., Geologic reconnaissance of a part of the Rampart quadrangle, Alaska: U. S. Geol. Survey Bull. 535, pp. 19–21, 1913.

LITHOLOGIC CHARACTER.

The rocks here called Mesozoic sediments north and west of Holitna River are lithologically shales and sandstones. Spurr,[1] who first described these rocks, says:

From this point [south of the conglomerate noted downstream from Vinasale] all of the way to the Holiknuk [Holitna] the rocks are generally uniform in appearance, being composed of granitic arkose and sandstone alternating with carbonaceous shale, the arkose or sandstone often passing into the shale laterally within the limits of a single cliff. Plant remains are common in both shales and arkoses. At the junction of the Kuskokwim with the Holiknuk [Holitna] the rock becomes more limy with not quite so much arkose but contains similar plant remains. Below the Holiknuk [Holitna] rocks of the same character are found, but they grow continually more sandy and contain frequent beds of coarse granitic arkose. On the right bank of the river for some distance above Kolmakof the same series of shales, sandy limestones, and arkoses show frequent plant remains, also ripple marks and all other kinds of shore markings.

Eakin,[2] describing this same assemblage of rocks in the region near Iditarod and northward, says:

The Cretaceous rocks are chiefly sedimentary but include volcanic strata which are irregularly distributed among them. The sedimentary rocks comprise coarse and fine conglomerates, sandstones, and slates. The volcanic strata are basic flows, breccias, and tuffs. * * * The rest of the Cretaceous sedimentary series [exclusive of the conglomerates], by far its larger part, is composed of sandstones and shales or slates. The sandstones are for the most part impure. Arkosic types are the most common and are widespread. There are also locally calcareous and argillaceous sandstones. The slates and shales are all dark-colored, and some are notably graphitic.

The relative amount of sandstone and slate varies from place to place. Near the margins of the areas, as in the Iditarod district and in the region about the Cripple Creek Mountains, the rocks are massively bedded sandstones and minor amounts of slate. In the Innoko district, especially near Twin Mountain and about the mines, the slates predominate and the rocks are thinly and evenly bedded.

Throughout the series, in both sandstones and slates, well-rounded chert pebbles are scattered. These are abundant in some strata and at one locality south of the Cripple Creek Mountains they form a bed of conglomerate that lies at least 2,000 feet above the base of the series.

In the region southwest of the Beaver Mountains the series includes thick beds of basaltic flows, breccias, and tuffs, interbedded with massive sandstones and shales. Similar volcanic rocks are said to occur also along Innoko River above the mouth of North Fork.

Presumably the massively bedded sandstones immediately overlie the basal conglomerates and underlie the upper thinly bedded part of the series.

The volcanic rocks are absent from thick series of strata in some localities. They indicate the activity of rather widely separated volcanic centers and form an important part of the series only in restricted areas.

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[1] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 159–160, 1900.

[2] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, pp. 23–24, 1914.

Little change is needed to make these descriptions fit the rocks between the Holitna and Iditarod. Limestones such as were reported by Spurr were not seen and are probably not common. Some of the coarse sandstone and fine conglomerate had a somewhat calcareous matrix, but neither was calcareous enough to be correctly called limestone. Ripple marks and other indications of shallow water are not common in these rocks. The only notable marks of this sort were seen in the region north of that here mapped on the divide between Eldorado and Bonanza creeks, on a ridge about 5 miles south of Table Mountain, where some irregular markings like those interpreted as raindrop imprints and others of a pseudofucoidal form were fairly common. In this same general region the best-preserved fossils that were found between the Kuskokwim and Iditarod occurred. Elsewhere throughout the sandstones indistinct traces of vegetal remains were by no means rare, but they were only comminuted fragments that were entirely unsuitable for determining the age of the beds.

Lavas seem to be much less commonly associated with the shales and sandstones in the region between the Kuskokwim and Iditarod than in the region north of Iditarod, described by Eakin. Some lavas and many small intrusive bodies were recognized, but they formed an insignificant part of the stratigraphic sequence. Possibly these rocks may be more abundant in parts of this region remote from the route traversed.

Mr. Maddren, who is now preparing a description of the Mesozoic rocks in the region just west of the one here described, states that similar rocks occur in that region, but he notes a rather sharp division between the sandstone-shale member, which he regards as near the base of the Mesozoic section, and the arkosic beds, which he believes are near its top. In the region examined by the writer this subdivision could not be made. Possibly, however, further study will show that this subdivision is applicable to the Mesozoic rocks of both.

STRUCTURE.

Wherever seen the Mesozoic rocks north and west of the Holitna have been considerably deformed. They are so much folded that they nearly everywhere dip at angles of more than 30°. In the vicinity of the mines near Iditarod steeper dips seem to be more common than elsewhere in the region, but at many other places vertical dips were observed. The direction of neither dip nor strike is persistent for long distances, although the strike is more uniform than the dip. Spurr notes that near the contact of these rocks with the underlying conglomerate the strike is about northwest. Farther down the Kuskokwim the strike swings around until it is nearly north, parallel to the general course of the Kuskokwim. Near the place where the expedition of 1914 crossed the Kuskokwim the strike is north and the dip is steep to the west, but a very short distance downstream from this place the dip changes abruptly, as if a thrust fault had dislocated the beds.

At Parks quicksilver prospect, below Sleitmut, the strike of the sedimentary rocks is about northwest and the dip is variable in amount but dominantly northeast. Between the Parks prospect and Georgetown the strike of the rocks is nearly east, and the dip alternates rather frequently from north to south. This general strike continues to and beyond Georgetown, but near Iditarod the strike swings around toward the north. The dip, however, changes from east to west within rather short distances.

Owing to the absence of beds that mark easily recognized stratigraphic horizons in the sedimentary series, the structure of the region as a whole is not now determinable. Apparently, however, the strata lie in a broad synclinal basin and have appressed into a number of subordinate folds, which are in places accompanied by faults.

Both normal and thrust faulting has been recognized, but the amount of movement along any of the great fault planes has not been determined because of the absence of horizons that would permit the identification of the same bed on the two sides of a fault plane. Many of the faults observed probably mark rather small displacement, but some of them undoubtedly involve considerable movement.

The numerous changes in the direction of dip, the absence of definitely recognizable horizons of reference, and the scantiness of good exposures prevented accurate determination of the thickness of these Mesozoic rocks. The region is characterized by rounded summits bearing abundant frost-riven fragments of rock. Some ledges in the lower part of the valley walls have been uncovered by the revival of stream's down cutting, but the thick brush and the poor traveling made examination of many of these exposures so laborious that it could not be attempted on a reconnaissance trip like that made by the expedition of 1914. Several places, however, were examined where the Mesozoic section included thousands of feet of sediments without notable break.

Many of the rocks exhibit ripple marks and raindrop imprints. Cross-bedding, indicating that some of the sediments accumulated in shallow water or in water in which were rather strong and variable currents, was seen in several exposures.

Jointing is common in many members of this series. In some of the finer-grained rocks the joints are rather closely spaced, but in most of the coarser rocks the joints are rather far apart. The shales here and there show cleavage, but it is in only a few places slaty. None of the cleaved shales seen contained secondary cleavage minerals, such as mica or chlorite, and at no place did they show pronounced schistose structure. Near their contacts with the larger intrusive masses the shales and sandstones showed baking and similar contact-metamorphic features, but at few places had metamorphism extended far from the borders of the igneous masses or formed new minerals.

Slickensiding was noted on several fault planes, where beautifully polished, nearly mirror-like surfaces had been formed by movement, particularly at the Parks prospect. They were probably especially distinct there because that was the only place where excavations made it possible to see rocks unaffected by weathering. The amount of movement along the fault planes did not seem to have been great, for slips of only a few feet produced well-developed slickensides.

AGE AND CORRELATION.

The Mesozoic sedimentary rocks north and west of the Holitna are identical in part with the rocks first described by Spurr as the "Holiknuk series." Concerning these rocks Spurr[1] says:

It has been mentioned that the Holiknuk series overlies unconformably the Tachatna series, in which have been found fossils indicating a Middle Devonian age. In the Holiknuk series itself fossil remains, though frequent, are generally too imperfect to admit of identification. At a locality about halfway between the Chagavenapuk and Vinasale a small specimen containing imperfect plant remains was collected, which Dr. F. H. Knowlton, of the National Museum, pronounces to contain a fragment of a dicotyledonous leaf, indicating an age presumably later than the Jurassic. Midway between the Yukwonilnuk [incorrectly named on map accompanying Spurr's report; should have been Crooked Creek] River and the camp of August 5 [25 miles downstream from that river] the limestone contains abundant remains of *Inoceramus*, and the same fossils occur a short distance above Kolmakof, associated with the ripple-marked shales and shaly limestones. These fossils were submitted to Dr. T. W. Stanton, of the National Museum, who made the following comment: "Localities 11 and 13 yielded only fragments of *Inoceramus* too imperfect to determine whether more than one species is represented. The genus *Inoceramus* begins in the Trias and continues to the end of the Cretaceous, being most abundant in the latter. So far as can be judged from the very imperfect material, the fragments in this collection probably belong to a Cretaceous species."

Fossils were collected from these rocks by the expedition of 1914 near the top of the 1,800-foot hill about 6 miles east-northeast of the Parks quicksilver prospect and north of the mapped area near the camps of September 6 and 7, on the divide between George and Iditarod rivers. Concerning these collections Mr. Stanton reports:

9222. No. 14 AS 134. Station LXIII, George-Kuskokwim divide. *Inoceramus* sp. represented by fragmentary imprints. Probably Upper Cretaceous.

9223. No. 14 AS 135. Station LXIII, George-Kuskokwim divide. *Inoceramus* sp. fragments. Probably Upper Cretaceous.

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[1] Spurr, J. E., op. cit., p. 161.

9224. No. 14 AS 136. Same locality as 9223. *Inoceramus* sp. fragment. Probably Upper Cretaceous.

9225. No. 14 AS 136a. Same locality as 9223. *Inoceramus* sp. fragment. Probably Upper Cretaceous.

9226. No. 14 AS 166. Station LXXXVII. *Ostrea* sp. represented by small casts. *Inoceramus sp.* represented by fragments. Probably Upper Cretaceous.

9227. No. 14 AS 167. Near station LXXXVIII near Georgetown-Iditarod trail. Fragments of two dicotyledonous leaves. Upper Cretaceous or Tertiary.

9228. No. 14 AS 170. One mile west of station LXXXVIII, Georgetown-Iditarod trail. *Ostrea* sp. *Inoceramus* sp. Both represented by fragments. Probably Upper Cretaceous.

Eakin in 1912 collected fossils from the probable continuation of this series of rocks in the Innoko district. These were submitted to Stanton, who reports:

7822. No. 12 AE 2. Ridge north of Folger Creek, 2½ miles from margin of flats. *Unio* sp. Casts of a very small undescribed species. Specimens of a small *Unio*, possibly belonging to this species and in closely similar rock, were collected by Collier at Good Island, on the Yukon above the mouth of the Koyukuk. The fossils give no direct information as to the age, for similar types occur in both Cretaceous and Tertiary, but the geographic relations indicate that the locality at Good Island ought to be near the base of the Upper Cretaceous.

7823. No. 12 AE 3. Ophir Creek, 1 mile above town. *Inoceramus* sp. Several fragmentary distorted specimens that may belong to *Inoceramus digitatus* Sowerby, an Upper Cretaceous species. Whether it is really this species or not, it is believed to be an Upper Cretaceous type.

Similar fossils were collected also in the southwestern extension of these rocks near Kolmakof, and these also were regarded by Stanton as probably Upper Cretaceous.[1] These fossils were obtained from arkosic sediments which Maddren states conformably overlie black shales and form the upper part of the series of beds observed by him.

Although the Upper Cretaceous age of these collections seems to be indicated with a good deal of certainty, the age of the series of rocks as a whole is by no means definitely proved. Apparently none of the collections were made close to the conglomerate, which is believed to mark the base of a great stratigraphic series. So far as can be learned, the locality nearest to this supposed basal conglomerate where fossils were collected is the one found by the writer near station LXXXVIII. (See above.) This place, however, is more than 15 miles in an air line from that conglomerate, and the intervening rocks have considerable dip. As already noted, Maddren calls attention to the fact that his collections were made from the arkosic beds which apparently form the upper part of the great sedimentary sequence.

Mesozoic rocks other than Upper Cretaceous may therefore be included in the cartographic unit here called "Mesozoic rocks north and west of the Holitna," especially the dark shales which underlie

[1] Maddren, A. G., The lower Kuskokwim region: U. S. Geol. Survey, Bull. — (in preparation).

the fossil-bearing beds and which may belong to the older rocks described under the heading "Mesozoic shales south of the Kuskokwim" (p. 63). Possibly some of these shales are of Jurassic age and may antedate the period of great granitic intrusions in southwestern Alaska. The determination of this apparently theoretical point may throw considerable light on the distribution and relations of the mineralization.

In view of the fact that this thick series may contain rocks other than Upper Cretaceous rocks, it can not with certainty be correlated with series or formations in other parts of Alaska. Some of the Mesozoic sedimentary rocks north of the Kuskokwim have many features in common with certain of the rocks south of the Kuskokwim, a fact which would suggest that the rocks of the two places should be grouped together, but the differences noted make this correlation so uncertain that it does not now seem to be warranted.

Although in the absence of specific determination of the age of the rocks here described their correlation with other known Mesozoic rocks is not possible, it may be noted that these rocks correspond lithologically most closely with the sandstones and shales of the Shaktolik group of the region between the Yukon and Seward Peninsula. The distribution and probable extent of the Mesozoic rocks north and west of the Holitna and their correlation with those in near-by regions has already been stated. Other Upper Cretaceous rocks have been reported north of the Endicott Range in northern Alaska in the Matanuska and Copper River basins, in small areas in southeastern Alaska, at several places in the Yukon-Tanana region, and in large areas in British Columbia and Yukon Territory.

UNCONSOLIDATED DEPOSITS.

SUBDIVISIONS.

Unconsolidated deposits cover by far the greater part of the Lake Clark-Central Kuskokwim region and form many of the most characteristic features of the topography. Several different kinds of unconsolidated deposits were recognized, but in the following descriptions slight attention will be paid to the thin residual cover of unconsolidated material which has been formed by normal weathering wherever ledges of bedrock have been exposed at the surface. Although thus summarily dismissed from description, these residual nonsorted accumulations are widely represented. On many of the hills no ledges in place are exposed, but the summits are covered by frost-riven fragments, as represented on Plates VI, *A*; VII, *A* and *B*; and VIII, *A*. These views show angular untransported material ranging from slabs measuring a foot or more across to particles only a fraction of an inch in diameter.

The unconsolidated deposits described in this report originated in different ways, and they are here grouped, according to their mode of origin, into six main subdivisions—glacial, fluviatile, lacustrine, marine, volcanic ash, and organic deposits. Although pure types of each deposit except those of marine origin are represented in this region, the bulk of the glacial, fluviatile, and lacustrine deposits has been formed by the complex interaction of different agencies, so that many of the deposits can not be assigned to a single mode of origin. Under these conditions the individual deposits must be grouped under the appropriate heading largely by personal interpretation of the dominant agency.

Much of the geologic history revealed by these unconsolidated deposits is still obscure or undetermined, partly because of the hasty methods of reconnaissance employed, and partly because enormous areas in southwestern Alaska have not yet been surveyed or even visited. Until these unknown areas have been traversed even as hurriedly as the Lake Clark-Central Kuskokwim region many of the facts observed must await final interpretation.

GLACIAL DEPOSITS.

No glaciers occur in the part of Lake Clark-Central Kuskokwim region that was surveyed in 1914, but several small glaciers are reported by Martin in the adjacent Iliamna-Lake Clark region, and many large ones have their source in the snow-covered mountains east of the route traversed by the expedition of 1914. The high, perpetually snow-clad peaks shown by isolated contours in the extreme northeast corner of the area (see Pls. I and V) still bear glaciers that could be recognized with field glasses even at a distance of 50 miles from our route of travel. The glacial deposits in the Lake Clark-Central Kuskokwim region have all been formed by the ancient glaciers which, heading in the present high mountains, flowed thence toward the lowlands. Some of these undoubtedly were the greatly extended predecessors of the small existing glaciers, but many of them have no present-day representatives.

The extent of these earlier glaciers has not been determined, for many of them apparently extended beyond the Lake Clark-Central Kuskokwim region into the unexplored areas to the west. The limits of glaciation observed are therefore not to be regarded as the actual limits. Figure 4 (p. 86) is an attempt to represent graphically the best information and surmise as to the former extent of glaciation in this region. In some places the recognized moraines undoubtedly mark the westernmost extension of the great glaciers, but until the region west of that here described has been explored the maximum limit of glaciation can not be determined. In view of this uncertainty the glacial and glaciofluviatile deposits and the features of each of the present drainage basins will be described separately.

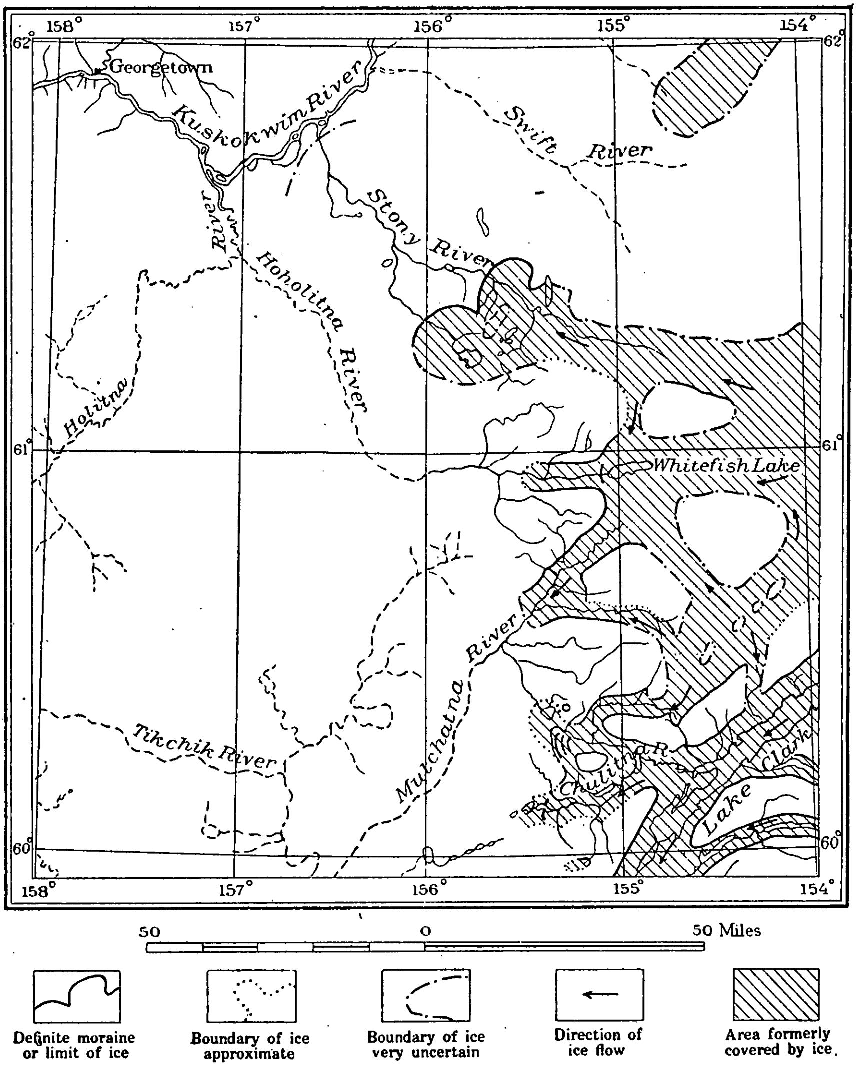


FIGURE 4.—Map showing extent of former glaciation in Lake Clark-Central Kuskokwim region.

ILIAMNA LAKE BASIN.

The basin of Iliamna Lake was at one time occupied by a glacier which extended at least as far west as the upper part of Kvichak River. The general conditions in the Iliamna region are summarized by Martin and Katz [1] as follows:

Although glaciers once occupied the greater part of this region, as is shown by the general physiographic features, as well as by the presence of more

[1] Martin, G. C., and Katz, F. J., op. cit., p. 82.

minutely scoured exposures, the surface areas of unmodified glacial deposits, such as till, are rather small. In fact, such material was seen only in the immediate vicinity of the existing glaciers and in the lower part of the valley of Newhalen River, for short stretches at the base of the bluffs on the lower part of Iliamna Lake, and along the upper part of Kvichak River. * * * The general absence of till is explained in part by the fact that the glaciation was of alpine character and so vigorous that the glaciers and the glacial floods and mountain-side erosion, which accompanied and followed their extinction, obliterated in large part their constructive products, and in part by the fact that drowning of the lower glacial sites during and subsequent to the retreat of the ice, buried the larger accumulations of moraine beneath younger water-laid deposits. It follows from the latter condition that glacial deposits have a much wider extent beneath the terrace and alluvial deposits than they have at the surface.

Concerning the thickness of the ice in this part of the adjacent region Martin and Katz[1] state:

Over the lowlands around Roadhouse Mountain and Chekok Bay, where the Clark and Tazimina glaciers and those from the east met, they spread out notably and, as would be expected, the upper limit of glaciated surfaces and glacial débris descends to about 1,400 feet. In the still broader basin of Iliamna Lake, which received practically all the glacial ice of the region, the glacier deployed considerably and its surface stood at a still lower elevation.

LAKE CLARK BASIN.

The basin of Lake Clark received ice from the mountains northeast of its head and from the rugged range east of it, but relatively small amounts of ice reached it from the hills on the west. Martin and Katz[2] say:

It is a noteworthy fact that, in the upper part of Lake Clark valley, the mountains east of the lake are clearly shown by their physiographic character to be glaciated to a considerably greater height than the mountains on the west side of the lake. This is regarded as evidence that the bulk of the glacial flow came from the east and that the valley of Lake Clark existed prior to the glacial invasion and deflected the westward glacial flow from the Chigmit Mountains, so that large areas west of the lake were not overridden.

The only parts of the Lake Clark basin seen by the expedition of 1914 were the extreme lower end of the lake and the Chulitna and Koksetna basins. At these places the results of the occupation of the region by ice were observed, but they were evidently, in part at least, the work of a glacier that was waning rather than of one that was growing. So far as has now been determined, the glacier originating in the headward part of the Lake Clark basin flowed southward along the trough of Lake Clark to a point near Chulitna Bay, where it split into two streams, one continuing southwestward down the Lake Clark valley, the other diverging toward the west and

[1] Martin, G. C., and Katz, F. J., op. cit., p. 88.
[2] Idem, p. 86.

flowing up what is now the lowland of Chulitna River. The Chulitna Bay lobe of the Lake Clark glacier, near the mouth of what is now Koksetna River, again split into two ice streams, the larger apparently continuing up the valley of the Chulitna in a general westerly direction and the other flowing up the lowland of Koksetna River and Black Creek nearly northwestward toward Tutna Lake.

The southern of the lobes that extended into Chulitna Valley undoubtedly received accessions of ice from the south, from the glacier that extended down the valley of Lake Clark and Newhalen River, spilled over the ridge, and flowed through the lowlands that bound the Lake Clark valley on the west. This course is indicated by the form and features of the low passes and by the altitude of the deposits, which had evidently been transported from places outside the Chulitna basin under glacial and glaciofluviatile conditions. High-level deposits of this sort were noted particularly on the hills north and northwest of the lower end of Sixmile Lake. Large angular granite blocks more than 4 feet long were abundant on the top of the 1,800-foot hill west of the camp of June 19, and foreign material, in part not water rounded, was recognized at elevations of more than 2,000 feet on Hoknede Mountain, the high hill 3 miles east of the camp of June 21. The hummocky topography, the lakes, and the character of the unconsolidated material in the region north of these places show that it has been covered by glacial ice. Glacial striae were but seldom observed on the ridges, but their infrequency is probably due to their removal by weathering.

The tongue of ice that extended up the Chulitna lowland was undoubtedly larger than any of the other distributary glaciers from the Lake Clark basin except the main stream. The area it covered has not been determined, but it apparently extended westward beyond the limits at which morainic features could be identified from the route traversed. Apparently the Nikabuna Lakes, near the head of the Chulitna, are in part impounded behind morainic barriers formed by the ice of this lobe, and some of the still more distant ridges may be morainic accumulations. No ridgelike moraines were recognized in the part of the valley of Chulitna River that was scrutinized in detail, but well-preserved striae were found on bedrock exposures on the shore of Long Lake. The striae showed clearly that the ice flow had been parallel to the trend of the lake, and that the movement was from the east toward the west. Apparently the major topographic features of the region had been outlined before the date of the maximum extension of the glaciers, because they deployed into the existing lowlands.

The lobe of the glacier that extended up the lowland now occupied by Koksetna River and Black Creek apparently received some ice from the eastern headward part of Koksetna River, but it probably did not extend far beyond the longitude of Tutna Lake. This conclusion is suggested by the remarkable perfection and development of the moraines in the region and by the elevation of the upper limits of recognized glaciation. The ridge north of the stream on which the camp of June 29 was situated is a strongly marked moraine whose crest rises to an elevation of 1,800 feet but gradually decreases in height toward the west, so that within 6 miles its elevation is only about 1,000 feet. On the north wall of the valley of Koksetna River, above the camp of July 2, the upper limit of glacial deposits is about 1,500 feet above sea level. The moraines in the lowland stand out with almost diagrammatic distinctness, the western ones bowing westward in a fashion which shows unmistakably that the ice came from the east and moved westward. The younger or inner moraines—those toward the east—showed the influence of the isolated hard-rock knob in the center of the lowland of Koksetna River, in that they looped back against it and bowed out farther west in the lowland area either north or south of the knob. The steep ice contact slopes of the moraine change from the northern side in the southern part of the valley to the south side in its northern part. The knob and kettle type of topography is remarkably well preserved and is particularly prominent in the older higher-level deposits.

Here and there, as at points 1 mile due north and 2 miles west of the camp of June 29, narrow gorges not now occupied by streams cut across the moraines and disclose bedrock. Apparently these gaps were cut by water which was produced by the melting of the glaciers and which, after accumulating behind the morainic barriers, overflowed and cut gorges across the barriers. The floors of these transverse gaps differ considerably in elevation, probably because they represent outlets occupied by the glacially impounded waters for different lengths of time.

The earlier formed drainage channels have been so much obstructed by glacial deposits that the region contains many lakes and poorly drained areas. The traveling near the marshy areas is difficult, but fortunately the morainic ridges between them afford good footing, so that the Lake Clark basin as a whole is easily traversable. Some of the present streams, which were earlier guided by the general slope of deposits of outwash material, have in places cut into ridges of bedrock and formed precipitous rocky canyons, such as the one east of the isolated knob already noted in the valley of Koksetna River.

No striking forms produced by glacial erosion were observed in the part of the valley of Koksetna River that was seen at close range.

The typical U shape of the valley of the eastern headwater branch of the Koksetna, however, could be seen distinctly in the distance. Apparently most of that part of the basin that was traversed was an area of deposition rather than one of erosion.

MULCHATNA AND HOHOLITNA BASINS.

The extent of glaciation was not determined so closely in the Mulchatna and Hoholitna basins as in the Lake Clark basin. Inability to outline the glaciated area in the basins of these rivers is in large measure due to the fact that glaciation extended beyond the region close to the route traversed. Many of the general facts indicating glaciation in the Mulchatna and Hoholitna basins are so closely related that the two basins are here treated as a unit. The close interrelation of the glaciation in the two basins is due to the fact that the ice originating in the high mountains of the Alaska Range, to the east, flowed westward down a broad open lowland to a point 30 to 35 miles east-northeast of the camp of July 12, where it separated into two distinct lobes, one of which flowed westward, down the basin of Whitefish Lake and the Hoholitna, and the other down the valley now occupied by the main fork of Mulchatna River.

Perhaps some ice was contributed to the central part of the Mulchatna basin by glaciers that flowed down the valley of Chilikandresten River. Certainly the hills in the vicinity of Mesa Mountain, east of Tutna Lake, appear to have borne small glaciers. Two cirques were noted particularly, one at the head of the valley containing two small lakes $2\frac{1}{2}$ miles north of the camp of July 2 and the other in the valley $1\frac{3}{4}$ miles north of the camp of July 5. The floors of these cirques are at an elevation of about 2,100 feet. The glaciers that flowed from them seem to have extended only a short distance and consequently had no marked effect upon the glaciation of the region.

Precipitous slopes leading to flat-floored valleys suggest glacial cirques in many of the hilly parts of the region, but apparently this form is not always to be explained as result of glaciation. Glacial erosion is, however, recognizable at many places. The steeply cliffed valley wall on the south side of the Mulchatna, in the longitude of the eastern end of Whitefish Lake, is undoubtedly due to glacial action. The form of the basin of Whitefish Lake and the topography of the adjacent area also strongly suggest glaciation, though neither was examined at sufficiently close range to prove this intepretation.

Deposits of glacial and glaciofluviatile origin were distinctly recognized at many places. The well-marked terrace on the south side of the valleys of Chilikandresten and Mulchatna rivers has also been noted and illustrated by Plate II, *A*. The top of this terrace between Dummy Creek and the Chilikandresten stands at an elevation of a little over 1,400 feet. At a distance it looks like a bench having the slope of water-deposited material, but seen close at hand, the general flat upland surface is indented by many deep kettle-like holes. Some of these depressions, like those shown in Plate IX, are as much as 20 feet deep and more than a hundred yards across. Most of them are nearly circular and have no outward discharge of surface water. The flat upland around most of these depressions is devoid of trees, but in the bottoms of nearly all of them good-sized spruce trees are growing.

The origin of these depressions is by no means clear. The smooth surface of the upland seems to negative the explanation that the deposit is a moraine. On the other hand, the depressions must have been kept free from sedimentary material by some substance which has disappeared without leaving other traces of its presence, and the substance most likely to act in this manner is ice. The most reasonable explanation of this deposit seems to be that it is part of a "pitted plain," so called by Tarr and Butler, who describe it as commonly developed at the front of a large glacier, the depressions having been formed by the melting out of ice which, together with other material derived from the glaciers, had been built into the deposit. This plain has been dissected by Mulchatna River, and its surface now stands 600 to 800 feet above the lowest part of the near-by region.

North of the Mulchatna the glacial and glaciofluviatile deposits were particularly closely examined on the hill 2 miles north of the camp of July 12 and in the lowland immediately south of the camp of July 17. On the hill large angular blocks of nonwater-worn foreign materials were recognized up to an elevation of 1,800 feet. One of the blocks was more than 5 feet long and 3 feet thick. The highest angular blocks were found several hundred feet above the level of the top of the strongly marked terrace deposits. In the lowland indicated morainic topography is strikingly developed. Apparently this belt of moraine was formed by a lobe of the glacier which occupied the Mulchatna Valley and which extended into the lowland at the head of the stream tributary to Gnat Creek, which is in turn a tributary of the Hoholitna. The streams have dissected this moraine but little. The upper part of these morainal and glaciofluviatile deposits rises to an elevation of about 1,200 feet. The upper limit of glaciation recognized indicates that this moraine marks practically the terminus of this lobe of the Mulchatna glacier. Although the front of the ice apparently did not extend beyond this divide the outwash deposits and the blocking of the former stream lines have materially

[1] Tarr, R. S., and Butler, B. S., The Yakutat Bay region, Alaska: U. S. Geol. Survey Prof. Paper 64, p. 13, 1909.

modified the drainage in the group of hills between the camps of July 17 and 20, in the vicinity of Halfway Mountain.

The extent of the branch that probably flowed down the lowland now occupied by Whitefish Lake has not been determined. The absence of morainic topography in the lowland where it was crossed by the party suggested that the ice had not extended that far west, but in the valley of Gnat Creek, on the sides of the ridge 4 miles northwest of the camp of July 20 up to elevations of nearly 2,000 feet, are a number of light-colored granitic boulders which were apparently carried to their present position by glaciers. Some abandoned water courses on the same ridge are doubtless channels that were temporarily occupied by streams when their normal courses were blocked by ice.

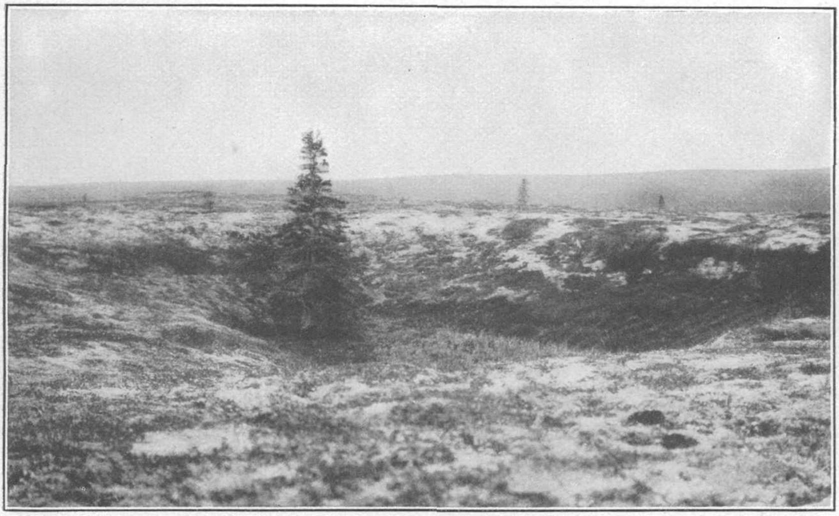
At the lower end of Whitefish Lake are many blocks of rock so large that they were recognized with field glasses at a distance of 9 miles. These are believed to have been glacially transported, and they probably form part of a glacial moraine that obstructs the lower end of Whitefish Lake.

Although the extent of the glacier in the Hoholitna basin has not been determined, the drainage modifications produced either directly by the ice or by deposits of outwash from the ice are everywhere recognizable. Almost all the valleys of the main branches of the Hoholitna were apparently formed by much larger streams than those that now pass through them and have been filled to a greater or less depth by the large amount of detritus delivered to the streams by the glaciers. Several terrace levels in the larger valleys appear to mark stages in the retreat of the glacier from the region, but the deposits are mainly of fluviatile origin and are only indirectly associated with glaciers.

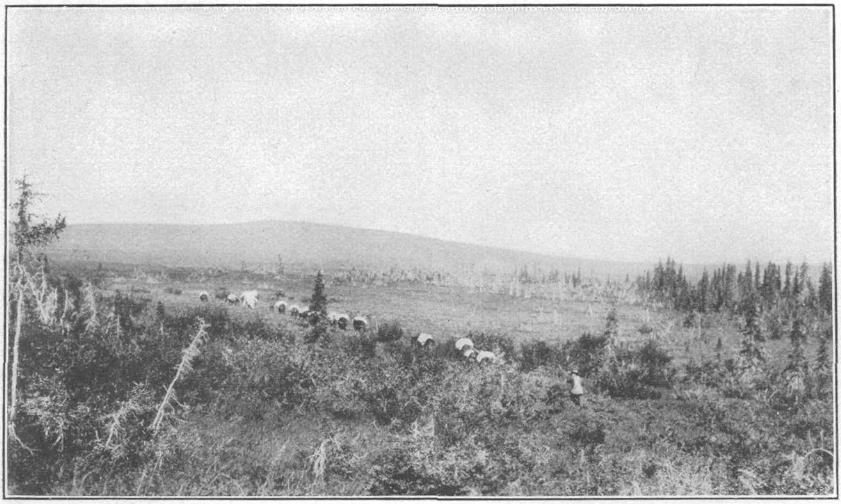
STONY RIVER BASIN.

According to the reports of natives, Stony River rises in glaciers in the mountains of the Alaska Range, a report corroborated by the fact that the water of the stream is milky with glacial flour even as far away from the mountains as the camp of August 6. Whenever the stream overflows it leaves a deposit of this glacial flour on the submerged country, so that glaciofluviatile deposits are even now being laid down over a large part of the Stony River basin, and of course characteristic glacial deposits are being formed in areas near the existing glaciers.

The Lake Clark-Central Kuskokwim region, however, now lies outside the area that receives large quantities of material from the existing glaciers, though it has been notably modified by glacial action. Although the collecting ground of the ancient glaciers was much larger than that of the existing glaciers, it seems to have been



A. SURFACE OF TERRACE WEST OF CAMP ON DUMMY CREEK, MULCHATNA BASIN.



B. MORAINIC HILLS IN STONY RIVER BASIN NEAR CAMP OF AUGUST 5.

View looking northward from point near Lime Hills.

in the same general area. The collecting ground of the now vanished Stony River glacier, for example, was approximately the same as that of the present-day Stony River glaciers. The ice of this ancient time apparently flowed outward from the highland area and in general followed and of course materially modified the topography.

The most definite evidence of the extent of the former glaciation in Stony River valley is found in the hills north of the range of limestones. This ridge of hills, shown in Plate IX, *B*, was seen close at hand in the vicinity of the camp of August 5. The summits of this ridge stand at elevations of about 1,200 feet, or 600 to 800 feet above the present surface of Stony River. The form of the ridge and its composition show that it is a moraine. On its crest are many large angular boulders of porphyritic granite, which must have come a long distance, for no similar rocks are known in the neighborhood. The boulders are considerably decomposed and must have been exposed in their present position for a long time. This ridge is composed of unconsolidated material; it includes no exposed ledges of bedrock. Even on its upper slopes there are many undrained areas which were probably due to irregular deposition of material by the ice. Many of these depressions have been filled by vegetation, and none of them are now occupied by ponds. In the lower ground, however, lakes and ponds are numerous.

This moraine marks the westernmost limit of the ice in the Stony River basin that can be definitely recognized, but the outwash of material from the ice at this stand may have covered earlier less-marked deposits that lay farther west. In fact (see pp. 94–95), a ridge that may mark a buried moraine was noted between the camps of August 13 and August 14. Many of the deposits along Stony River as far at least as the mouth of Stink River are of glaciofluviatile origin. The bluffs that border the river immediately below the mouth of Stink River consist of gravel beds through which large angular boulders of foreign material are irregularly distributed, though few boulders occur in the upper 10 feet of the section exposed in the bluffs. The bluffs on the west side of Stony River near the camp of August 13 are about 20 feet high and are composed of sand, silt, and boulders. Their upper part is formed of rather thin layers of well-stratified sands and muds. Several large striated granite boulders, 4 feet in diameter, evidently washed out from the bluffs, line the foot of the bluff and form rapids in the river. The pebbles in the deposit consist of rocks of many kinds and must have been derived from a large and distant area.

Features due to glaciation were recognized at many places east of the moraine on which the camp of August 5 was situated. The northwestern slopes of the Lime Hills north of the camp of August 3 are marked deeply by glacial and glaciofluviatile deposits to elevations of at least 1,000 feet. Above this elevation, however, erratic blocks of foreign material were recognized up to nearly 1,600 feet. One of the most striking erratics noted was a much decomposed block of porphyritic granite which lies near the summit of the highest knob on the subordinate range of limestones at an elevation of nearly 1,600 feet.

The lowland which lies between the limestone range and the conglomerate range, and which contains many lakes separated by morainic ridges, was evidently at one time occupied by ice, and during that time some of the changes which affected the arrangement of the streams in the Hoholitna-Stony divide west of the camp of July 29 may have been produced. The history of these changes is, however, complex and obscure, and no attempt to unravel its intricacies can yet be made. Material brought from a distance, probably of glacial or of glaciofluviatile origin, was noted on Cairn Mountain east of the camp of August 1 up to elevations of 1,900 feet, and thick deposits of the same material cover the lowlands up to elevations of 1,200 feet.

Possibly some of the ice of the tongue of the Mulchatna glacier that flowed down the lowland now occupied by Whitefish Lake may have coalesced with the ice of the Stony River glacier, for prospectors report low passes with lakes in them and hummocky topography between the two basins. In the area that was seen by the writer, however, the ice from these two sources apparently did not unite, but the topography and drainage in the area between the two streams had been greatly modified, not only by the obstruction of the streams but by the great deposits of glaciofluviatile material.

OTHER PARTS OF THE KUSKOKWIM BASIN.

The ancient glaciers of the Kuskokwim basin seem to have originated mainly in the high mountains of the Alaska Range and to have flowed thence outward along the larger preexisting valleys toward the lower country. In form they were valley glaciers rather than huge ice sheets, though on reaching the lower country they may have spread out into lobes of the piedmont type. The basin of the Kuskokwim has apparently never been filled with glacial ice, though the distance to which the glaciers extended from the tributary valleys into the main Kuskokwim basin has not been determined. None of the valleys other than that of Stony River has been explored sufficiently to afford any information as to the western limits of glaciation. In the Stony River basin the farthest place definitely reached by the ice was the moraine on which the camp of August 5 was situated. Between the Stony and Holitna rivers, nearly midway between the camps of August 13 and 14, there is a ridge that rises 5 to 20 feet above the general level of the flats. This ridge was followed for nearly half a mile and in that distance it had all the appearance of a moraine. It was composed mainly of gravel, had a somewhat crescentic form bowing to the west, and was interrupted here and there by marked kettle-like depressions. If this is a moraine it has been nearly buried under the outwash material that was spread out from the glaciers when they stood much farther west than the clearly defined moraine near the camp of August 5. In other words, it may mark a much earlier front of the ancient glacier than has yet been recognized. The position of this ridge is such that without considerable more study of the surroundings definite conclusions regarding its origin can not be formed. It lies not more than 1 mile from Stony River and probably less than 3 miles in an air line from the Kuskokwim. If this is a moraine it must mark the front of a glacier that followed Stony River valley rather than one that followed either the main valley of the Kuskokwim or that of the Holitna.

The higher peaks of the Bear Creek group of mountains, southwest of Kolmakof, according to Maddren, at one time supported small local glaciers. The highest of the peaks rises to an elevation of 4,700 feet, and the general elevation of the crest is about 4,000 feet. The glaciers that had their source in these mountains did not extend beyond the front of the range and consequently had no great effect on the main basin of the Kuskokwim.

The highest peak in Russian Mountains, north of Kolmakof, rises to an altitude of 4,500 feet, but most of the other peaks are less than 4,000 feet high. These mountains, according to Maddren, now show no striking glacial features in the area explored by him, but they were at one time apparently subjected to incipient glaciation, for cirquelike depressions at the head of some of the valleys and somewhat oversteepened slopes suggest slight glacial erosion. The amount of glaciation, however, was so slight that it had almost no effect upon the glacial and glaciofluviatile deposits of the main Kuskokwim Valley.

None of the basin of the Kuskokwim north of the main river in the area traversed by the expedition of 1914 seems to have been glaciated. Practically all this part of the region lies below 3,000 feet, and so far as has been learned from other localities glaciers did not originate in this part of Alaska in isolated groups of hills whose summits stand much below 3,000 feet. Even hills that rise to 4,000 feet did not support glaciers more than a few miles long.

Although the larger part of the Kuskokwim basin appears not to have been occupied by glaciers and therefore contains practically no true glacial deposits, the great volume of detritus produced by glaciation and then distributed by glaciofluviatile action over almost the entire lowland of the basin is one of the most notable features of the region. These deposits mark many different stages in the deglaciation of the region and the readjustment of the drainage. Some of them were closely associated with the now vanished glaciers; others, like the glacial mud now deposited from the waters of Stony River, are but remotely connected in origin with the glaciers; and between these two kinds there are all gradations.

FLUVIATILE DEPOSITS.

In nearly all parts of the Lake Clark-Central Kuskokwim region are some glacial or glaciofluviatile deposits. These glacial deposits merge into fluviatile deposits, so that no sharp line of separation can be drawn between them. Some deposits that are now being formed by Stony River are composed in large part of rock flour derived from the glaciers at its head, a hundred miles above. Not only is there difficulty in separating the products of the two processes where they are now being formed together, but there is still greater difficulty in unraveling the history of the two types of deposit, for practically all the larger streams are re-sorting and retransporting detritus that has been at some time subjected to glacial action. The only streams that are handling nothing but the bedrock material of the basin in which they lie are the small recent headwater streams. The basins of all the other streams contain unconsolidated deposits, a large part of which has been brought from other drainage basins, a fact that should be noted by prospectors for valuable minerals, as the float may not represent rocks in place in the basin in which it is found. Furthermore, the normal stream deposits which would now be found in the region if it had not been subjected to glaciation and its accompanying processes have either been removed or deeply mantled over by glacial deposits. The present streams have done little to make the topographic features of the deposits conform with those due to normal fluviatile action; and therefore the prospect for the concentration of valuable minerals in placers is not so favorable here as in regions where the deposits have been sorted by streams alone.

Most of the work of the streams at present is that of reshaping the glaciofluviatile deposits into normal fluviatile features. Practically all the larger stream valleys carried a far greater volume of water while the region was being deglaciated than they do now, so that most of the streams are now flowing in irregular courses in valleys that are much too big for them, and are not eroding deeply nor transporting much material. The clearness of the water of almost all the streams shows that they are carrying very little material in suspension. Stony River and the Kuskokwim were practically the only muddy streams seen by the expedition of 1914. The Kuskokwim, even in flood, was not so muddy that its water could not be used for drinking, though its flood waters on receding left a thick film of silt on the area it overflowed.

Some of the smaller streams that rise in the lowland tundras are sluggish and carry a good deal of decaying vegetable matter, so that their water ranges in color from that of weak tea nearly to that of coffee. These streams, however, do not carry enough material to make notable deposits.

Taken as a whole, therefore, the fluviatile deposits now being laid down consist chiefly of retransported detritus which had been brought into the basins of the larger streams by glaciation. The deposits in the basins of the smaller streams are more nearly typical stream deposits of a single cycle, but most of them occur only at the heads of the valleys, where stream action is generally least effective. Distinct deposits that owe their formation to river work alone are exceptional.

LACUSTRINE DEPOSITS.

Lakes are numerous throughout the area that was occupied by glaciers or by glaciofluviatile deposits. These lakes range from long, deep lakes like Lake Clark to small, shallow ponds only a few feet in diameter. Some of them, like Lake Clark, Long Lake, and Whitefish Lake, seem to have been formed by glacial scouring; others, like Tutna Lake and the host of ponds in the lowland south of the camp of August 3, seem to occupy depressions in the outwash and morainic deposits. The lakes formed by glacial scouring are probably deep, the others are relatively shallow. In all these lakes some deposition is taking place and lacustrine deposits are accumulating. At many places depressions that were probably once occupied by ponds have now been filled by rock detritus and by vegetation and no longer contain water. Most of the smaller depressions have been filled with mud and fine sand.

The larger lake basins contain deposits whose components range in size from fine particles of mud up to cobbles a foot in diameter. Many of the lakes are surrounded by glacial or glaciofluviatile deposits from the erosion of which the material on their beaches has been in large part derived. Owing to the additional erosion to which the rock fragments in this material has been subjected they are well worn and are not like those of normal lacustrine deposits.

Where rivers enter the lakes they form delta deposits, the material in which is different from that in the beaches of interstream areas. A delta built westward into Long Lake, near its outlet, has already been noted as an abnormal feature. This delta was probably due to a change in the course of the lower part of Koksetna River, whereby this stream entered Long Lake, rather than Chulitna River, as it does at present.

On Tutna Lake there is a notable deposit of shells and other lacustrine material. Only the south shore of this lake was traversed, but ridges of shells several inches high and a foot or more wide were seen at several places. Concerning these shells Mr. W. H. Dall writes: "I have examined the material from Tutna Lake, southwestern Alaska * * *. The specimens are recent shells and comprise *Lymnaea randolphi* Baker (dwarfed specimens); *Planorbis deflectus* Say; *Valvata helicoidea* Dall; and a species of *Pisidium*, not recognized." Although these shells are very numerous they are so fragile that they form but a small bulk of the deposit now being laid down in Tutna Lake. No similar deposits of shells were seen on the shores of the other lakes.

Many of the lakes in the lowlands near Kuskokwim and Stony rivers appear to be cut-off meanders of the rivers. Their deposits therefore are in part fluviatile and in part lacustrine. The shores of most of these lakes are formed of mud so soft that they can be traversed only where they are bound together by the roots of vegetation.

Some lakes in the Lake Clark-Central Kuskokwim region were formed by the impounding of glacial waters, but their history has not been worked out, and the deposits laid down in them have not been differentiated from other unconsolidated deposits. None of these ancient lakes seems to have been very large, because no considerable height of land intervened to impound the waters between this region and the front of the glaciers.

MARINE DEPOSITS.

Parts of the Lake Clark-Central Kuskokwim region are now so near sea level that any considerable depression might have allowed the sea to invade them. Sixmile Lake is 215 feet above sea level and the Kuskokwim at Georgetown is less than 300 feet above sea level.

Spurr,[1] in the report of his trip in 1898, states:

> The mountains on the lower or middle Kuskokwim, especially in the vicinity of Kolmakof, show rounded forms and often distinct terracing up to a height of 1,000 feet above sea level; their tops, which are generally below 2,000 feet in height, are remarkably level and straight and probably indicate an ancient sea level like the terraces on their sides. The general plane in which lies the level tops of the hills might be held to represent an ancient peneplain, but the writer believes that the appearance is largely the result of leveling by the sea.

If the sea had recently invaded the lower part of the Kuskokwim as far as Kolmakof to a depth of 2,000 feet or even of 1,000 feet,

[1] Spurr, J. E., op. cit., pp. 250–251.

some evidence of marine action should be found in the region in the Kuskokwim basin traversed by the expedition of 1914. No features attributable to sea action were observed. Not only were no marine features seen, but all the evidence points to the conclusion that in recent geologic time the sea has not been in the region. The conclusions reached from the long-range observations by Spurr therefore do not seem to be substantiated by the more detailed studies.

Martin,[1] in discussing the origin and extent of the deposits which cover broad areas on the shores of Iliamna Lake and along the southern end of Lake Clark, states that they are formed of "stratified gravels and sands. The same deposits extend throughout the Kvichak Valley and the Bering Sea coastal plain." These gravels are called by Martin[1] the terrace gravels. In describing the origin of these gravels he says:[2]

> These terrace deposits were probably derived chiefly, if not almost entirely, from glacial detritus. They were laid down in the present position by water.
>
> The terraces at the lower levels on Iliamna and Clark lakes probably consist chiefly of material deposited near its present position as moraine and reworked by waves. The waters in which the reworking and redeposition were accomplished are believed to have been those of an estuary extending from the present Bristol Bay into the lower ends of the valleys of Iliamna and Clark lakes. The reason for the postulation of an estuary rather than a larger lake follows from the absence of a barrier high enough to hold a lake up to the higher terrace levels.

According to these statements the region was invaded by Bering Sea to elevations of 400 to 600 feet. This incursion of the sea water must have taken place after the period of maximum glaciation, at a time when the topography of the region was nearly the same as it is now. Marine deposits laid down under estuarine conditions, however, would be difficult to distinguish from other water-laid deposits. Some of the low-lying terrace deposits may have been formed and worked over in the manner suggested by Martin, but no deposits of undoubted marine origin were observed by the writer in the vicinity of Sixmile Lake.

The evidence as a whole indicates that although estuarine conditions may have prevailed at low elevations at the southwest end of the Lake Clark basin no considerable part of the Lake Clark-Central Kuskokwim region has been occupied by marine waters in recent geologic time. If this conclusion is correct the assumption that there was depression of the land or elevation of the sea of more than 600 feet in the vicinity of Lake Clark or of more than 400 feet in the vicinity of Georgetown or of the Holitna is not supported by field evidence. This conclusion is in accord with observations made in Seward Peninsula, where the inner margin of the coastal

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[1] Martin, G. C., and Katz, F. J., op. cit., p. 88.
[2] Idem, pp. 92–93.

plain at most places stands at elevations of considerably less than 400 feet. It should be noted, however, that according to Brooks the recent movements in different parts of Seward Peninsula were irregular in amount and the region has not gone up as a block. Apparently, therefore, the Lake Clark-Central Kuskokwim region has lately been relatively stable in comparison with the Alaska Range region, where recent changes of level amounting to many hundreds or even thousands of feet have been recognized.

VOLCANIC-ASH DEPOSITS.

In June, 1912, the volcano of Katmai, which stands about 100 miles south of Sixmile Lake, was in violent eruption. The volcanic dust or ash then blown into the air, according to Martin,[1] who made a study of the country adjacent to the volcano, was carried great distances. Particles of it fell at Ketchikan, 900 miles away, and at Iliamna village, 115 miles away, the layer of ash was 1½ inches thick. The map accompanying Martin's account of the eruption shows by contour lines the depth of the ash that fell in different parts of southwestern Alaska. On the map the contour line indicating a fall of a quarter of an inch of ash passes through the mouth of Newhalen River and through points 10 to 20 miles east of the eastern shore of Lake Clark. In the region northwest of this line less than a quarter of an inch of ash fell.

When the region was visited by the Survey expedition in 1914 distinct traces of the ash were observed here and there in the Iliamna Lake region and at many places in the lowlands a layer of whitish ash nearly an inch thick was seen. On the divide between Iliamna Bay and Chinkelyes Creek the ash had been drifted about by the wind and had collected in small inequalities of the surface so that at several places it was more than 6 inches thick.

The fall of ash in the vicinity of Lake Clark was so slight that in 1914, two years after the eruption, almost all traces of it had disappeared. Prospectors state, however, that the ash did fall in this region and that near Big Bonanza Creek, in the Mulchatna basin, it was so thick that it lay on the snow as a gritty cover, which seriously impeded travel with sleds. Some light-colored volcanic ash was seen among the grass roots on the hill west of Nondalton village, but it formed no distinct layer and was identified only by the use of a hand lens. Thus, the ash blown out of Katmai in 1912 formed no noticeable deposit in the Lake Clark-Central Kuskokwim region.

[1] Martin, G. C., The recent eruption of Katmai Volcano in Alaska: Nat. Geog. Mag., vol. 24, pp. 158–161, 1913.

Several other active or dormant volcanoes stand within a few score miles of the region. The nearest of these is Mount Iliamna, which is about 65 miles east of Sixmile Lake and which, as distinctly seen from the hills near the outlet of the lake in 1914, was then emitting white vaporous clouds. St. Augustine Volcano, which is less than 70 miles southeast of Sixmile Lake, was last active in 1883, though it still gives off steam. Redoubt Volcano, which is about 30 miles north of Mount Iliamna, is reported by Martin and Katz[1] to have been in eruption in January, 1902, when it sent showers of volcanic ash over the country from Lake Clark to the Skwentna Valley. It is still throwing out steam and occasional light showers of volcanic dust.

None of these volcanoes, however, has in recent times contributed sufficient material to the unconsolidated deposits of the Lake Clark-Central Kuskokwim region to make a recognizable deposit, though some, like Katmai, may have ejected volcanic ash, a part of which may have fallen within the region.

ORGANIC DEPOSITS.

Beds of vegetable matter have accumulated at many places on the unconsolidated sands, gravels, and silts, but no satisfactory measurement of the thickness was obtained. At a few places on the cut banks of streams measurements were made, but these places are usually least favorable for the accumulation of thick deposits of peat because they are relatively well drained and stand rather high above the general water table of the region.

In the lowland of Hook Creek, in the basin of Hoholitna River, about 2 miles south of the camp of July 29 recent movements of the surface had thrown the deposits of the lower ground into ridges which allowed an examination of the usually concealed material. Plate VIII, *B* (p. 72), shows the features at this place. The surface of the general flat lowland, which here stands about 20 feet above the main stream, is seen on the right. Some of the ridges are 6 feet high and their average height is about 3½ feet. All the exposed material of these ridges is peat. In many places cracks across the ridges disclosed sections of peat 4 feet thick but did not show the bottom of the deposit. The peat was apparently of good quality and was nearly free from sand or like material.

As this thick deposit was formed in areas not recognizably different from much of the lowland area of the Lake Clark-Central Kuskokwim region and had been exposed only by chance, many other similar deposits probably occur throughout the region, especially in parts of the lowland of the Kuskokwim. At several places in this lowland

[1] Martin, G. C., and Katz, F. J., op. cit., p. 94.

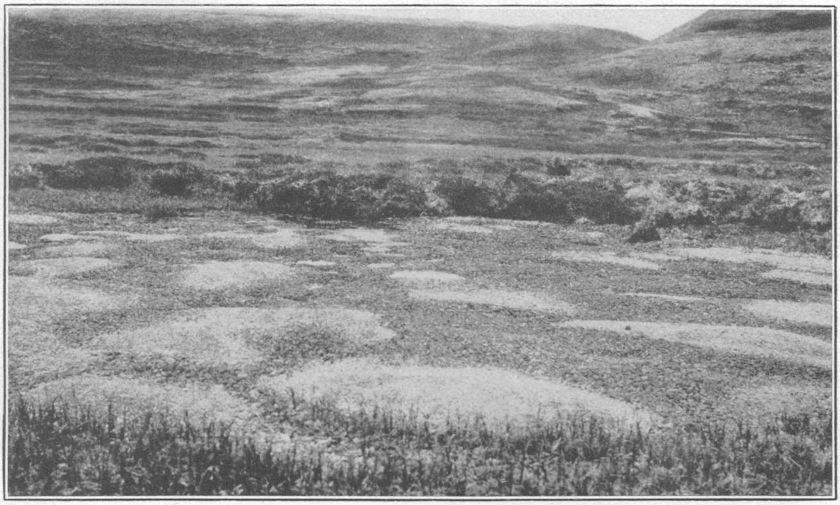
men sank nearly to their waists in the peaty accumulation without reaching hard footing, and in trying to find footing for the pack horses it was impossible to reach the bottom of the peaty deposits by plunging an ax handle vertically into them.

Most of the thicker peat deposits are in shallow depressions, which had apparently held pools of water and had been more or less completely filled with vegetation and débris. Some of these depressions lay behind artificial barriers, such as beaver dams. Many basins of this kind were seen near Muskeg Creek, between the camps of August 9 and August 12. Other depressions noted were apparently the irregular original surface of the glacial and glaciofluviatile deposits. Still others were abandoned stream meanders, some of which had been filled so completely that their mode of origin is not obvious.

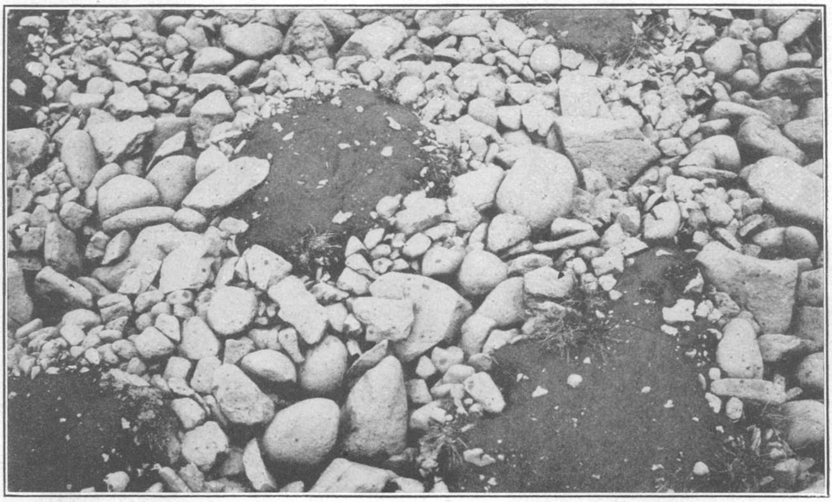
No noteworthy deposits formed of the remains of animals were seen in the region. On the shore of Tutna Lake the shells of small fresh-water mollusks are so numerous that they form windrows along the beach 3 or 4 inches deep and a foot wide, almost unmixed with other material. Nowhere else were similar deposits observed, and even those on Tutna Lake form only an infinitesimal part of the unconsolidated deposits.

MUD SPRINGS AND EARTH RUNS.

A notable feature in many parts of the Lake Clark-Central Kuskokwim region is the movement of the upper part of the unconsolidated deposits by processes that are but little understood. These soil movements give rise to what may be called mud springs and earth runs. Plate X, *A*, is a general view of an area where springs of this sort are fairly numerous. In this area certain places, shown in the view by the lighter-colored masses, seem to be points at which the material was "boiling" up from the deeper parts of the unconsolidated deposit. A close view of one of these springs is shown in Plate X, *B*. The central mud part of this spring is slightly above the surrounding area, so that the blocks of rock and pebbles that have been brought up with the mud have apparently worked toward the margin of the spring, forming a rim of coarser fragments. The arrangement of the small particles in the central part of the spring indicates that the material moves from the center outward. Most of the larger fragments are loosely thrown together, so that in dry periods they form unstable footing and the traveler sinks several inches as they are compacted under his tread. After a period of prolonged drought the mud may be so hard that one may step on it without sinking. Even at those times, however, treading with a slight swaying motion will gradually cause the mud to soften and become a quaking mass. If the experimenter keeps this process up



A. MUD SPRINGS IN FLAT NORTH OF CAMP OF JUNE 29.



B. DETAIL VIEW OF MUD SPRINGS IN FLAT NORTH OF CAMP OF JUNE 29.

long enough and is not engulfed, he may thus shake areas 20 feet or more in diameter.

These mud springs are probably due in large measure to the frozen subsoil, which prevents normal ground-water drainage and favors an upward rather than a lateral or downward relief of pressure. Such springs are therefore common in some of the lowlands and on the flats on some of the broad smooth-topped hills. At many places on hill slopes the downhill creep of the surficial material that lies above a heavily water-soaked substratum, which in turn lies on a layer that is nearly impervious because frozen, produces earth runs. The turf above the mobile mass in places resists rupture, so that it is thrown into wrinkles. These wrinkles are remarkably developed on the hill slopes west of the fish village at the south end of Sixmile Lake. (See Pl. XI, *B*.) Probably the wrinkled deposits of peat on Hook Creek (see Pl. VIII, *B*, p. 72) owe their surface form to a process of this sort.

IGNEOUS ROCKS.

SUBDIVISIONS.

Igneous rocks of many different kinds were recognized in the Lake Clark-Central Kuskokwim region, and doubtless fuller examination of the area would disclose others. These rocks have been formed at different times and under many different conditions, so they may be described under a number of different categories. Unfortunately, however, the data for thoroughly distinguishing the igneous rocks of different ages are not complete enough to permit all the rocks of the same age to be grouped together and separated from igneous rocks of different ages. Consequently, although the purpose has been to subdivide the rocks according to their ages this purpose could not be carried out consistently, so the subdivisions that are used in the following pages are mainly lithologic, though in a measure they indicate also the chronologic relations of the rocks.

Two series of effusive rocks and two series of intrusive rocks have been shown on the accompanying geologic map (Pl. V). Further study of the region may show that certain intrusive rocks that are here separated from certain effusive rocks occupy in fact simply the conduits through which the latter were brought to the surface.

The subdivisions of the igneous rocks and the names under which they will be here described are (1) older lavas, (2) granitic rocks, (3) dike rocks cutting Mesozoic sediments, and (4) younger lavas. The groups are described in chronologic order, the oldest first. Each group is represented by distinct phases, which may be clearly recognized in the field and among whose different members there is little or no overlapping. In fact, the subdivisions here suggested are so well defined that though some of the groups may be split up into smaller divisions there will probably be no considerable shifting of the lines between the major groups.

Each of these four groups of igneous rocks will be described in the following pages as fully as the data at hand will permit. All the known facts concerning their distribution, lithologic character, field occurrence, structures, age, and relation to similar rocks in other parts of Alaska will be presented. The relation of mineral deposits to the different kinds of igneous rocks is discussed under the heading "Mineral resources" (pp. 137-139, 147-148).

OLDER LAVAS.

DISTRIBUTION AND FIELD OCCURRENCE.

The older lavas found in the Lake Clark-Central Kuskokwim region occur entirely in its southwestern part. They form the greater part of the surface rock in a belt 12 to 15 miles wide east of Lake Clark. They are probably the bedrock in much of the area covered by unconsolidated deposits between Lake Clark and Chulitna River, and they lie on the Mesozoic shales in more or less isolated areas in the region between Chulitna and Chilchitna rivers. No representative of this group of rocks was recognized north of the Chilchitna by the expedition of 1914; but, according to reports, they occur in the hills at the head of many of the tributaries of Takotna River, itself a tributary of the Kuskokwim, and in other areas still farther north of the Lake Clark-Central Kuskokwim region.

In the region south and east of Lake Clark the older lavas, according to Martin and Katz, form the bedrock of the hills south of Lower Tazimina Lake and extend eastward as far as the west end of Upper Tazimina Lake. In the region farther west they form the surface exposures throughout the higher ground but are covered by unconsolidated deposits in the lowlands near Sixmile Lake and Lake Clark. They extend northward almost uninterruptedly to Tanalian River and to the center of the south side of Kontrashibuna Lake. Beyond Tanalian River these rocks extend still farther northward in a belt about 6 miles long and 2 miles wide, parallel to the lake. Throughout this region the older lavas form highlands which have been considerably dissected by glaciers originating in the high granite axis of the Chigmit Mountains. Although dissected, the rocks form rugged mountains, many of whose summits rise to elevations of more than 4,000 feet. The topography they form does not seem to show any marked structural control.

The area that is probably occupied by the older lavas between Lake Clark and Chulitna River is so deeply covered with unconsolidated deposits that exposures of the bedrock in it are scarce. Not only are the older rocks covered by deposits of sand and gravel, but at many places they have been overflowed by sheets of the younger lavas, especially in the vicinity of Groundhog Mountain and of the hills northwest of the fishing village at the south end of Sixmile Lake. The older lavas probably lie beneath the unconsolidated deposits throughout most of the southern part of the lowland of the Chulitna, but they are exposed only where recent streams have cut canyons through the surface deposits down to bedrock. Such exposures were closely studied in the region between the camp of June 21 and Groundhog Mountain. In this region the general surface, as viewed from a distance, appears to be a gravel-covered northward-sloping plain, but the traveler on it comes suddenly every mile or two to a canyon about a hundred feet deep whose sides are precipitous. The lower parts of many of these canyons are cut in the older lavas. Where the streams have not cut deep enough to disclose bedrock the canyon form is not developed because the unconsolidated deposits erode with more flaring slopes.

In most of their exposures north of the Chulitna the rocks beneath the unconsolidated deposits seem to be Mesozoic shales. In this region the older lavas appear to occur in downfolded or eroded areas in the shales and consequently form the higher points, but in the lower ground the shales lie under them. The two main areas where this relation was noted are in the group of hills between the Koksetna and the Chulitna and the hills near Mesa Mountain, between Black Creek and the Chilchitna. The topographic expression of these rocks in the vicinity of Mesa Mountain differs materially from that of the older lavas in the areas already described.

In the group of hills near Mesa Mountain are a number of benches that stand at different elevations. These benches are particularly striking along the southern margin of the hills and on the northerly spur from whose form the name Mesa Mountain is derived. The surface of the most strongly marked bench on the southern slopes stands at 2,200 feet and the surface of that on the northern spur at 3,200 feet. Seen from a distance the benches resemble elevated planes of erosion formed at low levels, but closer inspection shows that they probably are not, for the highest recognizable traces of glacial or early fluviatile deposits do not rise to elevations greater than 1,400 feet. These benches appear to correspond more or less closely with planes of lamination of the effusive rocks and to mark planes of differential erosion developed at a considerable elevation above the local base-level. If they marked planes formed at earlier base-levels and are not due to the structure of the bedrock, they should occur at nearly the same level on hills formed of other rocks, but no such benches were seen on adjacent hills formed of other kinds of rock. The strongest argument, however, against the interpretation of these benches as old planes of erosion formed at low levels is the great number of them that occur in essentially the same state of preservation and at many different elevations. If they marked successive uplifts of the area, the oldest and the youngest should show a decided difference, for the length of time required to carve each at a separate base-level must have been great; whereas, if they were produced by differential erosion at a number of elevations, they would have been formed more or less contemporaneously.

The small isolated area of effusive rocks near the canyon of the Chilchitna forms a low ridge and rocky bluffs in the canyon walls. Its topography is not characteristic, because even the highest part of the ridge has been covered with unconsolidated deposits, through which the stream has intrenched itself and laid bare the igneous rocks. The topographic features of this area were therefore formed since the recession of the glaciers and have consequently been little modified by ordinary erosion in comparison with the features of the group of hills near Mesa Mountain, where the rocks are similar but where differential erosion has long been effective. This latter group of hills was probably little affected by glaciation at altitudes above 1,400 feet and has consequently long been subjected to subaerial denudation.

LITHOLOGIC CHARACTER.

Concerning the older lavas east of Lake Clark, Martin and Katz[1] state:

> Large areas around Lower Tazimina Lake and from there northward to Lake Clark are underlain by a group of rocks of porphyritic texture ranging in composition from acid rhyolites, through quartz porphyries, dacites, and mica andesites to intermediate hornblende andesites. * * *
>
> Summarizing, it may be said that these rocks range in composition from quartz alkali feldspar rocks with only small amounts of femic minerals to augite andesites. Their textures are usually porphyritic, with aphanitic or exceedingly fine granular groundmass, and not infrequently flow structures are evident. Tuffs and agglomerates of like composition are intermingled with these rocks. Some are of coarse and angular grain which distinctly reveals their true nature, but associated with them, and in places connected with them by intermediate types (gradation phases), are considerable masses of dense aphanitic, light-colored, and banded rocks which were designated "chert" in the field but which on study appear to be thoroughly indurated pyroclastics of very fine grain.
>
> In general these rocks are not fresh. The feldspars as a rule are more or less completely kaolinized or saussuritized. The hornblendes and biotites are largely altered to chlorites and iron oxides, etc. Epidote, calcite, chlorite,

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 53–55.

quartz, and iron oxides (limonite) are abundant along fractures and in vesicles of the scoriaceous and tuffaceous members. The tuffs for the most part are thoroughly indurated.

The igneous rocks assigned to the group of older lavas that are exposed between Lake Clark and the Chulitna seem to correspond closely with the more basic members of the group described by Martin and Katz in that they are dominantly dacites and andesites. They all show some decomposition; the pyroxene and amphibole have been altered to chlorite. The decomposition, however, in most of the specimens examined, has not gone so far as to prevent the determination of the original minerals. The rock in most of the exposures is fine grained and the minerals composing it are not readily recognized by ordinary inspection. At some places, however, as, for example, at the low knobs near the camp of June 21, the lava is coarser grained and is similar to that at Mesa Mountain. (See pp. 107–109.) This phase of the lava weathers into long, rather rectangular slabs somewhat resembling crudely squared fence posts.

The general appearance of the older lavas north of the Chulitna does not suggest their mode of origin. In fact, as seen in the field, before they were examined microscopically, they appeared to be made up of particles of rocks and minerals—mainly of feldspar, quartz, and mica—which looked as if they had been derived, with little transportation, from a granite. Associated with these minerals were angular bits of many different kinds of rock, notably black shale, sandstone, and chert. In other words, the rock was supposed to be an arkose made up of fragments of sedimentary and igneous rocks. When examined microscopically, however, the rock was seen to be a lava instead of a sedimentary rock. This anomalous appearance is one of the characteristic features of the rocks in the vicinity of Mesa Mountain.

On fresh fracture these rocks are generally of medium light-gray color but become somewhat darker on exposure, though here and there they weather to a rusty reddish color. The largest fragments of foreign material seen in the rock are half an inch in diameter, but the greater number are only about half that size. In addition to the foreign fragments, the rock consists of particles of feldspar, quartz, and mica, large enough to be easily recognized by the unaided eye, all embedded in a fine-grained groundmass. The crystallized minerals appear to average roughly one-fifth of an inch in diameter and to form more than 50 per cent of the surface cross section.

With the aid of the microscope the rock is seen to be composed of phenocrysts of quartz, feldspar, and biotite, which are embedded in a fine-grained groundmass of feebly refracting volcanic glass. Most of the quartz occurs in strongly corroded crystals whose embayments are filled with the glassy material of the groundmass. Many of the thin sections show crystals of quartz almost completely cut in two by corrosion embayments. The quartz shows no optical evidence of strain and is but little fractured.

The feldspars apparently belong to several varieties; some are unstriated, others are strongly twinned, and still others show zonal structure. The unstriated variety is mainly orthoclase, and the plagioclase feldspars are albite-oligoclase, oligoclase, and andesine. The more acidic varieties of feldspar seem to have been corroded to practically the same degree as the quartz, but the more basic varieties have been very little affected by corrosion. Practically all the feldspars are glassy and undecomposed. A few particles of orthoclase have been kaolinized, but these occur only in the surficial part of the rock.

The only mica recognized was nearly black biotite, which occurs in well-formed crystals, many of them having the characteristic hexagonal cross section. Some of the blades of biotite show a small amount of distortion by bending, probably caused by slight flowage of the rock before it had consolidated. In thin section the biotite shows strong absorption. The margins of the crystals of mica show but little corrosion.

The groundmass is so fine grained that its composition can not be fully determined even by the use of high powers of the microscope. It is mainly isotropic and is apparently volcanic glass. It is dirty gray to light brown in color and contrasts strongly with the colorless phenocrysts of quartz and feldspar. This fine-grained groundmass penetrates all parts of the rock so thoroughly that practically no open spaces are left. It must have been introduced as a rather thin fluid. In some places the groundmass had begun to differentiate into feldspathic minerals before it consolidated, so that its composition is approximately the same as that of the well-crystallized parts of the rock.

The fragments of material foreign to the lava have evidently been picked up by the lava as it flowed over the region. They are firmly built into the rock and their margins, like those of the phenocrysts of quartz and acidic feldspar, are penetrated by the volcanic glass of the groundmass. In some specimens the flow structure in the groundmass may be seen to wrap around these fragments. The fragments consist of fine-grained sandstone, chert, and igneous rocks, mainly of granitic composition and texture. The fragments in the lava are of especial interest because they show some of the rocks that were in existence before the lava was poured out.

The rock in the small area of lava near the canyon of the Chilchitna is somewhat darker and finer grained than that in the larger area of lava near Mesa Mountain. The two lavas differ in that the phenocrysts in the rock in the canyon are mainly pyroxene, whereas those in the rock near Mesa Mountain are quartz and feldspar. Most of the pyroxene is nearly colorless to pale green, but some of it is rather pleochroic, ranging from light green to medium brown. It occurs in the aphanitic isotropic groundmass in well-formed crystals that show little or no corrosion. The rock contains some small phenocrysts of feldspar but practically no quartz. It contains also a few inclusions of fine-grained dark sedimentary rock and some pieces of another kind of lava. Variations in texture that mark either slightly different flows or that represent banding in a single flow were more apparent in thin sections made from specimens collected near the canyon of the Chilchitna than in those made from specimens collected near Mesa Mountain. In spite of these differences in the lithology of the rocks from the two places no doubt is felt that both belong to the same general series of lavas, for the differences are probably no greater than those which might have prevailed under the different conditions which may have existed at the two places.

STRUCTURE.

The description and maps prepared by Martin and Katz give but little information as to the structure of the older lavas east of Lake Clark. Apparently these lavas have not been much deformed by folding, though at many places they have been affected by faulting and intrusion. In the area between Lake Clark and the Chulitna that is probably underlain by these rocks exposures were so scarce that the structure could not clearly be determined. On the whole, however, the rocks seemed to dip at very low angles.

In the hills north of the Chulitna the lavas appear to have undergone but slight deformation. As their original flow structure is not clearly recognizable in the field their general attitude must be inferred from the observed attitudes of adjacent sedimentary rocks. In the group of hills between the Chulitna and Black Creek and in the group of hills near Mesa Mountain the lavas seem to occur in synclines in the sedimentary rocks. In the hills north of the camp of June 27 the axis of the syncline trends about N. 60° E., but its west end is covered by unconsolidated deposits.

Near the older lavas adjacent to Mesa Mountain the sedimentary rocks dip beneath the lavas on their north, south, and east sides so that the lavas occupy a syncline, the western limb of which is covered by heavy deposits of unconsolidated material. The lavas are less deformed than the sedimentary rocks and therefore probably rest unconformably upon them. The numerous fragments of shale similar to the Mesozoic shale which are included in the lavas also indicate that the sedimentary rocks were formed and consolidated before they were covered by the lavas. The lavas on the south side of Mesa Mountain appear to lie more nearly horizontal than those on the north side. Although the exposures on the north side were badly broken up by frost, the observations made on that side indicate that here and there the dips are nearly vertical. If these indications can be trusted the lavas form an asymmetric fold.

The original flow banding is conspicuous in the field at only a few places and the successive flows are rarely traceable. Jointing is generally well marked, so that on weathering the rock readily breaks up along the joints into angular blocks. The joints are rather widely spaced in the coarser phases of the lava which, under the action of frost, constantly yields a talus made up of large fragments.

AGE AND INTERRELATION.

The age of the sedimentary rocks in the Lake Clark-Central Kuskokwim region is not definitely known, and the age of the igneous rocks, which must be determined principally by noting the relation of the igneous to the sedimentary rocks, is therefore most uncertain. Some of the conclusions reached by the different geologists who have worked in this region appear to differ as to the age of these rocks. These differences can not be reconciled by office study but may be reconciled by more field work in critical areas. The writer suspects, however, that, though the observations relating to an individual member may properly apply to that member, some of the differences may arise from the grouping together of dissimilar units. It has already been stated that rhyolites and andesites, fine-grained and coarse-grained lavas, and light and dark rocks have been placed in the same group. In discussing the age of these rocks it will therefore be necessary to refer separately to the area east of Lake Clark and to the area north of the Chulitna.

The age of the older lavas east of Lake Clark is thus stated by Martin and Katz:[1]

> No Lower Jurassic faunas have been found west of Cook Inlet either in the beds here described or in any others, but the volcanic beds described above from the west shore of Cook Inlet, and also those from Iliamna and Clark lakes may possibly be correlated with the beds at Seldovia and assigned to the Lower Jurassic on the evidence of similar lithology and sequence. * * * The assignment of the rocks west of the [Chigmit] mountains to the Lower Jurassic is dependent on a correlation through the rocks on Iliamna Bay, and is hence doubly weak, since there is no very good local stratigraphic evidence on the age of the rocks on Iliamna Lake and east of Lake Clark or any definite proof that they are of the same age or that any of them are synchronous with those on Iliamna Bay.

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 58–59.

The age of the effusive rocks north of the Chulitna has been determined mainly by considering the structural relations between them and the adjacent sedimentary rocks. The age of these sedimentary rocks is not certainly known, though it is believed to be middle or late Mesozoic. The lavas lie in synclines in these shales and are therefore younger; moreover, many facts indicate that they overlie the shales unconformably and are therefore later than middle Mesozoic. Some hesitancy has been felt in assigning these rocks to the Mesozoic rather than to the Tertiary-Recent epoch. The main reasons why the lavas are believed to be of Mesozoic age are that they differ decidedly from the younger lavas in lithology, they do not look so fresh, they seem to have been much more deformed, and they occupy topographic positions which indicate that they have long been subjected to erosion. None of these reasons is in itself especially cogent, but taken together they give considerable weight to the conclusion stated. Therefore, although some doubt as to their age is acknowledged, these lavas are regarded as not older than middle Mesozoic and probably not younger than Cretaceous or early Tertiary.

Though Martin and Katz assign the rocks of this group that they saw to the Lower Jurassic, the writer is inclined to put the rocks he studied into formations higher than Middle Jurassic. The assignment of these rocks to the Lower Jurassic is admitted by Martin and Katz to be doubly weak, because it rests on their correlation with distant rocks through an intermediate uncertainly determined area, whereas their assignment to rocks later than the Middle Jurassic by the writer is doubtful, owing to the absence of near-by well-determined Middle Jurassic rocks. A reconciliation of the two views was at first believed to be possible by assuming that the older lavas east of Lake Clark and in the lowland south of the Chulitna underlay the lavas north of the Chulitna. This interpretation does not seem probable, however, because the distance between the two is too small to allow for the known thickness of the Middle Jurassic shales. On the other hand, whether the older lavas lie above or below the shales, it seems strange that in the section exposed in the hills from Cairn Mountain southward to the Mulchatna no lava flows were seen either above or below the shales.

In view of the great uncertainty regarding the age of these older lavas, their correlation with rocks in other parts of Alaska is hardly warranted. It may be pointed out, however, that the Mesozoic or younger lavas so far reported that may be the equivalent of the rocks here described are the andesitic porphyries and tuffs in the Talkeetna Mountains described by Paige and Knopf[1] and referred by them

[1] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U. S. Geol. Survey Bull. 327, pp. 16–19, 1907.

to the Middle Jurassic, though later placed by Martin and Stanton[1] in the Lower Jurassic, and the Skwentna group, on Skwentna River, described by Spurr[2] and by Brooks[3] and referred by Brooks to the Middle or Lower Jurassic.

The Mesozoic rocks, younger than the Skwentna group with which these lavas might be correlated, are the andesitic lava flows in the Naknek formation, of Upper Jurassic age, in the Alaska Peninsula-Cook Inlet region. It is reported that certain other volcanic rocks occur in the Alaska Peninsula near the top of the Upper Cretaceous or in the lowest part of the Tertiary. There are therefore few rocks in Alaska with which these older lavas can be correlated if their age is Mesozoic and if they are younger than the Lower Jurassic porphyries and tuffs.

GRANITIC ROCKS.

DISTRIBUTION AND FIELD OCCURRENCE.

The rocks here grouped together under the heading "Granitic rocks" occur at a number of widely separated places throughout the Lake Clark-Central Kuskokwim region. No sharp line can be drawn between these granitic rocks and some of those described under the caption "Dike rocks cutting Mesozoic sediments" (pp. 118–122). Of course, all dikes that are closely connected with granitic masses are considered as part of the granitic rocks, and only those whose texture, composition, and relations are not clearly granitic are placed in the group of dike rocks. In general, however, the granitic rocks differ from the so-called dike rocks not only in texture and composition but, what is far more important, they differ in age. The grouping adopted, therefore, emphasizes a really important difference.

Granitic rocks are extensively exposed in a great batholith in the Chigmit Mountains east of Lake Clark, beyond the region treated in this report. In the area northwest of this great batholith the exposures of granite become less abundant, until in the region beyond the Chilikandresten, with the exception of one small area on the branch of the Hoholitna, 5 miles northwest of the camp of July 23, no granite is exposed southeast of the hills west of the mouth of the Holitna, of which Barometer Mountain is one of the highest peaks. North of this group of hills no granitic rocks are exposed near the line of traverse within the region mapped except in a small area near the camp of August 31. Beyond the region mapped granite is exposed in the divide between Bonanza and Otter creeks.

[1] Martin, G. C., Geology and coal fields of the Lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, pp. 29–32, 1912.

[2] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 149–152, 1900.

[3] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pp. 85–87, 1911.

The area of granite south of Upper Tazimina Lake and the small areas of granite near the mouth of Tanalian River and on the north shore of Lake Clark east of the mouth of Portage Creek have here been mapped (Pl. V) as shown by Martin and Katz.[1] These areas were not visited by the expedition of 1914.

The southernmost area of granitic rocks studied by the expedition of 1914 included the low knobs near Chulitna River west of the camp of June 24. At this place the granitic rock cuts greatly shattered pelite, but it is not well exposed and it occupies a surface area of only a few hundred square yards. North of the camp of June 26, on Long Lake, is an area of granite measuring 1 mile east and west and nearly 2 miles north and south. It is surrounded by large deposits of alluvium, and even its top is gravel covered, so that its extent below the deposits may be considerably greater than the area indicated on the map (Pl. V). Another small knob of granite rises above the deep deposits of alluvium west of Tutna Lake. The coarseness of the grain of the rock in this exposure indicates that it may be part of a large area of granite, some of it buried under the unconsolidated deposits and some of it exposed in the hills west of the area surveyed.

Northeast of the camp of July 7 a mass of granite that measures over 2 miles from north to south is exposed on the ridge west of Chilchitna River. The eastern limit of this mass was not determined, for it is in an area that was not traversed, but the part seen is apparently the western prolongation of a large mass that occupies parts of the highlands between the basins of the Koksetna and the Mulchatna. A number of dikes and offshoots run out into the sedimentary rocks from this mass, which in this respect differs from most of the neighboring granitic masses, for they give off few dikes or apophyses. One apophysis large enough to be shown on the map outcrops on the middle slope of the prominent hill immediately north of the camp of July 7, and another, which is less obviously connected with the main granite mass, is exposed in the low knob near the camp of July 11, on Dummy Creek.

The granitic rocks of Barometer Mountain were not examined in detail, but specimens were collected and their larger features were determined. Apparently the highest part of the mountain consists of granitic rocks, which occupy an area at least 3 miles long and 1 mile wide. Another mass of granite that was seen from a distance lies west of Barometer Mountain. The part of this mass that was seen was of nearly the same size as that on Barometer Mountain, and an exploration of the country between the two places may show

[1] Op. cit., pl. 2.

that rocks of this type occupy a much larger area than that indicated on the map.

The small area of granitic rocks near the camp of August 31 seems to have been brought into its present position by faulting and it is probably a small offshoot from a much larger mass that is buried beneath the sedimentary rocks. The granitic rocks in the vicinity of Iditarod, north of the area shown on the geologic map (Pl. V), appear to occur in rather small stocks.

At most places where the granitic rocks are exposed they form the bedrock in only small areas and consequently do not produce notable topographic forms. In general, however, the granitic rocks are more resistant than the other rocks and therefore tend to strengthen the relief, and where they form the larger part of the country rock they produce really characteristic topography, giving rise to lofty highlands. Because of their height many of these granitic highlands have been centers of strong glaciation and have been deeply carved by the ice. Their relief is therefore great, and they form sharp, ragged crests separated by steep-walled valleys. Topography of this type is notably displayed in the Chigmit Mountains. As seen from a distance the high mountains in the northeastern part of the region mapped also appear to be composed largely of granite.

The granitic rocks generally weather into large angular blocks, which cover the summits of hills that are formed of rock of this kind. Such blocks were numerous on the low knob west of Tutna Lake, and, according to the reports of prospectors, also on the summits of the hills near Barometer Mountain. On the hill west of Tutna Lake some of these blocks are more than 4 feet in diameter.

LITHOLOGIC CHARACTER.

The granitic rocks in different parts of the region vary considerably in composition and texture. Martin and Katz,[1] in describing the granitic rocks in the Iliamna-Lake Clark region, state:

> There are many types of rock present, but by far the most abundant are hornblende granites and granodiorites. They are for the most part of medium grain, porphyritic habit, and light color, either light gray or pinkish. Mineralogically they are composed chiefly of albite or oligoclase-albite and quartz with either hornblende or biotite or both. Apatite and magnetite are constant accessories. Orthoclase is not commonly a constituent of the rocks and is nowhere important. The porphyritic habit is due to large crystals of feldspar. * * *
>
> On some of the islands in Lake Clark, which are near the northwestern border of the granite, are augite diorites or gabbros composed of basic plagioclase, augite, and magnetite. These rocks may be marginal facies of the granite or independent intrusions. The latter conclusion seems indicated. * * *

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 74–75.

The granitic rock north of Long Lake consists mainly of feldspar and pyroxene. Two varieties of feldspar were recognized microscopically; one—probably orthoclase—practically untwinned and considerably decomposed into kaolinic material, the other—probably albite—was much twinned and but slightly decomposed. Some of the crystals of the albite feldspar showed notable zonal growth. The pyroxene, which is light green, was abundant throughout the thin sections. Some biotite was also recognized, but most of it had been altered to chlorite. Thin sections of the rock from the southern part of the mass contained little or no quartz, but in sections of the rock from other parts of the mass quartz was only a little less abundant than pyroxene. Small quantities of sulphides occur irregularly in the rock.

The granite that forms the knob west of Tutna Lake consists essentially of quartz, feldspar, and biotite. The quartz and feldspar occur in about equal amounts and are much more abundant than the biotite. The feldspar is untwinned (probably orthoclase) and broadly and minutely twinned (probably albite). The margins of the crystals of quartz and of the less twinned feldspar have been considerably corroded, and, as seen under the microscope, some of these minerals appear to be so embayed that they are cut to pieces by resorption canals. The fillings in these embayments in places resemble micropegmatitic intergrowths. The biotite shows both brown and green pleochroic colors. In places it has been somewhat chloritized. No other dark silicates were recognized. The rock contains small quantities of sulphides and of other accessory minerals.

The granite in the basin of the Chilchitna, near the camp of July 7, consists mainly of feldspar, a small quantity of quartz, and still smaller quantities of dark-colored silicates. The feldspar includes an untwinned variety, probably orthoclase, and twinned varieties, mainly albite and oligoclase. Some of the feldspar shows zonal growths. Most of the quartz is in the interstices between the grains of feldspar. The dark silicates are pyroxene, hornblende, biotite, and chlorite. The pyroxene is light green, notably pleochroic, and shows high birefringence. Most of it seems to have been altered to amphibole, as it forms the core of some of the crystals of amphibole. The amphibole is very dark green and exhibits strong absorption, so that, seen in certain directions, it becomes nearly black under the microscope. The crystals of amphibole are partly altered to chlorite at their margins. The biotite is mostly brown, but it has so strong absorption that under the microscope it is nearly black. A small amount of sulphide, apatite, and some iron ores are common accessory minerals in the granitic rocks of this area. A contact zone marked by abundant chiastolite was noted in the sedimentary rocks near this granitic mass.

The rock of the small intrusive mass in the hills between the Hoholitna and its tributary, Hook Creek, is so greatly decomposed that its original composition could not be accurately determined. It is a granular rock consisting mainly of feldspar, quartz, and chlorite. The feldspar has become nearly opaque because of the large amount of brown dust (kaolin?) which has apparently been formed in it by the decomposition of the original mineral. Little of the feldspar seems to have been twinned. The original mineral from which the chlorite was derived is not evident, but it was probably in large part pyroxene or hornblende. Some of this chlorite was probably formed by the decomposition of biotite, though it does not clearly show the characteristic cleavage of that mineral. Iron oxide in well-formed crystals is common in the chlorite.

The granitic rock exposed near Barometer Mountain consists mainly of quartz and feldspar but contains small quantities of the dark silicates. Its texture is somewhat porphyritic, and the larger crystals are mainly quartz or feldspar. The feldspar as determined by J. B. Mertie is acidic andesine. A few crystals of biotite occur sparingly as phenocrysts. The groundmass is composed of orthoclase, plagioclase, and quartz. The petrographic name suggested for this rock by Mr. Mertie, who made the microscopic examination, is quartz latite porphyry.

The granitic rock on the ridge north of the Kuskokwim near the camp of August 31 is composed dominantly of plagioclase feldspar and chlorite. The feldspar occurs mainly in holohedral forms and is twinned in broad lamellae. Between the feldspar crystals is a small amount of quartz. Much of the chlorite seems to have been formed as a result of decomposition of biotite. The rock seems at one time to have contained considerable amounts of an iron silicate mineral, probably a pyroxene, but this mineral is now much changed, having been apparently altered first to an amphibole and next largely to a yellowish-brown mineral with low birefringence, probably a member of the chlorite group. The general texture of the rock strongly resembles that of a gabbro, but its composition indicates that it is too acidic to belong in that family and it is believed to be a granite.

AGE AND INTERRELATION.

The conclusions reached by Martin and Katz[1] regarding the age of the granite in the Chigmit Mountains and the adjacent parts of the Lake Clark-Iliamna region are fully set forth in their report. They state that the granitic rocks cut closely folded Upper Triassic beds on Bruin Bay and form boulders in the Chisik conglomerate

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 76–77.

which lies at the base of the Upper Jurassic. From these facts, as well as from evidence found in other parts of the Cook Inlet region, Martin and Katz conclude that the rocks are older than Middle Jurassic and possibly younger than part of the Lower Jurassic, so that they were probably formed in the upper part of the Lower Jurassic.

In discussing the age of the granitic rocks in the Alaska Range Brooks [1] states that they cut the Tordrillo formation (Middle Jurassic), but he found no rocks by which the upper age limit of the granitic intrusions could be determined. These granitic rocks were therefore assigned by Brooks to the "post-Middle Jurassic."

If all the granitic rocks in this region are of the age determined by Martin and Katz for the granitic rocks in the Iliamna-Lake Clark region, many of the correlations already made would fail to explain the facts observed. The broad application of the determination by Martin and Katz, however, is not warranted, for, as indicated by the geologic map (Pl. V), the granitic rocks intrude sediments which are possibly Jurassic and others which are without much doubt Upper Cretaceous. The facts upon which the sedimentary rocks have been correlated have already been fully stated. Admittedly many of the correlations are based on inadequate evidence, but the fact that the granitic rocks near Iditarod definitely cut rocks which only a short distance away contain definitely determined Upper Cretaceous fossils seems to be conclusive evidence that certain of the granitic rocks must have been intruded later than that period.

Evidence of the later age of certain of the granitic rocks is found not only in the Lake Clark-Central Kuskokwim region but in the Yukon region [2] and in the Nulato-Norton Bay region.[3] In the two regions last named Upper Cretaceous rocks are cut by granitic intrusions, which must therefore be later than the sediments. In the Broad Pass region some granitic rocks cut Eocene sediments.

There is also evidence that some of the granites in Alaska are Paleozoic, which is not surprising, for the different parts of the country have different histories, and even in the same region igneous activity has often occurred at different times. Furthermore, in the intrusion of a great mass of igneous rocks, such as the granites of the Alaska Range, which, with its continuation, extends for nearly 4,000 miles, exact contemporaneity throughout in time of intrusion is less to be expected than variation. Under these conditions the

[1] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pp. 91–92, 1911.

[2] Prindle, L. M., The Fairbanks and Rampart quadrangles, Yukon-Tanana region, Alaska: U. S. Geol. Survey Bull. 337, pp. 26–27, 1908.

[3] Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, pp. 70–71, 96, 1911.

presence of granitic rocks is by no means a safe criterion for determining the age of any of the rocks with which they are in contact. Therefore, the most definite statement that can be made as to the age of the granitic rocks in the Lake Clark-Central Kuskokwim region is that they are probably mainly of Mesozoic age, but that some of those which cut the Upper Cretaceous sediments may be of early Tertiary age.

DIKES CUTTING MESOZOIC SEDIMENTS.

DISTRIBUTION AND FIELD OCCURRENCE.

Many dikes occur near some of the granitic intrusive masses, to which they are obviously so closely related that they have been described in the text pertaining to the granitic rocks (pp. 112–118). The rocks here to be described do not seem to lie areally close to the intrusive masses, and although they are believed to be in general related to the granites, they differ from them somewhat in composition, texture, and perhaps in age. Most of the exposures of the rocks of this group were seen in the area north of the Kuskokwim, but some were seen in other parts of the region.

In the area north and west of the Holitna dike rocks were noted, especially in the bluffs at the mouth of the Holitna, at Parks quicksilver prospect, in the hills south and west of the camp of August 31, and at several places near the Georgetown-Iditarod trail, beyond the area shown on the maps accompanying this report. The same kind of rock was reported by Maddren[1] on Crooked Creek immediately adjacent to the northwestern part of the Lake Clark-Central Kuskokwim region and in the bluffs north of the Kuskokwim, about 4 miles west of Georgetown. Maddren also described many dikes at other places along the Kuskokwim more remote from the region here described. Most of these dikes are rather small and have had little effect on the topography. In the hills west of the camp of August 31 the igneous rocks are thicker and form small knobs, which rise a hundred feet or more above the adjacent ridges of sandstone and shale. Most of these rocks are light colored, so that they can be recognized with certainty at some distance. In color they present a strong contrast to the darker shales and sandstones, so that in places where both kinds of rock are extensively exposed in the freshly cut bluffs west of the mouth of the Holitna, the irregularly branching stripes of light rock cutting at random across the dark rock present a very striking appearance.

Some of the light-colored igneous rocks, however, seem to be especially favorable to the growth of lichens, and therefore when

[1] Maddren, A. G., oral communication.

seen from a distance they appear nearly black. This appearance is very general and characteristic, so that at places far from the route traversed it helps in the discrimination of the igneous rocks from the sedimentary rocks. The coating of lichens is not thick, and the traveler is surprised, in walking over rocks that at a distance appeared black, to find that underfoot their light color is evident, even by casual inspection.

In the region south of the Kuskokwim dikes that cut rocks which are correlated with the Mesozoic sandstones, shales, and older lavas were observed on the eastern flanks of Halfway Mountain in the group of hills between Chulitna River and Black Creek, on the southern slope of the hill north of the camp of July 7 and on the eastern slopes of Groundhog Mountain. At none of these places, however, are the dikes large enough to have any distinctive effect on the topography. The usual light color of the float, however, makes the presence of dikes of this rock easily recognized in many places where actual exposures are poor.

At some places near their contact with Mesozoic dike rocks, as near the mouth of the Holitna, where dikes are especially numerous and well exposed, the sandstones and shales are somewhat baked and indurated. The baking which the rocks have undergone has made them much sought by the natives for whetstones. The settlement of Sleitmut ("sleit" meaning whetstone) was so named because stones suitable for sharpening knives are found near it. The contact effect produced by these dikes does not extend far into the sedimentary rocks and at many places is not readily apparent.

LITHOLOGIC CHARACTER.

Several rocks of different composition have been included in the group of dike rocks. These may be divided into two main types—the granite porphyries and the andesites. The granite porphyries are especially abundant in the region north and west of the Holitna. They also occur on the east slope of Groundhog Mountain and on the east slope of Halfway Mountain. These rocks were first studied by Spurr,[1] who says:

> Just below the Holiknuk [Holitna] are heavy intrusive bodies of siliceous porphyritic rock which cut across the bedding of the sedimentaries or run parallel to it in heavy sheets. * * *
>
> Examined microscopically, it is found that the dike rocks are all members of a decidedly siliceous series. Beginning with a peculiar quartz scapolite porphyry * * * the series runs through many varieties of granitic rocks which make up most of the specimens, the varieties being always porphyritic and generally having a granular groundmass. Finally isolated specimens of garnetiferous biotite syenite and aleutite (andesite) were observed.

[1] Spurr, J. E., op. cit., p. 160.

A reexamination of the specimens collected by Spurr failed to disclose the presence of scapolite in any rock that according to his report contains that mineral, nor was it found in any specimen collected by the writer. The rocks represented by these specimens are normal granite porphyries, in which the phenocrysts are dominantly quartz or feldspar and the groundmass is feldspar, quartz, and sericitic material. Most of the quartz phenocrysts are an eighth to a quarter of an inch in diameter, so that their mineral composition is readily determinable by simple inspection. Under the microscope the margins of the quartz crystals are seen to be much resorbed. Some of the embayments filled with the material of the groundmass penetrate the crystals so deeply that the unembayed area is less than half the original area of the crystal. The quartz in a few of the thin sections examined shows a roughly rectangular fracture resembling cleavage. Some of the phenocrysts of feldspar are also embayed. The larger particles of feldspar generally show little twinning or, if twinned, the lamellae are broad. Much of the feldspar has been decomposed to kaolinic or sericitic material, a fact which suggests that some of the feldspar is orthoclase, but optical tests show that it is generally albite or oligoclase. The groundmass of the granite porphyries consists mainly of quartz, feldspar, and secondary mica. Practically no dark silicates were recognized except a little biotite, which had been altered to chlorite. Metallic minerals, some of which appear to have been sulphides, occur in the rocks in small quantities, but apparently most of these have been broken down into a reddish-brown product of the decomposition of iron. Certain of these rocks contain also small quantities of some black, opaque metallic mineral of unknown composition. Two specimens contain small areas filled with opaline silica, which resemble the amygdules in an effusive rock.

The andesitic or more basic phase of the Mesozoic dike rocks is exposed on the southern slopes of the hill north of the camp of July 7, at the Parks quicksilver prospect, and on the ridge north of the camp of August 30. The andesite exposed north of the camp of July 7 consists of phenocrysts of pyroxene and a smaller number of phenocrysts of plagioclase embedded in a fine-grained groundmass of devitrified glass, feldspar, and undetermined minerals. The rock contains practically no quartz. The pyroxene is very light in color and shows little or no pleochroism. In many places it has been altered to chlorite. Chlorite also occurs in narrow veinlets traversing the rock. The feldspar has also been considerably decomposed and in some specimens has altered to zoisite and other minerals. These andesites contain also small amounts of the iron ore.

The andesite rocks at the Parks quicksilver prospect are in composition more like the granite porphyries than the andesites, but they contain less quartz and their feldspar is rich in lime and is probably andesine. They are so much altered that few of their original minerals are preserved. The scarcity of quartz in certain of the dike rocks shows that they originally contained very little of it. Carbonates occur in the rock in considerable quantities as secondary minerals. Some of the secondary carbonate contains small particles of cinnabar. Sericite is a common secondary mineral, and the rock is generally much stained with iron hydroxides. A specimen found near the Parks prospect, which, however, was less weathered than most of the material examined, is a porphyritic rock whose phenocrysts are composed of quartz and completely altered feldspar. The feldspar has been altered to quartz, sericite, and a fine-grained undetermined material. The groundmass is a fine-grained mixture of primary quartz and secondary products, which were doubtless derived from feldspars by decomposition. This rock is probably a rhyolite porphyry or latite porphyry. The quartz-bearing and quartz-free igneous rocks occur near together, and this position suggests that the two are genetically closely related and that they are more closely related to the granite porphyries of the area north and west of the Holitna than to the andesites of the hill in the Chilchitna basin north of the camp of July 7.

Near the Parks prospect an outcrop of diabase occurs as a narrow, poorly exposed, slightly inclined layer. Its relations to the other rocks are not clear, but it is apparently later than the shales and is a sill rather than a flow interstratified with the sedimentary beds. When examined microscopically the rock is seen to be composed mainly of small laths of feldspar and large flakes of biotite. The feldspar is not excessively twinned and is little decomposed. It is in large part labradorite. The biotite occurs in large blades, which are but little decomposed and show strong absorption in polarized light. Chlorite is scattered irregularly through the thin section and has apparently been derived mainly from ferromagnesian minerals. No other undecomposed iron silicates were recognized, but the rock contains fairly numerous blades and fragments of altered minerals whose apparently original rectangular cleavage suggests their derivation from augite. The relations of the rocks here considered are not clearly evident, but the diabase is probably older than the granite porphyry or the andesites that are exposed in the same general region.

AGE AND INTERRELATION.

The dikes that cut the Mesozoic sediments include rocks of very different composition and are therefore probably not all contemporaneous, but they can not yet be separated into different kinds. There are dikes in the black shales, which are supposed to be middle Mesozoic; in the older lavas, which may be Lower Jurassic or younger; in the sandstones near Halfway Mountain, which are probably middle or late Mesozoic; and in the sandstones and shales north of the Kuskokwim, a part of which are Upper Cretaceous. Sedimentary hard rocks younger than late Cretaceous were not recognized by the writer in the Lake Clark-Central Kuskokwim region, so that the age of the latest dike rocks was not determined.

The relation of the dikes to the granites in this region was not determined definitely by the writer, but their relation in the adjacent regions was observed by Martin and Katz,[1] who state:

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

Basic dikes are reported to cut the granites near Iditarod and at other places north of the Lake Clark-Central Kuskokwim region, but these dikes appear to be different from those seen by members of the expedition of 1914 and their relations therefore may not indicate the relation of the granites to the dikes in this region.

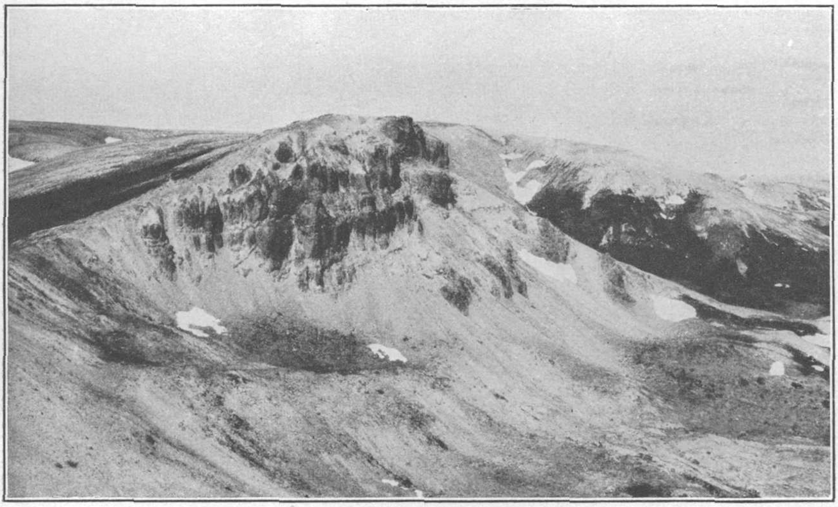
Although the relative ages of the granitic rocks and of the granite porphyry and andesite dikes can not yet be positively determined, these dikes may mark the closing stages of the period of great intrusion in Alaska and therefore may tentatively be regarded as slightly younger than the granite but not of notably different age. Some of them are certainly younger than others, and the granitic rocks are not all of the same age but apparently range from Jurassic to Upper Cretaceous or are possibly even younger. Therefore the most definite statement that can be made as to the age of the dike rocks here described is that they were probably formed in late Mesozoic time, and some of them perhaps in early Tertiary time.

YOUNGER LAVAS.

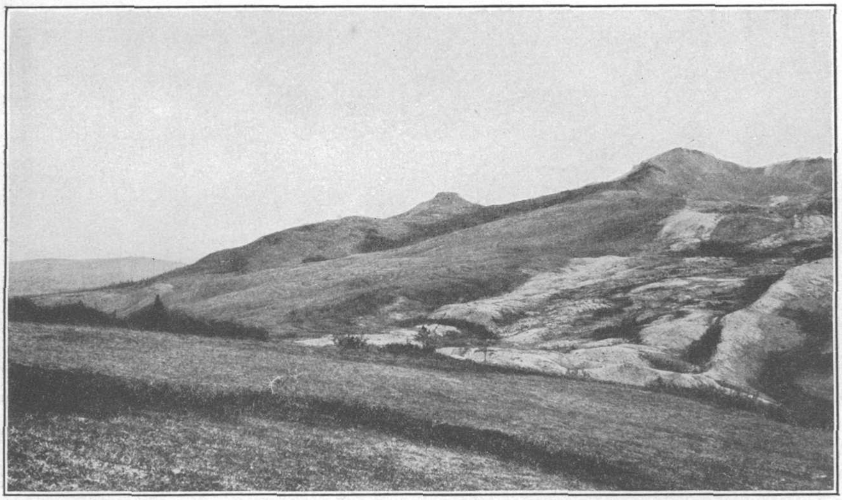
DISTRIBUTION AND GENERAL FEATURES.

The younger lavas are widely distributed through the Iliamna-Lake Clark region and occur at several places in the southeastern part of the Lake Clark-Central Kuskokwim region. Martin and Katz[2] noted outcrops of rock of this kind at the southern point of the promontory east of Portage Bay, at several points on the northern shore of Chulitna Bay, and on the hill on the southeast shore of

[1] Martin, G. C., and Katz, F. J., op. cit., p. 76.
[2] Idem, pl. 2.



A. EXPOSURES OF RECENT LAVAS ON HILL WEST OF SIXMILE LAKE.



B. RECENT LAVAS AND EARTH FLOWS ON HILL WEST OF SIXMILE LAKE.

Lake Clark immediately south of Old Kijik. These rocks were seen by the writer on Groundhog and Hoknede mountains, on the hill 3 miles west of the fishing village at the outlet of Sixmile Lake, and on the ridge northeast of the camp of June 27. Similar lavas are reported to occur north of the Lake Clark-Central Kuskokwim region and they may also occur in some of the unexplored areas east or west of this region.

The lavas noted by Martin and Katz near Lake Clark, except those on the hill south of Old Kijik, are all small exposures at low elevations and produce no distinctive topographic forms. They have been eroded by the ancient glaciers and covered by glaciofluviatile unconsolidated deposits, so that they are exposed only in places where cutting by streams or by the waves of the lake has been recently effective. The area of lava on the hill south of Lake Clark stands at an elevation of 800 to 1,400 feet and gives rise to a distinctive table-topped hill. It is apparently the remnant of a once more extensive flow.

The recent lavas west of Sixmile Lake form the upper part of hills whose lower parts are presumably formed of the older lavas. Viewed from a distance the hills formed of rock of this kind appear flat topped, but viewed from a near-by point their general features are like those seen in Plate XI. The lavas at the place shown in Plate XI, *A*, have been somewhat tilted, but those in the more distant hills shown in Plate XI, *B*, lie flat and give rise to knobs that have nearly flat tops.

The younger lavas may be divided, according to their composition, into two distinct phases, acidic and basic. The acidic lavas are light colored, and at a distance they closely resemble the Paleozoic limestones, except in structure. The basic lavas are dark, but at a distance they can not easily be distinguished from many other rocks by their color alone. The acidic lavas are best exposed in the hills 3 miles west of the fishing village at the outlet of Sixmile Lake; the basic lavas are best exposed in the higher parts of Groundhog Mountain, but they also form the country rock of the upper part of Hoknede Mountain and of a small shoulder on the spur north of the camp of June 27, and probably the rock of all the exposures of lava of this kind reported by Martin and Katz in the area here considered.

In the area examined by the expedition of 1914 practically no trees grow in places where the younger lavas form the bedrock, perhaps because these rocks occur mainly in highlands that would bear no trees, no matter of what kind of rock they might be formed. According to Martin[1] the number of trees growing in areas in which the younger lavas form the bedrock varies greatly and seems

[1] Oral communication.

to be dependent mainly on other factors than the lithology of the country rock. Taken as a whole, however, the younger lavas support but a scanty growth of trees.

LITHOLOGIC CHARACTER.

The younger lavas seem to be divisible into two distinct groups. The rocks in one of these groups are acidic and are best described as rhyolites; those in the other are basic and are basalts. The rhyolites range from nearly pure white through various shades of light pink to dark reddish brown. Some tuffaceous beds of colors like those of the rhyolites are associated with the lavas, but the bulk of the series is effusive rather than ejectamental. The rocks are very fresh; all specimens show a glassy rock of grain so fine that their component minerals are not distinguishable. In fact, certain layers of the rhyolite are composed entirely of black glassy obsidian, which is remarkably fresh and uncrystallized. A few small blebs scattered at random through the obsidian seem to mark centers around which crystallization started but was soon checked. The black obsidian contrasts strongly with the white or pink normal rhyolite. Even under the microscope most of a thin section of the obsidian is seen to be a glass that contains almost no recognizable minerals. In a few of the specimens part of the glass is crystallized, and the rock contains a few crystals of plagioclase and quartz. Some reddish dustlike material in the slides marks lines of flowage which are recognizable not only in the slides but in many of the hand specimens. In fact, in the field flow structure is not only distinct in the mass of the rock but is also represented by the actual surface of the lava. The actual surface of one of the rhyolite flows was particularly well seen at the north end of the exposures of the younger lavas on the hill 3 miles west of the fishing village at the outlet of Sixmile Lake. Here the lava has a ropy flow structure which allows the rock on weathering to break into woody sticklike pieces.

Some cavities that were formed in the lavas have been more or less filled by opaline silica. These cavities are not scattered uniformly through certain parts of the rock, as are gas cavities, but seem to be irregularly distributed. Some of these cavities are lined with silica only a fraction of an inch thick, others are partly filled with it, and still others are completely filled. In one that is nearly filled the silica shows well-marked banding parallel to the base of the cavity, 8 or 10 distinct bands being recognizable in a linear height of 1 inch. In this specimen the planes of banding of the opaline silica are not parallel to the flow structure observed in the adjacent rock. This banded opal was formed later than the translucent, even layer of opaline silica that lines the cavity because it lies unconformably on that layer. Veinlets of opaline silica were also noted in some microscopic sections of rocks of this group.

Beds of fine-grained, light-colored tuffs are associated with the rhyolite. They split into thin layers, which form characteristic deposits on the surface of areas underlain by this rock. The tuff examined was so fine grained that practically none of its component minerals could be recognized by the unaided eye. When examined under the microscope it is found to be composed almost exclusively of volcanic glass, practically none of whose minerals have formed crystals. What looked like ripple marks were seen at a few places in the tuff. This structure may be due to slight wrinkling by folding, but it was probably formed by the agencies that laid down the tuff. The tuff differs in color from place to place as does the rhyolite, but, unlike the rhyolite, it is nowhere dark brown.

The basalt contains no olivine and is composed of plagioclase feldspar, pyroxene, and glass. The feldspar has optical properties which show that it is labradorite. This mineral is abundantly scattered through the rock in small laths which under the microscope mark strongly developed flow structure. The rock contains also some phenocrysts of feldspar of apparently the same composition. Most of the pyroxene is colorless, but some slightly pinkish or slightly greenish varieties occur. The pyroxene is not recognizably pleochroic. It forms a relatively small proportion of the distinguishable minerals in the slide, but probably much of the material that might form pyroxene has not been crystallized out from the glassy groundmass. Metallic minerals, some of which are apparently sulphides, were observed in thin sections of the basalt, but they form an insignificant part of the bulk of the rock. No recognizable tuffaceous beds were associated with these basic lavas.

The basaltic lavas generally lie nearly flat, but at a few places they have been somewhat tilted, and their patchy distribution in the field shows that they have been much eroded, so that what were probably at one time extensive flows are now cut up into a number of smaller areas. Nowhere was the original surface of a basalt flow well exposed, so that the surface features noted in the rhyolites were not observed. Very glassy, obsidian-like phases, which had evidently been formed on or near the surface, were common. Columnar jointing, which is characteristic of the central part of a flow, was especially prominent near the top of Groundhog Mountain, where the "steps" from one bench to another were generally formed by these vertical columns.

AGE AND INTERRELATION.

The younger lavas clearly seem to be later than the other consolidated rocks and older than the glacial and postglacial unconsolidated deposits. The only fossils that afford definite paleontologic evidence of the age of these lavas were collected from exposures on the south shore of Iliamna Bay, described by Martin and Katz.[1] At this place beds of sandstone that are supposed to lie at the base of the basaltic rocks yielded fossils which, according to determinations made by F. H. Knowlton, are presumably Tertiary, though the material was rather poor. The evidence that the basalts are pre-Pleistocene is afforded by the fact that on the summit of the 2,000-foot hill west of the outlet of Sixmile Lake, as well as at many other places, blocks of granite and other rocks derived from distant sources are numerous. Many of these blocks of granite are roughly angular, and some are so large that a man can not lift them. No glacial striae were seen on the younger lavas, but their absence is probably due to the great disintegration the rocks have undergone where they are well exposed or to the small amount of surface that is visible where the rocks have been well protected from rapid weathering.

Some difference of opinion exists as to the correlation and age of the rhyolitic and the basaltic portion of the younger lavas. The rhyolites clearly are older than the basalts and were correlated by Martin and Katz with the Lower Jurassic lavas and tuffs. This correlation does not seem to agree with the facts observed on the hill west of the outlet of Sixmile Lake, where, in the walls of the creek, an older, much decomposed andesitic lava is unconformably overlain by rhyolite, which in turn, near the top of the hill, is overlain by basalt. Three distinctly different lavas are therefore represented in the sections, and either the lowest one noted by the writer must be far older than the older lavas recognized by Martin and Katz or else the correlation made by these geologists does not hold. In view of the slight extent to which the rhyolites have been affected by decomposition, of the lack of strong deformation, and of the apparent similarity of the lowest lava in this section to most of the lavas in the older group the writer is constrained to offer the above modification of the earlier explanation. If this interpretation is correct, the group of younger lavas, including both the rhyolitic and basaltic phases, is probably Tertiary.

The relations between the rhyolites and the basalts is not clearly evident, but the rhyolites are certainly older than the basalts. The rhyolites have apparently been somewhat more deformed than the basalts in the region most carefully studied, but the deformation may have been due to faulting and attendant movements that did not affect the adjacent area in which flat-lying basalt is exposed. No basalt was found lying directly on the rhyolite in a position that showed unmistakably original unconformable deposition. The ab-

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 81–82.

sence of rhyolites under many of the basalt flows strongly suggests that the two types of rock were not deposited in conformable sequence, although doubtless their original distribution was not coextensive. In spite of the absence of conclusive evidence as to the relations between the two kinds of rock the impression gained in the field was that the two are not conformable.

MINERAL RESOURCES.

GENERAL ECONOMIC CONDITIONS.

WAGES AND SUPPLIES.

Few mines or prospects are being developed in the Lake Clark-Central Kuskokwim region, and the probable future development of mining in the region must in large measure be inferred from the facts and conditions noted at the mining camps in adjacent regions. It therefore seems desirable to report the general conditions that prevail at these camps, for they afford the only sure basis for safe deductions.

Wages during the summer for miners in the Iditarod district, the nearest place at which active mining is in progress, are $5 a day and board at the small mines and $4 a day and board at some of the larger mines. In the more remote districts the usual day wages are $7.50 and board, the board being assumed by the operators to cost about $2.50. Practically no natives are employed in the producing mines, and probably the natives are too few ever to have a marked effect on the cost of labor. Along Kuskokwim River, however, the usual wages paid to a native are $2 a day and board. This is also about the price demanded for native labor on Iliamna and Clark lakes. Nearer the settlements of whites in the interior, however, the natives usually receive somewhat more. As most of the natives are paid in trade the actual cost is considerably less than if they were paid in cash.

In winter, when snow and ice prevent shallow placer mining, fewer men are employed and the oversupply of labor tends to lower wages. If more men were employed in winter, through an increase in deep placer mining or the development of lode mines, the difference between winter and summer wages would probably be less, but the summer wages would probably go down rather than the winter wages go up. This condition would result because many more persons would find permanent employment during the seven or eight winter months in which the shallow placer mines are now closed and would not be compelled to support themselves for an entire year on the proceeds of their labors during the four or five months of the open season. It is therefore believed that in the future the general tendency of wages will be to decrease.

In an area so remote from sources of supplies as much of the Lake Clark-Central Kuskokwim region supplies of all kinds are expensive. High prices are inevitable because of the long transportation all supplies must undergo, the danger of loss or damage to which they are subjected in transit, the short time available for bringing them in, the need of an exceptionally large reserve supply, the financial uncertainty as to the stability of the boom towns and the pecuniary resources of the merchants in newly organized camps, the high wages and the consequent high overhead and construction charges, the social and educational disadvantages incident to life in a remote region, which justify a larger income from investments, and the many other real though less tangible hardships to which all frontier life is subjected. With the changes that naturally follow the permanent settlement and development of the region many of these drawbacks become less or disappear, so that in general the cost of supplies will tend to decrease. In less than four years the cost of some supplies has been lowered several hundred per cent. For instance, in 1910 oats and hay sold in Iditarod for over 20 cents a pound, but in 1914 they sold for 6 cents a pound. Even now, however, high prices prevail in the remote parts of the district, and 25 cents is the smallest monetary unit.

Although prices in Iditarod are high as compared with those in eastern United States, most of the supplies carried in the stores there are of good quality and of great variety, comprising a much better assortment than is carried by stores serving a settlement of similar size in the States. Even the poorest prospectors usually have canned milk, butter, and other things that elsewhere may be regarded as luxuries. Possibly this demand for a liberal ration is caused by the severe cold and the long-continued darkness to which the people are subjected in the winter.

TRANSPORTATION.

In all mining enterprises one of the important items is transportation. Not only does it affect materially the cost of supplies, but it may even determine the feasibility of an enterprise. Practically the only ice-free winter route from the States to this part of Alaska terminates at a small bay on the west side of Cook Inlet, from which the route to the interior crosses several ranges of mountains and presents many difficulties, which add to the cost and time of transportation.

Kuskokwim and Yukon rivers, which would afford easier routes, are blocked by ice from November to June, and as both lie north of the winter limit of sea ice, they can not be reached by boats from the States during seven months of the year. Therefore, although the rivers are much used during the summer for hauling supplies, they are of much less value than they would be if at least parts of them could be reached throughout the year by boats from the outside world.

In winter transportation is carried on mainly by dog teams or on well-beaten trails by horse-drawn sleds. Throughout the greater part of the Lake Clark-Central Kuskokwim region no winter roads and scarcely any trails are kept open except for purely local use. The nearest well-established winter trail leads from Iditarod to the coast. This trail, which is used as a mail route, runs in general eastward to the Kuskokwim and thence southeastward to the head of Cook Inlet. Road houses maintained at intervals along it afford food and shelter for both persons and animals. It is staked and flagged each year by the Alaska Road Commission, so that it is recognizable even in the severe and by no means infrequent storms.

In summer the main lines of transportation to the region from the States are by sea to St. Michael and thence up Yukon River, or by the so-called "Inside Passage" to Skagway, thence by rail to Whitehorse, and thence down the Yukon. The coastwise steamships that call at the ports on the southern coast of Alaska afford a third mode of approaching the region. This route, however, presents the difficulty already pointed out, namely, that no easy route of transportation from the western shores of Cook Inlet into the interior has been developed.

The two main summer lines of transportation that have been developed are by the Yukon and by the Kuskokwim. A fleet of shallow-draft river steamers, operated by the White Pass & Yukon Route, follows a more or less definite schedule on Yukon River. Other smaller boats belonging to the same company run up Innoko and Iditarod rivers to Dikeman, from which town still smaller boats, operated by other companies or individuals, complete the water trip to Iditarod. Several individuals and independent companies also run river boats on irregular schedules to ports on Yukon and Innoko rivers. From Iditarod a well-marked foot trail leads to Georgetown.

On the Kuskokwim the Kuskokwim Commercial Co. runs a steamboat from Bethel as far as Takotna, but the boat makes only three or four round trips in a season, and the amount of freight carried is small. A few small boats and launches, operated by other companies and individuals, also do some transportation business on the Kuskokwim.

The decision to build a Government railroad in Alaska called attention to the routes available from the southern coast into the interior. Among others the route from Iliamna Bay to Iditarod and

Yukon River was considered by the members of the Alaska Railroad Commission,[1] but though its value for local uses was recognized it was dismissed by the commission because it "is too far to the southwest to permit its use as a trunk line into the interior." This route had already been surveyed by private persons, and the papers are on file in the General Land Office. The route presents no very difficult engineering problems and would afford easy grades into the interior, but it would lie in a country that holds, so far as known, little promise of immediate value.

In summer transportation is carried on mainly by boats on the rivers and by horses or back packing on cross-country trips. A few wagon roads have been built, but most of them are so wet and muddy that only very light loads can be drawn on them. That good roads can be built, even under the adverse conditions that are encountered in this part of Alaska, is convincingly shown by the road from Flat City up Flat Creek, in the Iditarod district. This road compares favorably with many roads in the States, but it was expensive to build.

POWER.

Owing to the small amount of development in the region little power is used. In the vicinity of Iditarod power for various purposes is produced mainly by using wood or mineral oils as fuel. The manager of one of the larger mines near Iditarod estimates that the wood delivered at the boilers costs from $15 to $18 a cord. Not only is wood used at the larger mines, but it is also the main source of the power used on the larger boats. The wood used for the steamers does not cost so much as that used for the mines because it does not have to be transported so far. Wood cut and piled on the bank of the river sells for about $6 to $7 a cord. Most of the small boats and launches use gasoline or distillate for fuel. This fuel is also used on one of the dredges and at some of the smaller mining properties. The cost of distillate in small lots at Iditarod in 1914 was $5 for a case of 10 gallons.

No water powers with volumes larger than a few sluice heads have been developed in this region, although in the adjacent Iliamna-Lake Clark region a considerable number of water-power sites are available. Scarcely any coal is used.

The few statements given above regarding power are based entirely on information obtained in the immediate vicinity of Iditarod. In order to use this information for the adjacent Lake Clark-Central Kuskokwim region, the data require modification to fit the local conditions of the precise locality to which they are to be applied. As

[1] Railway routes in Alaska: H. Doc. 1346, p. 8, 1913, 62d Cong., 3d sess.

a rule, the determination of the amount of modification required will depend in large measure on personal judgment, but help in reaching a decision may be obtained by consulting figure 2, which shows the distribution of forests, and Plate I, from which the distance and the available routes to the project under consideration can be ascertained. Increased transportation facilities may be expected to decrease somewhat the cost of oil fuels that are shipped from a distance, but probably they will only slightly decrease the cost of wood as fuel, because the depletion of the supply will more than offset the improvement in the means of transportation.

KINDS AND DISTRIBUTION.

The mineral resources of the Lake Clark-Central Kuskokwim region have been so slightly explored that those now known are probably only a part of those which would be disclosed by a full examination of the region. The known deposits will be described and attention will be directed to those places in the undeveloped areas where the geologic conditions indicate that similar deposits may be sought with some assurance of success.

Gold placers have been mined or prospected at many places in areas adjacent to the Lake Clark-Central Kuskokwim region, but the only localities within the area mapped where placers have been reported are on the Holitna, on Big Bonanza Creek and the bars in the Mulchatna basin, and on Koksetna Creek and Kijik River, in the Lake Clark drainage basin.

The only gold lodes that are being prospected lie northwest of Lake Clark and at Candle Creek, on the Takotna. Neither of these was visited by the Survey expedition of 1914, and the only information regarding them was gained from prospectors and from the local papers. Some gold is associated with the base metals in the other lodes of the region.

Quicksilver has been reported at several places in the basin of the Kuskokwim. Some of these deposits lie west of the region here described, but the prospect on which most work has been done is within the region. At this prospect, which is on the Kuskokwim about 15 miles by river above Georgetown, the metal occurs in lodes in the form of cinnabar (the sulphide of mercury) and in gravel deposits in the form of native mercury. The lodes are far more valuable than the placers.

Deposits of other metals, such as copper, antimony, silver, lead, molybdenum, and manganese, have been found in or near the region, and some of them have been more or less developed. Deposits of copper have been reported at several places and have been prospected near Iliamna Lake and in the vicinity of Lake Clark. Most of the copper is reported to occur combined with sulphur, forming the mineral chalcopyrite.

Antimony occurs most commonly as the sulphide, stibnite. It is associated with quicksilver ores on the Kuskokwim and in the vicinity of the igneous contacts near Iditarod. Not any of the stibnite deposits have been developed.

Deposits of silver-bearing lead ore, or argentiferous galena, have been found and opened to some extent in the hills south of Iliamna Lake. These deposits lie outside the region here described but are so close to it as to suggest that similar deposits may be found within the region.

Molybdenite, the sulphide of molybdenum, has been found in small quantities in deposits west of the north end of Lake Clark. This ore carries some gold, and it is mainly on account of the gold that the deposits are being prospected.

Deposits containing manganese have been found in the same region as the silver-bearing galena. The mineral is the black manganese oxide, which has been reported also in the basin of the Kuskokwim.

Coal has been found at a few places in the central part of the Holitna basin and, outside the region here described, near Iditarod and on the Kuskokwim below Bethel. Formations that elsewhere in Alaska are coal bearing are rather widely distributed in the Lake Clark-Central Kuskokwim region, so that a survey of unexplored parts of the region may disclose other exposures of coal. No oil or gas has been found in this region, though both occur on the west coast of Cook Inlet north of Iliamna Bay.[1]

The water resources of the region have been developed only locally and on a small scale to meet domestic and mining needs. Fuller settlement and development of the region will undoubtedly necessitate examination of the now undeveloped water resources.

Each of the mineral resources mentioned above is described in some detail on the following pages, in which the known facts of geologic significance about them are stated. The information given is far from complete, but may be of service to prospectors, investors, and others who contemplate mining in the region.

GOLD DEPOSITS.

IDITAROD REGION.

Deposits of placer gold have been found in many parts of the Lake Clark-Central Kuskokwim region, but none of them have been developed sufficiently to show clearly the conditions under which they have been formed. The general features of the nearest actively productive placer camp, Iditarod, will be described in order to aid

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 126–128.

the reader in understanding the conditions that exist in this general region. Only the general facts relating to the developments at Iditarod will be given, for the details have already been studied by other geologists and the results published. The reader who desires more specific information regarding the Iditarod region should therefore consult the report by Eakin.[1]

The gold comes entirely from placers which are of two distinct types. In one the gold occurs in the stream gravels that form typical creek placers; in the other it occurs in disintegrated but not water-sorted material that forms residual placers. The placers of both

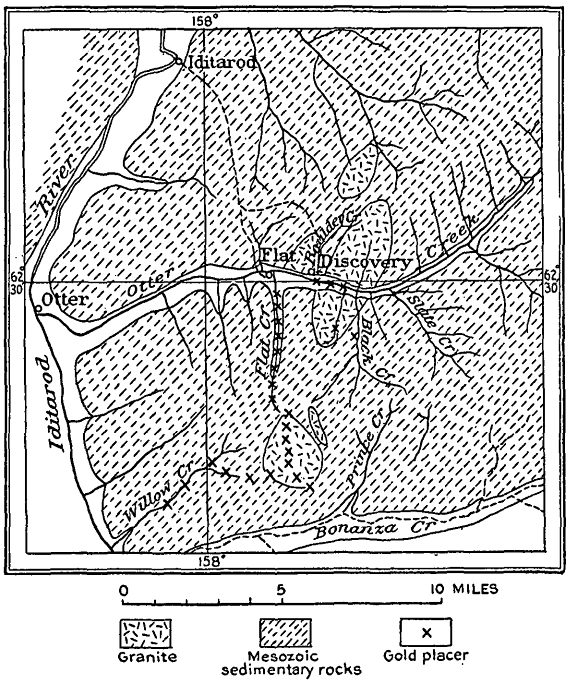


FIGURE 5.—Map showing distribution of placers and igneous rocks in the vicinity of Iditarod. (After Eakin.)

types are areally closely associated with granitic rocks. Figure 5, a copy of part of the geologic and economic map accompanying the report by Eakin,[2] shows the close relation between the distribution of the placers and that of the igneous rocks in the vicinity of Iditarod. Eakin's map shows no placers within 30 miles of Iditarod except those indicated in figure 5. The proximity of the placers to the granitic rocks gives a clue to the places in near-by undeveloped areas where prospecting is warranted.

The placers near Iditarod are mined mainly by small plants. The general conditions here do not differ materially from those found

[1] Eakin, H. M., The Iditarod-Ruby region, Alaska: U. S. Geol. Survey Bull. 578, 45 pp., 1914.

[2] Idem, pl. 3.

in placer mining in other parts of Alaska. Two dredges have been installed and are in successful operation. One of these is equipped with buckets having a capacity of 7 cubic feet. It is capable of handling more than 4,000 cubic yards of gravel a day and is operated each year for about 175 days. This dredge is operated by electricity generated at a plant near the mine. The ground mined is in general permanently frozen, so that it must be artificially thawed before being dredged. It is thawed by steam generated by the use of wood as fuel. The thawing is expensive, as the steam points are usually set only 8 feet apart and the operation requires the labor of more than 25 men. The depth dredged is at few places more than 25 feet, and the average is between 10 and 15 feet.

The success of this enterprise seems to be due to the high tenor of the gravel, which is derived largely from the near-by contact area, to adequate financial backing, and to efficient management, shown not only in the actual dredging operations but in thorough preliminary sampling of the ground, in careful investigation of many incidental problems—such as the effectiveness and cost of thawing—and in close scrutiny of costs, so that wasteful and expensive practices are discovered and remedied.

The operators of the smaller plants, which employ mainly hand labor, are confronted with many of the problems already noted. However, because the area of placer ground they can mine is less and the cost per unit is greater they seek only the richer placers. The material usually mined is permanently frozen, so that the expense of thawing must be provided for. Most of the small mines have been located on the shallower deposits and are therefore near the heads or on the slopes of valleys. In these places a considerable volume of water for sluicing or for mechanical purposes can be obtained only at high cost. The larger mines, which employ powerful machinery, are able to work deeper placers and most of them are therefore located in the valley bottoms, where the alluvium is deeper and the volume of the streams greater. The gradients of the valley floors, however, are so low that a large supply of water at a considerable head is not obtainable except by ditches that tap the supply a long distance upstream from the mine. Some of the mines have tried to overcome this difficulty by pumping water from the larger tributary streams with gasoline engines, but this practice has usually been so costly that it has been abandoned.

KUSKOKWIM BASIN.

In the Kuskokwim basin gold placers have been reported in the valleys of Takotna River, George River, and Crooked Creek, at many places west of the Lake Clark-Central Kuskokwim region, in the Holitna basin, and at several places on the main Kuskokwim. All these places, except the deposits on the Holitna and the main Kuskokwim, lie outside of the area described in this report, and as they afford little new information in addition to that already acquired at Iditarod concerning the general conditions under which placers have been formed in the region, they will not be described here. The reader desirous of information regarding the Takotna, George, and Crooked Creek placers should consult the report by Mertie and Harrington,[1] and for the placers west of the Lake Clark-Central Kuskokwim region, the report by Maddren.[2]

Gold has been found at a number of places on the Holitna, but the only definite report concerning that region was given to the Survey by Mr. W. R. Buckman, a prospector who spent the winter of 1902–3 in the Holitna basin. He states that small quantities of gold were found in many parts of the basin. On bars in the lower part of this stream accumulations of black sand with minute particles of gold were found, especially a short distance above the junction of the Holitna and the Hoholitna. On the headwater branches colors of gold were found in the lower parts of all the streams, but nearer the mountains the number of colors decreased and the indications of placers were less promising. The lower parts of these streams were difficult to prospect, as the gravel was unfrozen and consequently the ground was very wet. The gravels are composed of a variety of rocks, including granite, sandstone, greenstone, quartz, conglomerate, and a little limestone. No placers that could be profitably mined were found. Considering the immense size of the area to be investigated and the difficulties of prospecting, the negative results obtained by Mr. Buckman in the short time spent on the search do not prove that further investigations of the region will not disclose workable deposits.

Two different parties started up the Holitna late in August, 1914, intending to spend the winter prospecting in the upper part of the basin.

The occurrence of gold on the main Kuskokwim was noted by Spurr[3] in 1898, and he seems to have recognized its mode of occurrence so accurately that his description, which follows, is entirely adequate to-day:

> As soon as the Kuskokwim leaves the vicinity of Tordrillo Mountains, however, and flows through the Tachatna series and the succeeding Cretaceous rocks it seems to be entirely without any gold in its gravels. An exception to this was at the mouth of the Chagavenapuk, where the gravels contain many

[1] Mertie, J. B., jr., and Harrington, G. L., Mineral resources of the Ruby-Kuskokwim region: U. S. Geol. Survey Bull. 642, pp. 223–266, 1916.

[2] Maddren, A. G., Gold placers of the lower Kuskokwim, with a note on copper in the Russian Mountains: U. S. Geol. Survey Bull. 622, pp. 292–360, 1915.

[3] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 260, 1900.

colors of fine gold, but these gravels consisted of the characteristic dike rocks of the Terra Cotta Mountains, where the stream heads, and undoubtedly the gold together with the gravels had been brought from this source. In the region below Kolmakof, where siliceous dike rocks again cut through the mountains, it is reported by traders that gold occurs in small quantity.

The gold on the Kuskokwim, therefore, is * * * derived from the mineralized rock and the quartz veins which result from the action of ore-bearing solutions accompanying or following the intrusion of Eocene dikes.

MULCHATNA BASIN.

Gold has been reported from several parts of the Mulchatna basin. Spurr[1] states:

As early as 1890 three prospectors, Harry Mellish, Percy Walker, and Al. King, are said to have ascended the Mulchatna 200 miles and there to have found gold, which, however, was too fine and flaky to save. A few prospectors have been wintering on the Mulchatna the past season [1898], but the results of their explorations are not yet known. From one of them, Mr. Murkle, who came back after a month or two, the writer learned that fine colors had been found on the Mulchatna but none on the Swan.

In 1909 F. J. Katz,[2] of the Geological Survey, visited the Iliamna region and obtained the following notes on the gold deposits in the Mulchatna basin:

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

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

In 1914 the only prospecting for gold in the Mulchatna basin is reported to have been on Big Bonanza Creek. This stream apparently heads in an isolated group of hills, and its middle course lies in a steeply incised gorge and its lower part in the rather widely open gravel-floored lowland of the Mulchatna and its tributary, the Chilikandresten. A small camp, consisting of about six persons, has been established. This place was not visited, but from what are believed to be reliable reports it was learned that a hole 65 feet deep had been recently sunk to bedrock and gold discovered. Granitic

[1] Spurr, J. E., op. cit., p. 261.
[2] Katz, F. J., Notes on the Mulchatna region: U. S. Geol. Survey Bull. 485, p. 133, 1912.

intrusives cutting the shale country rock were found in the hills south of this creek, and probably their contacts were the source of the mineralization. No information as to the value of the placer found has been received, and the lack of actual investigation of the region makes conjectures as to the probable value almost worthless. Nevertheless the impression gained from the study of adjacent regions was that while workable placers may occur here their distribution must be irregular, or, as the miners say, "spotted," and they must be rather closely limited to those areas which derive placer material mainly from the contact zones that surround the intrusive rocks.

LAKE CLARK AND ILIAMNA LAKE BASINS.

According to Katz:[1]

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

When the region was visited in 1914 no claims other than those at the head of Lake Clark were being prospected, and operations on these consisted of little more than the usual work required by law. A quartz vein had rather recently been discovered on the upper part of Kijik River, about 10 miles northwest of the extreme head of Lake Clark. The lode is reported to cut granitic rocks and is probably a pegmatite vein. The gold content is reported to be sufficiently high to make mining profitable, but the great expense necessary for opening a property at this place will probably prevent active development in the near future. Associated with the quartz and gold in this vein are small, irregularly distributed crystals of molybdenite, the sulphide of molybdenum. This mineral is in platy bluish silvery flakes, the largest aggregates of which are about half an inch in diameter. The occurrence of the molybdenite and the presumable pegmatitic character of the vein point to the conclusion that this gold-bearing vein was formed at moderate to high temperatures.

POSSIBLE FUTURE AREAS.

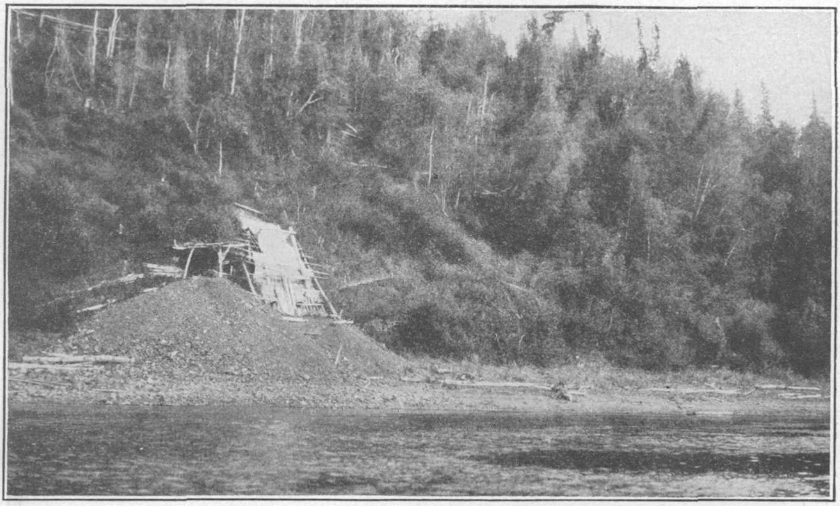
From the foregoing account of the places where gold-bearing deposits have been reported certain general conclusions may be

[1] Martin, G. C., and Katz, F. J., op. cit., p. 126.

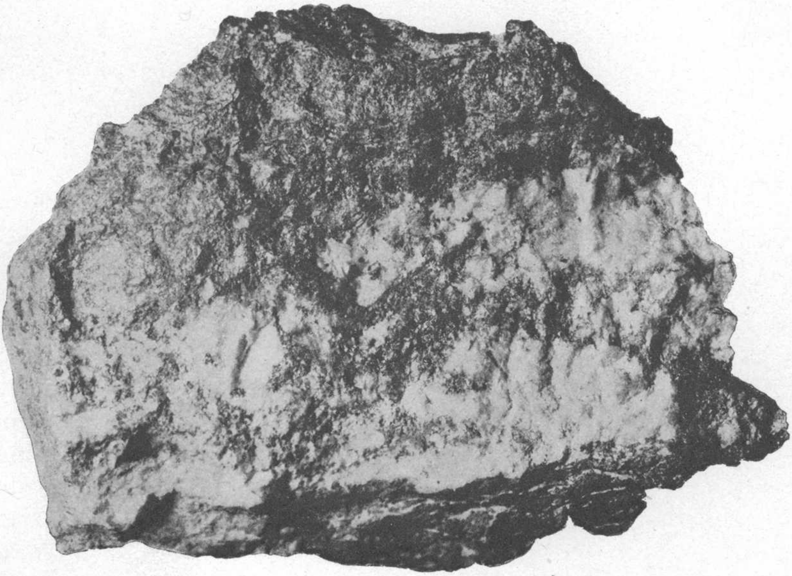
drawn. The most important of these is that the auriferous mineralization was closely associated with the intrusion of the granitic rocks or the dikes. This conclusion does not mean that gold deposits will be found at all places where these igneous rocks occur, for many other factors determine the places where ore bodies are formed. It does mean, however, that the contacts of these rocks are the most promising areas in which to prospect for mineralization and possible ore bodies. The positions of all known areas of igneous rocks of this sort have been indicated on the map (Pl. V) accompanying this report. Much of the area, however, is still unsurveyed, and probably these rocks occur at other places. The mode of occurrence of the igneous rocks that may be found in the unsurveyed areas is probably essentially similar to that at the known localities—that is, they will prove to have an irregular distribution and a rather small areal extent.

Judged from the facts now known, a great part of the mineralization is disseminated through the country rock near the contacts with the igneous rocks. In a region of disseminated mineralization the search for lodes may not be successful, but the search for placers may meet with profit. In prospecting for placers, however, the same general laws are to be applied as in the search for lodes, but certain other features must also be considered. To produce a placer deposit on any particular stream the drainage must be so arranged that a considerable amount of the mineralized contact zone is traversed by the stream, the concentration must have been effective, and, furthermore, the placer accumulation once formed must not have been subjected to any destructive erosional process, such as glaciation, which has removed it.

The heavy outwash deposits from the waning glaciers that at one time occupied part of the region have mantled some of the low areas so deeply that whatever placers may have been formed previously are now in large measure concealed. Under these conditions prospecting is difficult and requires an understanding of the general geologic and physiographic history of the region in order to select the best places to examine in detail, and it is also necessary to have an outfit suitable for prospecting the buried deposits. Upstream from the outwash deposits the streams are usually eroding bedrock or earlier stream deposits, and small placers are likely to be found. In many of these places, however, the streams are cutting down their courses and eroding the hard rock. This work has been in progress relatively a short time, and the rocks attacked have weathered so slightly that the concentration of the valuable heavy minerals usually has not resulted in rich accumulations. Where the streams are cutting former fluviatile deposits that may contain gold accumulations the renewed erosion may possibly effect additional



A. VIEW OF DEVELOPMENTS AT THE PARKS QUICKSILVER PROSPECT, KUSKOKWIM RIVER.



B. STIBNITE AND CINNABAR ORE FROM PARKS QUICKSILVER PROSPECT.

concentration and produce very rich placers. In most places of this sort, however, the courses of the earlier and the present stream would not coincide in all parts, and as the rich concentrations would be limited more or less closely to the places where they did coincide the distribution would be decidedly irregular. The prospector therefore might find rich spots here and there along the stream, whereas the surrounding area would not be rich enough to warrant mining.

Furthermore, the probable irregular distribution and rather small extent of the mineralized areas would not lead one to expect, from present indications, a widespread distribution of placers such as is common in areas like Seward Peninsula and the Fairbanks district, where colors of gold may be found in almost every stream or in every deposit of the unconsolidated rocks.

To summarize, the present conditions indicate that placers may occur in parts of the region traversed by the Survey party of 1914, but probably they are not widespread or regular in their distribution. They may hold out promise of adequate returns to the observant and skilled prospector, but for others they will be difficult to find and costly to operate. So far as present information shows, the chance of finding gold lodes that can be worked at a profit in the near future does not seem encouraging.

QUICKSILVER DEPOSITS.

PARKS PROSPECT.

LOCATION AND DEVELOPMENTS.

The occurrence of quicksilver ore within the Lake Clark-Central Kuskokwim region was studied during part of the summer of 1914. The only place where any considerable amount of development work has been done is at the Parks prospect, on the north bank of the Kuskokwim about 15 miles above Georgetown by river, or about 330 miles above the mouth. It is readily accessible, for the main workings are situated not more than 100 feet from the river and about 15 feet above it. Plate XII, *A*, is a view of the main opening on the property, and shows the situation of the prospect, the character of the timber near it, and the easy facilities for water transportation.

Quicksilver ore was discovered at this place in 1906, and development work has been done on a small scale ever since. At no time, however, have more than two or three men been employed on the property, and this small force, with insufficient funds, has succeeded in opening the deposit only slightly. A small portable retort has been used in reducing the ore, and by means of it about 700 pounds of quicksilver has been produced. This has been sold to the placer miners in Seward Peninsula and in the vicinity of the prospect.

By the crude process employed only about 4 pounds of ore can be treated at a time, so that the reduction has been slow and costly.

The ore occurs along the bank of the stream and has been followed in the natural exposures for a few hundred feet. The main development has been the driving of a crosscut adit about 200 feet long across the general strike of the shales and sandstones that form the country rock. The rocks stand well, so that almost no timber is used except in the fractured and disintegrated surface zone near the entrance of the adit. Several prospect holes and shafts, the deepest of which is said to be about 45 feet deep, have been sunk farther up the slope. Most of these old pits have been lying idle so long that they are now filled with water and are not accessible. The small amount of development work that has been accomplished has not been planned so as to disclose most effectively the characteristics of the deposit.

The slope of the adit affords a sufficient grade for carrying off the water from the underground workings and aids in tramming out ore and waste. The "back" of ore above the adit level, however, is not great, and consequently, if the property is developed, power for pumping and hoisting must be provided. An attempt has been made to prepare for the installation of a modern furnace for reducing the ore, but lack of funds has allowed little more than the clearing of a site on the hillside near the crosscut adit. The installation of a furnace is hampered not only by the lack of funds but also by the lack of material suitable for the construction. The sandstones and shales of the neighborhood are not strong enough for walls and supports, so that even the rougher construction material will have to be brought several miles; and the special material, such as fire brick, must be brought from the States. A fairly resistant igneous rock, the diabase noted on page 121, occurs a short distance downstream from the site selected for the furnace, but it is not abundant; and probably the nearest place where a strong, durable rock can be obtained in sufficient quantity is Barometer Mountain, at least 5 miles south of the prospect.

GEOLOGIC OCCURRENCE.

The country rock in the vicinity of the prospect consists of Mesozoic sandstones and shales, which are probably of Upper Cretaceous age. The sandstones are rather fine grained and appear to contain no pebbly phases. Most of the grains are finely angular and consist of fragments of rather fresh dark iron silicates and quartz. Some of the sandstones contain a number of worn mica flakes, which have evidently been derived from the now buried older metamorphic or igneous rocks. The shales are black and are so fine grained that their individual particles are not recognizable by the unaided eye.

Near the mineralized area these rocks are considerably shattered and in places much slickensided. The rupturing does not appear to be widespread, and a short distance from the claims the rocks are in their normal unshattered condition.

Igneous rocks of two distinctly different kinds have been recognized. One of these, a gray-green medium fine-grained rock containing prominent flakes of biotite over a quarter of an inch in diameter, is closely comparable with diabase; the other, a light gray, nearly white rock, belongs to the group of granitic rocks.

The best exposures of the granitic rock are afforded in the crosscut adit. In this adit, beginning at the entrance and proceeding in a northeasterly direction toward the face, is a succession of sedimentary rocks having a northeast dip that is low at the entrance but gradually becomes steeper farther in the crosscut. These sediments

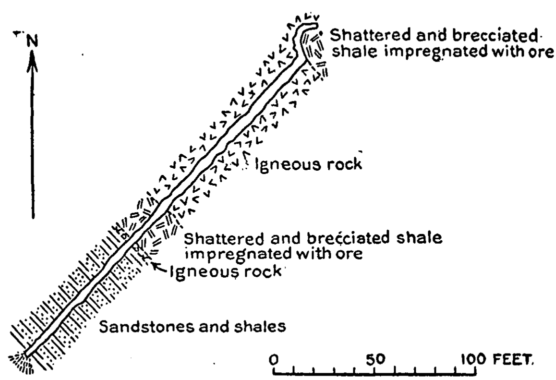


FIGURE 6.—Sketch map of the underground developments at the Parks quicksilver prospect.

are cut, about 75 feet from the entrance of the adit, by a 3-foot dike of the light-colored igneous rock. Succeeding the dike is an area of much shattered and brecciated dark slates. The shattering is so thorough, though apparently on a small scale, that within short distances trends toward almost all points of the compass may be found. Although the strike of the rocks is not constant, the dip is in general so steep as to be practically vertical. Many stringers of quartz have been formed in the open spaces produced by this brecciation, and most of the ore minerals have been introduced into this zone. Beyond it the sediments are followed by more of the granitic rock. This extends uninterruptedly for about 100 feet to a point where more shattered shale was found. At this point the adit was deflected northwestward along the contact between the shale and igneous rock, which was followed for about 30 feet until the fact became apparent that the adit was curving backward, so that it was only a few feet from the point where the deflection to the northwest had been made. The general conditions at this place are represented in figure 6, which shows the underground development and the geology as exposed in this opening. The amount of excavation has not been sufficient to determine the shape or size of the igneous masses, but judged from surface indications they are not large, and they appear to be more or less cylindrical bodies rather than extensive plugs or batholiths. The microscopic examination of the igneous rock from the adit, as stated on pages 120–121, shows it to be low in quartz and of general andesitic composition.

At a prospect pit a few hundred feet from the main adit described above is another exposure of intrusive rock which probably belongs to the same period of intrusion as the igneous rock in the adit. It is, however, less weathered, and a microscopic examination shows that it is an acidic porphyry probably of rhyolitic or latitic composition. The close relations between the rocks of these two kinds indicate that, although the rock from the adit appears to be much more basic than the one from the upper pit, they are equivalent and both are regarded as granitic or monzonitic porphyries.

The main occurrence of the ore is in the brecciated zone adjacent to the contacts of the igneous masses. Wherever this zone is found some mineralization has occurred. This shattered condition close to the igneous rocks is not limited to a single dike or stock, but seems to be general wherever the sediments have been cut by intrusive rocks. Where several dikes whose margins are mineralized occur close together exaggerated estimates of the possible future tonnage of the contact zone are likely to be made if the true geologic structure and relations are not determined. These can be determined only through careful prospecting by experienced men, and until work of this sort has been done the value of the property can not be calculated.

Although the distribution and direction of the deposit have not been definitely determined, the dikes and igneous bodies seem to trend in general northwestward, and this is probably the direction of their greatest horizontal extent. Some evidence in support of this view is afforded by the material in the creek several hundred feet west of the adit, about 50 feet from the Kuskokwim. This material is mainly ore, as if a highly mineralized lead were cut by the creek at this point. A notable feature of the unconsolidated material in this stream is the amount of native quicksilver it contains. The material in the bed of the creek, which is little more than a wet-weather stream, consists mainly of angular frost-riven fragments apparently derived from a near-by bedrock source. Pans of this slightly water-sorted material yielded so much quicksilver that perhaps half a spoonful was obtained from three moderate-sized pans. The origin of the native quicksilver was not determined definitely, but probably it was produced by the natural reduction of the cinnabar. This reduction may possibly have been assisted by the heat of former woods fires. The hillsides near the prospect have been recently burnt over, as is shown by blackened vegetation and standing fire-scarred trees, and other fires doubtless occurred in the past. The amount and distribution of the native quicksilver seem to preclude the possibility that it has been inadvertently spilled or has been lost in earlier operations. Native quicksilver, either as a primary constituent or as an alteration product, has been frequently reported to occur in cinnabar lodes, but it has seldom been reported to occur upon the present surface, as it does at the Parks prospect.

CHARACTER AND RELATION OF MINERALIZATION.

The mineralization is closely limited to the shattered and brecciated contact zone between the igneous dikes and the sediments. The metallic minerals are almost exclusively cinnabar and stibnite. Iron pyrite in narrow stringers, most of them less than an eighth of an inch wide, has been seen at a few places, but almost nowhere is it intermixed with the other sulphides. In fact, it is so distinct that the impression gained in the field was that it had been introduced at an entirely different time from the ore minerals. Subsequent study in the laboratory, although affording no conclusive evidence in support of this view, has shown no facts that are opposed to it.

In few places is a distinct veinlike form recognizable in the deposit. On the bank a little west of the main opening a veinlike mass about a foot wide, showing a somewhat banded structure, has been traced for a short distance. A characteristic specimen of ore from this place is shown in Plate XII, *B*. Normally, however, the mineralization has followed the irregular partings between the shattered fragments of country rock, and consequently forms a network of anastomosing stringers and lenses.

The ore near the surface is weathered to a rusty-brown iron-stained color. In the more oxidized portions of the deposit the cinnabar is practically unrecognizable by inspection of the fragments, owing to the coating of iron oxides. In less decomposed parts the characteristic red of the cinnabar becomes more evident, and in the unaltered parts the blood-red cinnabar is very striking.

The cinnabar occurs principally in small particles intimately mixed with the well-formed crystal blades of stibnite. These two minerals were deposited almost contemporaneously, for the stibnite incloses and is inclosed by the cinnabar. So closely together do the two minerals occur that the mineral livingstonite—the sulphide of antimony and mercury—was reported to be the metallic sulphide other than cinnabar occurring in this deposit. Tests by R. C. Wells, of the chemical laboratory of the Geological Survey, failed to find this mineral, and instead proved that the supposed quicksilver content of the stibnite really was derived from the minute particles of cinnabar that were intimately intergrown with the stibnite.

Tests were also made by Mr. Wells to determine whether any of the compounds of selenium or tellurium and quicksilver were present. Neither selenium nor tellurium was found in analyses of bulk samples, and therefore compounds of quicksilver and these elements are also absent.

The stibnite occurs usually in distinct crystals, which in places are so closely intergrown that their boundaries are those impressed upon them by the other particles with which they are in contact and are not the normal crystallographic faces. In places, however, where there was room for the crystals to form—for instance, in the vicinity of the vugs—the stibnite is in its characteristic bladed form with shining cleavage planes. Some of the crystals of stibnite are an inch long and a quarter of an inch wide, but most of them are smaller, and the smallest are hairlike radiating aggregates so minute that the crystal faces can not be recognized by the aid of a hand lens. In most of the specimens collected the stibnite is considerably more abundant than the cinnabar.

The character and amount of the gangue that accompanies the ore differ notably in different parts of the exposures. In places the sulphides are practically the only minerals in the deposits. Usually, however, considerable quartz and carbonate accompany the ore minerals. The carbonate consists of siderite or ferruginous dolomite and usually occurs in crystalline masses. Clearly in one specimen and apparently in others the carbonate has been traversed by narrow quartz stringers, associated with which are the bulk of the metallic minerals. The quartz in these narrow stringers near the contact with the carbonate is almost opaline, but farther away it is more crystalline, and in places where vugs have been formed small, perfectly terminated quartz crystals project into the cavities. In some of the vugs perfectly formed crystals of cinnabar have grown on the crystalline quartz.

In thus calling attention to the paragenetic arrangement that has been observed in some of the specimens the writer does not wish to convey the impression that the ore has a well-marked banded appearance. All the minerals were deposited so nearly at the same time that even the carbonate, which appears in places to be one of the earliest minerals formed, contains inclusions of the cinnabar, which appears usually to be one of the later minerals.

MISCELLANEOUS LOCALITIES.

Several claims have been staked in the vicinity of the Parks prospect, and explorations on a small scale have been made at these places. Willis & Fuller have been doing some work on the divide between Kuskokwim and George rivers about 2½ miles northwest of the Parks property. Some quicksilver ore has been found, but the development has not been carried much farther than that required by law to hold the property. The general geologic conditions are the same as at the Parks prospect—dikes of intrusive rock cut the sandstone and shale country rocks, and in the vicinity of the contacts mineralization has taken place.

According to Maddren[1] cinnabar has been found in the residual placer material in the areas of intrusive rock near Iditarod. Very little cinnabar has been observed with quartz in place, but angular fragments of vein matter that without doubt have been derived directly from joint fillings in the granite rocks contain cinnabar. Such fragments are commonly found in residual material in Happy and Black gulches. In the deposits, especially in Black Gulch, small subangular pebbles and grains of cinnabar, obviously derived from quartz veinlets, accumulate in appreciable amounts as concentrates in the sluice boxes. It is reported that 500 to 1,000 pounds of cinnabar pebbles accumulate in an ordinary string of sluice boxes during three or four days of shoveling-in operations.

Though cinnabar occurs with quartz in some of the small veins that occupy joint cracks, it also occurs in subordinate association with stibnite. In these veins the cinnabar appears normally in the more quartzose portions of the stibnite bodies. Several small veins of this sort have been observed on the lower part of Glen Gulch. In these veins stibnite is the most abundant metallic mineral, and the cinnabar occurs as flakes and blebs associated with quartz. The stibnite-cinnabar mineralization seems to have been confined to the stronger quartz stringers that are deposited here and there within the granitic rocks and to the stronger zones of small extent in the altered sediments at or near their contact with the intrusive rocks. One of these zones of stibnite-cinnabar mineralization, several feet wide but not very long, occurs in slaty rocks along the contact at the head of Glen Gulch. Some open-cut work was done to prospect this area, but it was soon abandoned because the metallic minerals were found to occur in rather disconnected lenses and vugs, with a large percentage of barren vein quartz, and the deposit as a whole did not appear profitable under present conditions.

A description of other quicksilver deposits in part of the Kuskokwim basin west of the area covered by the present report has been recently given by Maddren.[2]

[1] Maddren, A. G., oral communication.

[2] Smith, P. S., and Maddren, A. G., Quicksilver deposits of the Kuskokwim region: U. S. Geol. Survey Bull. 622, pp. 272–291, 1915.

ORIGIN AND PROBABLE EXTENT.

In discussing the general views held as to the origin of the quicksilver deposits of the world, Lindgren[1] states:

> When it is noted that hot springs and volcanic surface flows are present in almost all regions of importance * * * and that cinnabar in considerable quantities is associated with undoubted spring deposits or is actually deposited in hot springs, the argument becomes very strong, indeed, that such hot springs have formed the majority of the deposits. For the few deposits that have no such clear connection with volcanic rocks * * * the characteristic mineral association still holds good, and we are forced to the hypothesis that volcanism and hot-spring action are the causes of these also, though the products of the igneous activity may have failed to reach the surface, and the hot springs may have subsided.

In other parts of the book cited as well as in many of his other writings Lindgren has clearly shown that he does not restrict the term "hot springs" to those which derive their water from the surface but includes those which derive their water from hot ascending solutions, possibly of magmatic origin. If the term is used in this broad sense, the quicksilver deposits here described may appropriately be called hot-spring deposits. They are evidently closely associated with the igneous rocks and have derived their mineral content from the emanations of the intrusive masses in the form of solutions.

To judge from the geologic occurrence of the ores the depth below the surface at which they were formed apparently was not great. This conclusion is indicated by the number of open spaces that are still preserved and the number of open spaces that were in existence when the mineralization took place but are now filled with ore and gangue. It is further supported by the shattered condition of the rock adjacent to the intrusives, for the shattering probably could have taken place only under slight load, such as is characteristic of the surficial part of the earth's crust.

The significance of the determination of the depth at which the mineralization took place is that it gives an indication as to the probable extent of the deposit, both vertically and horizontally. If the deposit was formed near the surface it probably, like the California deposits, decreases in tenor with increase in depth. In the California deposits practically no workable ore extends to a depth of more than 1,000 feet. Furthermore, the shattering of the country rock near the intrusives formed an easily pervious zone, so that the mineralization would tend to be limited to this zone and not to spread far into the unshattered rock. This shattered zone, so far as is now known, does not extend far from the intrusive rock, and therefore mineral deposits are not to be expected far from the dikes. If the dikes are numerous the shattered rock may furnish sufficient

[1] Lindgren, Waldemar, Mineral deposits, pp. 469–470, 1913.

space for the accumulation of considerable ore, but as a rule the zone surrounding a single dike does not exceed a few feet in width.

At Barometer Mountain, a few miles south of the Parks prospect, a considerable mass of intrusive granitic rock is exposed. Possibly a similar intrusive mass also occurs still nearer the Parks prospect but at so great a depth that only the apophyses from it are exposed at the surface. These apophyses may be represented by the dikes near the ore bodies. If this interpretation is correct, probably the deeper parts of the country rock near the large masses of igneous rock are not so much fractured, and spaces for the deposition of the ore are not so numerous. Furthermore, at the higher temperature prevailing at greater depth the quicksilver minerals would not be so effectively deposited from the solutions that carried them as in the cooler rocks near the surface. Consequently a decrease in the amount of ore in the deep region is to be expected.

So far as observed, the ores at the Parks prospect show no considerable downward enrichment through the action of descending surface waters. A few small particles of a mineral that may be metacinnabarite, the black sulphide of mercury, which is generally believed to be formed as a secondary sulphide, have been seen, but their number is not great. As noted by Lindgren,[1] "the sulphide of mercury is practically insoluble in water, and ordinarily the processes of oxidation in the outcrop of the ore deposits are of little importance." Consequently a decided decrease in the tenor of the ore in depth through absence of downward enrichment is probably not to be expected.

POSSIBLE FUTURE AREA.

The mineralization by which quicksilver was introduced clearly seems to have accompanied the intrusion of the dike rocks. The neighborhood of these intrusives is therefore the place to prospect for quicksilver lodes. All the known bodies of these rocks have been indicated on the map (Pl. V), but much of the region is still unexplored and other bodies of these rocks probably exist in places that have not been studied.

The quicksilver minerals near Iditarod were found close to the large igneous masses, but at the Parks prospect they occur near the dikes, some of which are only a few feet wide. The search for the exposed large igneous masses is relatively simple, for most of the intrusive rocks are more resistant than the surrounding sediments and therefore are somewhat more prominent topographically. The smaller dikes and sills usually do not form noticeable topographic features and are more irregular in their distribution. Most of the

[1] Lindgren, Waldemar, op. cit., p. 801.

small dikes are more or less closely associated with the larger igneous masses and are abundant a short distance from these bodies. In many places, however, the larger masses from which the dikes are offshoots are not exposed at the surface, and their presence can be inferred only from the abundance of the small dikes. Search for places of this sort is exceedingly difficult, and they can be found only by close scrutiny of the float and bedrock exposures. When the dikes are found prospecting to determine whether or not quicksilver in amounts sufficient to warrant development is associated with them will usually be slow, laborious work.

The dikes whose intrusion was accompanied by the quicksilver mineralization cut rocks that are probably Upper Cretaceous, but they are believed to be older than the late Tertiary and recent effusive igneous rocks and sediments. Consequently prospecting for quicksilver deposits in the areas occupied by rocks of more recent age than the later part of the Tertiary is not warranted.

Although the search for quicksilver deposits might disclose others than those now known, the character and occurrence of those that have been found and the difficulties of reducing and marketing the ore seem to indicate that not many productive deposits will be opened in this region. A search for gold placers in the vicinity of the igneous rocks would probably be far more profitable than the same amount of search for quicksilver deposits.

ECONOMIC CONDITIONS AFFECTING THE PRODUCTION OF QUICKSILVER.

Quicksilver ores are relatively rare in nature. Consequently a brief statement as to the general uses of this metal, the amount produced, and the value has been thought desirable. This statement is given because only by considering these different factors can the economic conditions that affect the production of quicksilver be realized and properly evaluated in determining the probable future of any particular deposit.

McCaskey[1] describes the uses of quicksilver as follows:

> Quicksilver is used mainly in the manufacture of fulminate for explosive caps, of drugs, of electric appliances, and of scientific apparatus, and, to a diminishing degree, in the recovery of precious metals, especially gold. Mercuric oxide (red oxide of mercury) is the active poison in antifouling paint used on ships' bottoms. The metal appears to be but little employed now in silvering mirrors, for which purpose nitrate of silver is the chief material used. Increasing needs of quicksilver in normal times are probably to be expected in the manufacture of blasting caps and of electric appliances, and possibly of paints for protective coatings, and industrial chemistry and inventive genius are to be looked to for finding other needs in due time. The demand for quicksilver for amalgamation of gold and silver has greatly de-

[1] McCaskey, H. D., U. S. Geol. Survey Mineral Resources, 1914, pt. 1, p. 317, 1915.

creased, not only with the increased application of the cyanidation process and the decrease of free-milling gold ores and of placer gravels, but also with increased efficiency and economy in stamp milling, whereby losses of quicksilver have been reduced.

The world's production of quicksilver in 1913, according to figures compiled by McCaskey,[1] was, stated in metric tons of 2,204.6 pounds, as follows: Exports from Spain, 1,490; Italy, 988; Austro-Hungary, 855; United States, 688; Mexico and other countries (estimated), 150; making the total for the year 4,171 metric tons. The exports of quicksilver from the United States in 1915, according to McCaskey,[2] were 252,900 pounds, or a little more than 114 metric tons; the imports of quicksilver in 1915, according to the same authority, were 421,884 pounds, or a little more than 191 metric tons. Imports under the Underwood tariff bill are subject to a duty of 10 per cent ad valorem. In the United States 39 mines and prospects produced quicksilver in 1915, against 30 in 1914 and 24 in 1913. Of these 32 were in California and the other 7 were in Arizona, Nevada, and Texas. Formerly a small amount of quicksilver was produced also in Oregon, Utah, and Washington, but in recent years none of the quicksilver mines in these States has been in operation.

The following table gives the quicksilver ore treated and the recovery by States for 1915:[3]

Quicksilver ore treated and average recoveries by States in 1915.

State.	Short tons treated.	Pounds of metal recovered per ton.	Percentage of ore recovered as metal.
California	129,521	8.3	0.41
Nevada	21,975	7.9	.40
Arizona and Texas	7,321	45.3	2.27
Total and average for United States	158,817	9.9	.497

The following statement has been prepared by Mr. McCaskey [4] and issued by the Geological Survey regarding the market and prices of quicksilver for 1915:

The quicksilver industry continued to be of more than usual interest throughout 1915, owing to the large consumption of the metal in the manufacture of war supplies and the generally prevailing high prices resulting from the great demand. Soon after the outbreak of the war foreign embargoes on the exportation of metals made it seem that domestic producers would control the market in the United States during the war, and several shipments from Italy, made, it is reported, under contracts drawn prior to the disturbed conditions abroad,

[1] McCaskey, H. D., U. S. Geol. Survey Mineral Resources, 1915, pt. 1, p. 274, 1916.
[2] Idem, p. 276.
[3] Idem, p. 262.
[4] Idem, pp. 259, 261.

did not prevent a soaring market through 1915 and extending to March, 1916. Prices for the metal became so high in February and March, 1916, that domestic contractors for the allies induced the British Government to permit shipments of quicksilver to this country to complete contracts, and thus, to a small but important extent, competition in the home market between domestic and foreign supplies was reestablished and prices rapidly fell from $300 per flask in February, 1916, to $75, the price now (August, 1916). Although, owing to the efforts of producers to make capacity output, some stocks have probably accumulated, the price of quicksilver at London will probably justify exports from this country and cause reduction of stocks if the domestic quotations run much below $70. Therefore it would seem that producers here may count upon a fair price for their metal, possibly not below $1 a pound, during the war. * * *

At the average sales price reported by the producers of $86.86 per flask for 1915 the output was valued at $1,826,912, the highest value since 1880. In 1914 the value (based on average quotations published in the Mining and Scientific Press for San Francisco domestic) was $811,680 and in 1913 it was $813,171. Compared with 1914, the yield for 1915 showed an increase in quantity of 27 per cent, but of 125 per cent in value.

MISCELLANEOUS METALLIFEROUS DEPOSITS.

COPPER.

Copper-bearing deposits have been developed in the adjacent Iliamna-Lake Clark region, and have been described by Katz[1] as follows:

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

Only the deposits in the limestones have as yet developed any prospective value. These are known at four localities—2 miles west of the head of Iliamna Bay; 9⅜ miles west-northwest of the head of Cottonwood Bay; on Kasna Creek, near Kontrashibuna Lake; and at Millet's, on Iliamna Lake, 22 miles west of Iliamna village. At each of these localities the mineralization is in limestone, near its contact with an igneous formation. At the last-mentioned place the contact is not exposed, and there is no evidence as to its nature. At the other localities there are diorites or diabases intrusive into the limestone. The limestones are metamorphosed by coarse recrystallization of the calcite and the development of garnet, epidote, magnetite, hematite, and quartz, besides the sulphides pyrite and chalcopyrite. These developments in general are close to and parallel with the igneous contacts, but from place to place along these contacts they vary considerably in mineral association, in shape, and in size. They are irregular and nonpersistent. In all their features, their geologic position, mineralogy, and outline they have the characteristics of contact-metamorphic deposits.

The deposit on Kasna Creek is the only one that occurs within the Lake Clark-Central Kuskokwim region. The following abstract gives the details regarding this copper deposit as stated by Katz:[1]

[1] Martin, G. C., and Katz, F. J., op. cit., pp. 116–117.

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

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

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

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

Copper deposits have been found in the Russian Mountains at a locality north of Kolmakof and 50 miles west of Georgetown and have been described by Maddren.[2] This deposit is said to occur well within the granitic mass that forms the central part of the group of hills. The ore minerals have been deposited in a distinct fissure vein with quartz gangue.

From what is now known of the general geology of the Lake Clark-Central Kuskokwim region few places seem to hold promise of containing deposits of copper-bearing minerals similar to those of the Iliamna region. The same general statements that have already been made concerning the probability of finding gold lodes apply also to the copper lodes. In addition, however, the lower value of copper and the greater cost of producing it in a refined state make a copper deposit much more expensive to develop than a free-gold deposit.

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[1] Martin, G. C., and Katz, F. J., op. cit., pp. 121–122.

[2] Maddren, A. G., Gold placers of the lower Kuskokwim, with a note on copper in the Russian Mountains: U. S. Geol. Survey Bull. 622, pp. 358–360, 1915.

ANTIMONY.

Stibnite, the sulphide of antimony, has been found in the Lake Clark-Central Kuskokwim region at the Parks quicksilver prospect, but its occurrence is described so fully on pages 143–145 that further description here is unnecessary.

In the adjacent Iditarod region stibnite has been found near the head of Glen Gulch and has been examined by Maddren, from whom the following facts were obtained by Brooks:[1]

> These veins occupy fissures in the monzonite which forms the bedrock of the creek. They are filled with quartz and range in thickness from 2 to 12 inches, probably averaging about 4 inches.
>
> The vein filling is chiefly vitreous quartz, much of which shows crystalline outline, indicating the filling of open fissures at the time of deposition. Stibnite is the principal metallic mineral and appears to have been deposited after the quartz. A little cinnabar is associated with it and also some pyrite. The stibnite occurs in granular aggregates through which are scattered grains and crystals of vitreous quartz. Stibnite seems to be most abundant in the widest part of the vein, where it occurs as kidneys of irregular outline. * * *
>
> Scheelite occurs in the concentrates from the placers of these creeks but was not seen in the vein. So far as exposed the veins are not of sufficient width to permit development.

Particles of stibnite are found in the concentrates from many of the placer claims and have doubtless been derived from the same source as the gold. The placers at the head of Flat Creek afford perhaps the best illustration of this condition.

The conclusion that the stibnite mineralization was closely associated with the intrusion of deep-seated igneous rocks of the granitic family is indicated by the foregoing facts. The low price of antimony and the high cost of production make the probable commercial development of deposits of this metal in the near future in this region extremely doubtful. Inasmuch, however, as the antimony ore also carries some gold, possibly in some places the gold tenor may be great enough to warrant exploitation of the auriferous stibnite lodes. During the last two years, however, the demand for antimony has been so great and the price of this metal has risen so high that if the high price is maintained some of the lodes may justify more critical examination of their commercial value.

SILVER-LEAD DEPOSITS.

No silver-lead deposits have been found in the Lake Clark-Central Kuskokwim region, but in the Iliamna region to the south one deposit has been reported. This deposit was described by Katz, and the following notes are abstracted from his published report:[2]

[1] Brooks, A. H., Antimony deposits of Alaska: U. S. Geol. Survey Bull. 649, p. 49, 1916.
[2] Martin, G. C., and Katz, F. J., op cit., pp. 124–125.

Silver prospects have been found in the limestone belt that extends southwestward from Iliamna village. The silver claims aggregate about 2 miles in length, but only one group of eight claims has been developed sufficiently to make investigation possible. The only silver minerals disclosed are argentiferous galena (the sulphide of lead) and argentiferous sphalerite (the sulphide of zinc), which are also manganiferous and which occur in veins. In addition to these minerals manganiferous limonite and lead-bearing ocher, small amounts of smithsonite (zinc carbonate), and selenite (lime sulphate) are present in weathered parts of the veins. Pyrite is only locally and sparingly developed. Calcite and quartz, in veins that have been crushed, are found near the metalliferous veins but do not occur as gangue minerals in them. The limestone has been cut nearly at right angles to its strike by many small vertical dikes. Several larger dikes and irregular masses were also observed, most of which are parallel to the strike of the limestone. The ore bodies have apparently been formed in the limestones along fissures which are nearly vertical. Along these fracture zones the limestone is brecciated and some pieces are slickensided. To judge from the material collected, the galena, sphalerite, and small amounts of pyrite filled the fractures. To some extent also the limestone is impregnated with these sulphides.

No production has been made from this property, but the owners report that samples have yielded from 80 to 196 ounces of silver and as much as $20 in gold to the ton, 35 to 50 per cent of lead, and 15 to 20 per cent of zinc. The black manganiferous gossan, they report, carries 2 to 6 ounces of silver to the ton.

MOLYBDENUM.

The only known occurrence of minerals containing molybdenum in the vicinity of the Lake Clark-Central Kuskokwim region is on Kijik River about 10 miles northwest of the extreme north end of Lake Clark. Little is known about the geologic conditions at this place. Apparently the molybdenum occurs as molybdenite in scattered flakes in what is presumably a pegmatite vein closely associated with granitic intrusive rocks. So far as learned, the molybdenite is not sufficient in quantity to have commercial value on its own account, but the fact that the vein is said to carry gold also may make development of the property possible. If the molybdenite is closely associated with the granitic intrusives there are several places within the Lake Clark-Central Kuskokwim region where prospecting might be warranted. The small market and the high cost of mining, transportation, and treatment do not at present hold out much inducement to search for deposits of this metal in this remote region.

MANGANESE.

Manganese, as elsewhere noted (p. 153), occurs in the silver-bearing lead deposits south of Iliamna village. At that place it has not been utilized and apparently has slight commercial value.

Dall[1] states: "Black oxide of manganese has been received from the Kuskokwim." He gives no further notes concerning the locality from which the specimen was obtained or the mode of occurrence.

COAL RESOURCES.

In many parts of Alaska the Upper Cretaceous rocks, which in general are similar to the bedrock of a large part of the country north of Kuskokwim River, are coal bearing, but no workable coal deposits have been found within the Lake Clark-Central Kuskokwim region. At a few places in the adjacent region, however, as, for instance, on the hills east of Iditarod, on the Holitna, and on Big River, coal crops out, and at some of these places attempts have been made to mine it. Probably by more extensive exploitation other coal deposits will be found, and they may be of considerable economic value locally in a region where fuel is scarce and transportation charges are high.

The coal deposit on which most development work has been done is on the tramroad from Iditarod to Flat, about a quarter of a mile south of the crest of the divide between a tributary of Otter Creek and Iditarod River. At the time of the writer's visit (1914) the property was lying idle and the excavations were filled with water. The following notes were obtained from Mr. W. W. Acheson, of Iditarod, who was familiar with the mine when it was in operation. The bed of coal, which is exposed at the surface, dips about 45° SE. It is about 40 inches thick, and its walls are very smooth and in places slickensided. Near the surface considerable slate is mixed with the coal, but lower down the slate decreases in amount, and at a depth of 50 feet it is almost entirely absent. This prospect had been developed by a 40 foot vertical shaft, from the bottom of which a 30-foot incline on the coal bed had been driven.

The coal on the dump appears to slack badly. When mined it was intersected by numerous veins of ice. Many of the small pieces on the dump have polished and slickensided surfaces. It has been used as fuel in the near-by road house and also, though with not very satisfactory results, in a blacksmith forge.

The character and fuel value of the coal are not definitely known, for the information obtained from different sources was not in accord. A sample said to have been taken from this property, received

[1] Dall, W. H., Alaska and its resources, p. 478, 1870.

from Charles Estmere, of Iditarod, according to Brooks[1] was analyzed by A. C. Fieldner, chemist, of the Bureau of Mines, with the following results:

Analysis of coal from locality near Iditarod.

[Air-dry loss, 0.0.]

	Air dried.	As received.	Moisture free.	Moisture and ash free.
Moisture	1.40	1.42	....	....
Volatile matter	6.60	6.60	6.70	7.23
Fixed carbon	84.75	84.73	85.95	92.77
Ash	7.25	7.25	7.35	....
	100.00	100.00	100.00	100.00
Sulphur	1.10	1.10	1.12	1.21

Mr. Fieldner adds the following statement:

This analysis indicates that the coal is anthracite. The sample received was chiefly slack, and the data at hand indicate that the coal bed is crushed. It is doubtful whether this coal could be utilized without briquetting.

A somewhat different statement as to the character of the coal was given by Mr. Acheson, who says that it ignites rather easily and has the physical features of lignite. Perhaps these two discordant views can be reconciled by assuming that the coal is normally a lignite or a subbituminous coal similar to the other known Upper Cretaceous coals and that it has been metamorphosed locally into an anthracite as a result of the deformation and shearing to which it has been subjected.

Coal has also been reported from several other places in this same neighborhood. An exposure of coal is said to have been found on the Iditarod side of the divide between Iditarod and Flat at a point about a mile northwest of the locality described above. No mining has been done at this place, and the character and extent of the coal have not been determined.

Northeast of the last-mentioned locality are other coal outcrops that have been slightly exploited. No work was in progress on them in 1914 and the old pits were not visited. Some coal has been taken out and is said to have been used in Iditarod with satisfactory results. Probably, however, at most not more than a few hundred pounds has been so used.

Coal-bearing rocks have been reported to crop out on the Holitna at two places. One of these is about midway between the mouth and the head of the river, and the other is some distance farther up-

[1] Brooks, A. H., The Alaskan mining industry in 1913: U. S. Geol. Survey Bull. 592, pp. 72–73, 1914.

stream. The deposits have not been carefully investigated, but Mr. Buckman[1], who discovered them, says: "The coal indications on the Holiknuk [Holitna] are not extensive enough to permit the assertion that they will in time be of commercial importance."

Coal deposits have also been reported to occur on the western flanks of the Teocalli Mountains, east of Big River, a tributary of the Kuskokwim lying outside the region described in this report, but no details as to their extent or characters have been published.

West of the Lake Clark-Central Kuskokwim region coal crops out at several places, concerning which Spurr[2] states: "On the Kuskokwim below Kolmakof many of the shales become carbonaceous. Rev. Mr. Kilbuck, the missionary, has found small seams of coal here."

A statement regarding the coal deposits of the western part of the basin of the Kuskokwim has also been made by Maddren,[3] who says:

> Coal crops out in the foothills along the northwest flanks of the Kuskokwim Mountains on Eek and Kuethluk rivers, but little is known either of the areal extent of the coal-bearing formation or of the number and thickness of the beds, for no development work has been done on them.

WATER RESOURCES.

As yet almost none of the available water powers of the Lake Clark-Central Kuskokwim region have been put to use. In large measure this neglect is due to the small demand for power. The future use of the now undeveloped water powers depends upon their availability, which in turn depends upon the purposes for which they are to be employed and their cost relative to other sources of power. This matter involves so many factors and they interact in so complex a manner that they can be evaluated only by analyzing a specific problem.

The general areas in which mineral deposits may be sought with some assurance of success, as already pointed out, are those where intrusives cut the country rock and have brought in mineralizing solutions. Places of this sort are scattered here and there throughout the Lake Clark-Central Kuskokwim region, but most of them are of small size. The harder igneous rocks form the higher parts of the upland, and consequently the mineralized areas in most places are drained by small headwater streams which in their upper parts have exceedingly steep gradients and little volume. Under these conditions a water supply adequate for large-scale mining usually can not be found close at hand. In many places probably

[1] Buckman, W. R., unpublished letter.
[2] Spurr, J. E., op. cit., p. 262.
[3] Maddren, A. G., Gold placers of the lower Kuskokwim: U. S. Geol. Survey Bull. 622. p. 305, 1915.

small mining plants can acquire sufficient water by building short ditch lines, but many of them will undoubtedly experience the same difficulty as has been felt by those situated in the mineralized area at the head of Flat Creek, in the Iditarod district, where, except when rain is falling, the water supply is inadequate. Recourse to long ditch lines, such as have been built in Seward Peninsula to overcome the difficulties of a somewhat similar region topographically, may be feasible. Long ditches, however, are expensive and their construction should not be advocated until their courses have been carefully surveyed, the volume of the supply they tap accurately determined, their installation critically investigated, and the deposit to which they are planned to bring water proved to contain sufficient valuable minerals to defray their cost.

For agriculture the water supply would seem to be sufficient, even if a considerable part of the country should ultimately prove to be adapted to cultivation. In fact, one of the problems probably would be to drain the area rather than to bring additional water to it.

No hot nor thermal springs have been reported to occur in the region, and the general geologic relations indicate that they are not likely to be found except under special conditions.

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